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Exploring the Affect of Emotive Motion in Social Human Robot Interaction

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled “Exploring the Affect of Emotive Motion in Social Human Robot Interaction” submitted by John Harris in partial fulfillment of the requirements of the degree of Master of Science.

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Abstract

Motion can be a powerful channel of expression and as robots begin to take on increasingly personal roles in our daily lives, we propose that their inherent motion capabilities will become an important method for us to be able to communicate and interact with them in socially intuitive and easily understandable ways. In this thesis, we explore this concept of *emotive motion* as a design tool for social Human-Robot Interaction research: we leverage the ways in which the low-level style and characteristics of *how* robots move (e.g. slowly, smoothly, sporadically, etc.) affects our social and emotional interpretations of them.

We present a new conceptual taxonomy to frame our exploration of *emotive motion,* discuss a set of exploratory prototype robotic platforms we designed and a pair of in-depth user studies we conducted in order to better understand how the many facets of motion affects humans' emotional interpretations of social robotic agents. Our work demonstrates the powerful impact of *emotive motion* as a design tool in social HRI, shedding light on its interplay with other design considerations such as a robot's visual form and working context.

Publications

Some of the materials, ideas, and figures in this thesis have previously appeared in the following publications:

1. J. Harris and E. Sharlin, **“Exploring the Affect of Abstract Motion in Social Human-Robot Interaction”**, Proceedings of 20th IEEE International Symposium on Robot and Human Interactive Communication (Ro-Man 2011), August 2011, Atlanta, USA.

2. J. Harris and E. Sharlin, **“My Robot Is a Tree-Hugger: Leveraging Emotive Actuation in Sustainable Interaction Design”**, HRI Pioneers Workshop, Adjunct Proceedings of the 5th ACM/IEEE international conference on Human robot interaction (HRI 2010), March 2010, Osaka, Japan. Extended abstract.

3. J. Harris and E. Sharlin, **“Exploring Emotive Actuation and its Role in Human-Robot Interaction”**, In Adjunct Proceedings (Late-Breaking Reports) of the 5th ACM/IEEE International Conference on Human-Robot Interaction, 2010 March, Osaka, Japan. Extended Abstract and poster presentation (Best Late Breaking Report Nominee).

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1 Introduction

We believe that the essence of life and liveliness is intimately linked to the concept of motion. From an etymological perspective, the Latin word *anima* refers to the concepts of “soul”, “life”, “spirit”, and “vital principal” (Harper) and from this root we encounter the words *animal* (“living creature”) and *animate* (“to impart life”). Intuitively, we gain that same impression from the world around us: things that are moving, changing, and reacting are seen as somehow “alive” whether they are biological creatures or not.

Besides simple liveliness, motion is also a powerful channel for emotional expression. For thousands of years, humans have been expressing emotions through theatre, dance, and gesture; conveying frustration, sorrow, jubilation, and an entire spectrum of powerful emotions using only the movement of our bodies. In contrast, a person who is entirely motionless (e.g. their chest not even breathing) are quickly presumed to be in distress, injured or deceased. In the world of film, master animators have demonstrated for decades that there is emotional power to be expressed in *how* characters move, above and beyond the specific gestures of *what* those characters are doing (Johnston & Thomas, 1995).

The field of social Human-Robot Interaction (HRI) research is concerned with the development of robotic entities that can interact, communicate, and cooperate with humans in ways that are socially familiar, emotionally enriching, and require little to no training on the human’s part. In essence, social HRI seeks to elevate robots beyond simple, unthinking machines and imbue them with a social “spirit” with which we humans naturally understand how to interact.

Arguably, motion is also one of the primary differentiating features between computers and robots. Unlike computers, robots are capable of moving through their environment: gesturing, reacting, exploring, communicating, and affecting their surroundings in very dynamic, physical ways. Whether a robot’s purpose is to serve, create, explore, or destroy, we believe that it is this ability to move, interact, and affect the same physical world that we, as humans, live in which distinguishes them from almost all other forms of modern technology.

Critical to the field of social HRI then is the extension of this fundamental concept of the "liveliness of motion" to the normally non-living objects around us. From legends of "unseen spirits" of the wind passing through forest canopies overhead, to the skilful flick of a puppeteer's wrist as they manipulate a collection of wood and string, this attribution of liveliness, intelligence, and intent to moving objects is a seemingly innate human tendency and one that has powerful implications for the uniquely (e)motive realm of social HRI. We argue that concern for the characteristics and impact of a robot's motion should be a primary component of any research that involves the interaction between robots and humans; especially if these robots are deliberately designed to act as social agents.

In this thesis, we make this connection between movement, liveliness, and emotion explicit using the term "emotive motion". We explore the concept of *emotive motion* in the context of Social Human-Robot Interaction as well as whether and how social robotic entities can be designed to use their inherent motion capabilities to express emotion and engage their human observers. We explore the characteristics of *emotive motion* in robots, its use as a design tool, its limitations, and its relationship with a robot's other characteristics such as visual appearance and working context.

1.1 Research Questions

Throughout this thesis, our work attempts to explore the following research questions:

1) Do robots' motion characteristics (e.g. speed, smoothness, complexity, timing, interactivity) affect how humans perceive and interact with them?
2) Can these motion characteristics be used as deliberate design tools to promote specific emotional interpretations from the humans with which the robot interacts?
3) How are a robot's expressive motion characteristics affected by its other qualities such as visual form or working context?

1.2 Approach and Contributions

To address these research questions, we explored the concept of *emotive motion* in Social HRI from multiple perspectives. We developed a new conceptual taxonomy for *emotive motion* based on related Social HRI research, and used it to frame and guide our subsequent explorations and experiments. We developed several robot prototype platforms; each considering different facets of *emotive motion* such as the realities of technical implementation (e.g. time, cost, available materials), its application as a catalyst for long-term behaviour change, the challenges of studying *emotive motion* in an abstract and "pure" sense, and how our interpretations of *emotive motion* can change when it is experienced in public settings. We conducted a set of user studies using these prototypes and reflect on their results and implications to future social robot design.

Based on our stated motivation, research questions, and approach, this thesis presents 6 main contributions:

1) ***Qualitative and quantitative evidence of the expressive capabilities of emotive motion in social HRI (Chapters 5, 6, and 7)***
2) ***A theoretical framework and taxonomy for exploring emotive motion in Social HRI (Chapter 4)***
3) ***Design and implementation of a set of six unique robot prototypes, which we employed as emotive motion test bed platforms(Chapters 5, 6, and 7)***
4) ***Conceptualizing the use of emotive motion in a social robot agent to affect behaviour change, and the subsequent design of an interactive test bed platform (Section 5.3)***
5) ***A hyper-abstract study technique for exploring emotive motion (Chapter 6)***
6) ***A technique for studying emotive motion in a public setting (Chapter 7)***

1.3 Thesis Overview

The remainder of this thesis details the research contributions outlined above. In Chapter 2, we present a short history and insight on the development of social Human-Robot Interaction. In Chapter 3, we present a brief review of related work regarding *emotive motion* in social HRI. In Chapter 4, we introduce a novel conceptual taxonomy and theoretical framework which we use to bring clarity of discussion to some of the complex, multi-facted aspects of *emotive motion* and social HRI in general. Chapter 5 outlines a series of robot prototypes we developed to serve as preliminary probes of the *emotive motion* design space. Chapters 6 and 7 goes into detail about a pair of users studies we conducted to evaluate specific characteristics of emotive robot motion. In Chapter 8, we discuss future directions for our research. Finally, in Chapter 9 we revisit our research questions and review how our results are reflected in our research contributions.

2 Social Human-Robot Interaction

Before discussing our work on *emotive motion,* we present the larger research context from which social Human-Robot Interaction (HRI) is still emerging as a distinct domain. We discuss some of the historical significance of the rise of robotic technology and the social and cultural motivations for why *social* robotics in particular is an important area of ongoing research. This chapter is meant to provide a higher-level context for readers who are unfamiliar with the social HRI research domain prior to our delving into our lower-level exploration of *emotive motion.*

We begin with a brief overview of the history of robot development and its relationship to previous, revolutionary shifts in technology. We discuss how these rapid advances in technology can have unanticipated disruptive effects on social and culture values beyond their original practical or economic motivations. Finally, we discuss the unique, emerging role of robots; arguing for how the concept of *emotive motion* forms an integral facet of social robot design and how its intelligent use will become increasingly important as robots begin to take on ever more personal and ubiquitous roles in modern society.

2.1 A Series of Accelerating Revolutions

Over the course of more than 200 years, the Industrial Revolution has drastically affected the face of industry, individual standards of living, and global socio-economic progress. Cart and oxen have been replaced with motorized tractors; villages and weaving guilds have been replaced with enormous warehouses full of mechanical looms; caravans of horse drawn carts have been replaced with family owned cars; and a mass exodus of workers have flooded into rapidly developing urban centers to begin work as bankers, accountants, and businessmen (Human Population: Urbanization).

In just a few short decades, the Digital Revolution and the rise of computers have again transformed almost every facet of modern civilization (Tapscott, 2011) (Kotkin, 2000) (Thompson, 2011). From the early artillery trajectory calculation machines and room-filling “super computers” of the 1940’s, to the widespread adoption of desktop computers in the

1980’s, the explosive growth of the global internet in the early 2000’s, and to the always-on, always-connected mobile devices that can now be found in the briefcases, backpacks, and pockets of millions of people worldwide, the modern computer has become as integral a component of everyday life as electricity, automobiles, and mass-produced consumer goods.

Where the Industrial Revolution primarily affected the means of production, transportation, and labour, the Digital (Information) Revolution has affected our means of sharing, processing, and understanding information. Both revolutions have fundamentally affected the way we think, behave, work, and interact as a society. For example:

a) Whereas previously a father teaching his son how to shave for the first time might have been a personal “coming of age” moment to be shared between them, today almost anyone with access to the Internet can learn about shaving (or ironing, cooking, dancing, drawing, singing, calculus, changing a tire, sculpture, Renaissance painting, the history of punk rock music, Medieval law, and almost any fact, idea, or concept…) at the press of a button without any need for face-to-face human interaction.
b) Nearly anyone can have an inexpensive set of assembly line produced cookware (or any other example of basic consumer goods) delivered to their door from half-way around the world in less than a week and for less than the cost of a week’s wages.
c) The slow-brewing anticipation of receiving a carefully crafted letter from a far-away pen pal has been replaced with the rapid-fire immediacy of 140 character “tweets” (Twitter - About)

By today’s standards, these examples might seem somewhat mundane and commonplace. However, we present these examples to highlight how recently in the past these ‘everyday’ events would have seemed absolutely radical and unimaginable.

The incredible speed with which our societal environment is changing, updating, and evolving is unprecedented and the depth with which it is affecting modern culture is not without its detractors. Like the Luddite rebellions which protested the radical social upheavals introduced by mechanical looms in 19th century Britain (Power, Politics, and Protest: The

Growth of Political Rights in Britain in the 19th Century - Luddites), there is much that is still not understood about how the pace of change of the Industrial and Digital Revolution is affecting our modern society, both for the better and for the worse. As a result, there are various groups that are fighting back against it on various fronts. Academics, artists, politicians, and others have been protesting a perceived erosion of traditional, face-to-face social interaction and highlighting the negative side-effects of technological advancement (Turkle, 2011) (Economist, 2010). Yet others have championed the reverse perspective: social networking as a boon to health care, improved access to information for political transparency, benefits to the global economy, and internet access as a basic human right (Kravets, 2011) (Goldman, 2010) (Gaudin, 2011).

Even as we work to understand how global society is being influenced, disrupted, and changed by these two previous (and still ongoing) revolutions, others anticipate the development of a third global revolution that they claim has the potential to be just a ubiquitously disruptive to our modern society, if not even more so: The Robotics Revolution. This third global revolution serves as the background for the rest of this thesis' discussions, and it's potentially global scope, powerful disruptive potential and hypothesized ubiquity serve as the underlying motivation for our work.

2.2 The Robotics Revolution

Futurists like Ray Kurzweil (Kurzweil, 2005), noted academics like Hans Moravec (Moravec, 2000), science-fiction authors like Philip K. Dick (Dick, 1968), CEOs of major corporations (Guizzo, Do Robots Take People's Jobs?, 2011) and many others the world over have been theorizing about the rise of robots for decades. Envisioning some distant future time where society is filled with robots of all shapes, sizes, and purposes, these forward thinkers highlight the exciting promise of a robot-enhanced future that fuses the exponentially increasing capabilities of computing hardware (a la “Moore’s Law” (Moore, 1965)). These amazing future robots would have the ability to move through, manipulate and interact with the physical world autonomously.

Rather than existing solely as far-off future imaginings however, the (perhaps) surprising reality is that the first wave of the Robot Revolution is already well underway. We present the following three scenarios (military robots, autonomous vehicles, and domestic vacuum robots) as discussion points highlighting how imminently ubiquitous we believe robots are to about to become, if they are not so already. We subsequently demonstrate how these robots can have unanticipated social and cultural impacts and discuss them from the perspective of social HRI research.

2.2.1 Military Robots

Used primarily for reconnaissance and bomb disposal, more than 3000 iRobot Inc.'s "PackBot" robot platforms (Figure 1) have been sold since 2002 (Staff, 2010); with many of these being deployed to the current wars in Iraq and Afghanistan. Similarly, Predator and Reaper UAVs (Unmanned Aerial Vehicles) have since become a regular sight on both modern battlefields and national news reports.

Figure 1 - A U.S. solider and an iRobot Packbot robot platform (left) and an MQ-9 Reaper UAV (right)

Proponents of the use of robots for warfare argue that instead of putting soldiers' lives in dangers on the front lines, these robotic proxies can be sent into the battle instead. These war-bots are arguably even more effective than their manned counterparts thanks to their advanced sensors, precision capabilities, and tireless mechanical efficiency.

Arguments about their relative effectiveness aside, we again emphasize that the use of robots in military conflicts (Brannen, 2010), civil policing and border patrol (Wise, 2009), and even private photography (Draganfly, 2011) is already a widespread reality.

2.2.2 Autonomous Vehicles

Since the early 1980's, international teams of scientists and engineers have been attempting to realize fully autonomous vehicles; citing numerous advantages such as increased personal safety, fuel efficiency, convenience, and highway capacity. Much like the initially slow but steadily accelerating progress of computing hardware, more recent projects such as the pan-European EUREKA Prometheus Project (EUREKA Prometheus Project), the DARPA Grand Challenges (History of DARPATech Proceedings), and the Google Driverless Car (Google driverless car) have resulted in an accelerating series of breakthroughs in driverless car technology. Research obstacles that were impossible to solve decades prior begin to fall with increasing speed from year to year and then month to month. Using combinations of advanced computing algorithms, sensor suites, and robotic actuation, numerous robotic vehicles have now successfully navigated hundreds of kilometres of complex, real-life terrain (ranging from deserts, mountains, highways, and pedestrian-packed urban centers) without any human intervention.

Where once autonomous vehicles were being held back by the limitations of their technology, the primary factor preventing driverless robot cars from becoming a wide-spread, modern reality is now largely a question of legislation and legal liability. (E.g. if an autonomous car is involved in a collision, is it the drivers fault, or the manufacturers, the software programmers?) Yet even this hurdle is in the process of being overcome: in June 2011, the U.S. state of Nevada passed a bill to become the first jurisdiction in the world where driverless vehicles could be legally operated on public roads. (Green light given to Google as changes to the law make driverless car legal)

2.2.3 Domestic Vacuum Robots

While a far cry from the all-capable, pleasantly personable maid-robot “Rosie” (Rosie the Robot - Jetsons Cartoon Characters) from the science fiction cartoon series “The Jetsons”, the Roomba vacuum cleaner (iRobot Corporation) is one of the first commercially successful domestic robots in history. Having sold over 2.5 million units since its introduction in 2002 (according to its manufacturer iRobot) (iRobot), the basic Roomba design has been imitated, iterated, and improved upon by numerous other companies and spawned an entire competitive industry of domestic robot vacuum cleaners (Mint Robot Vacuum Cleaner) (Neato Robotics Inc.). When shopping between the various models on offer, the modern consumer can compare different specifications on their domestic robot vacuum cleaner (such as battery life, scheduling features, capacity, speed, and noise) just as they might compare specifications (such as CPU speed, RAM, storage capacity, and weight) when shopping for a notebook computer.

In addition to their flagship robot vacuum cleaner products, iRobot also markets mopping robots, rooftop eaves cleaning robots, and pool cleaning robots to domestic markets. While these other products have so far not been as successful as the Roomba vacuum cleaner robot (from a commercial perspective), the argument that we again highlight is that these products exist *now;* where once there was science-fiction, there now exists a variety of domestic robot products that people of average means can purchase from major international retailers alongside their everyday groceries and cloths shopping.

Together with our previous examples of the widespread adoption of military robots and the rapid advancement of autonomous vehicle technology, we argue that the Robots Revolution is already well underway. Robots are already affecting different aspects of our society in ways that may not be fully understood for years or decades to come.

In response, multiple unique fields of research have emerged to study and understand these disruptive new technologies. The primary focus of this thesis is the field of Human-Robot Interaction (HRI) and, more specifically, the sub-field of *social* HRI. We now briefly describe the distinction between the two and re-examine our three example scenarios from these new perspectives.

2.3 “Traditional” Human-Robot Interaction

Early computers were enormously complex mechanisms that could only be operated by a select few highly trained individuals and the inner workings of which were only fully understood by even fewer. As computers became more powerful, more complex, and more ubiquitous, increasingly more attention was paid to the careful design of how users perceived and interacted with these devices and how those devices were designed to allow for easier and more intuitive interaction regardless of the users’ formal training.

Successive leaps from punch cards, to command lines, to WIMP (Windows, Icons, Menu, Pointing Device), and more recently to touch-screen (and even touch-less gesture-based (Microsoft Corporation)) interfaces has allowed ever increasingly more people to interact with their increasingly powerful and complex digital devices. The field of research concerned with studying and improve these interactions is known as Human-Computer Interaction (HCI) research. HCI researchers explore concepts such as users’ visual perception and cognitive loads, interface design, effective means of exploring large data sets, new interaction paradigms, collaborative work, and many other facets concerned with how we humans understand and interact with computers; often with a focus on the efficiency of control and interaction with these systems.

Similarly, as robot technology has become increasingly powerful, complex, and ubiquitous in recent decades, the research field of Human-Robot Interaction has emerged (Kiesler & Hinds, 2004). While concerned with many of the same ideas as HCI research (by virtue of their common technological basis), HRI research also explores many problems and ideas unique to robotics: areas such as situational awareness during tele-operation, dynamical control methods, artificial intelligence, sensor processing, machine vision, electro-mechanical engineering, and so on.

In the context of our previous examples, HRI researchers might be concerned with:

1) How a driver knows when/if their autonomous vehicle is experiencing difficulties navigating a city and the visual feedback displays or audio cues that signal this information.
2) How a robot vacuum cleaner senses the room around it (e.g. walls, furniture, occupants) and plans its cleaning schedule and working path around them.
3) To what degree a UAV pilot is able to maintain spatial awareness of their remote aircraft such as its location, its orientation, and its condition based on only that data which is available. (e.g. a live fighter pilot can look around outside their cockpit to visually spot enemies, but a remote UAV pilot may not have this capability.)

Much like traditional HCI research, traditional HRI research is often concerned with the efficiency of control and interaction between robots and their human operators.

2.4 *Social* Human-Robot Interaction

Whereas traditional HRI is primarily concerned with the more mechanistic aspects of how to control and operate robots, the sub-field of *social* HRI focuses more on the psychology and sociology of how, when, and why humans interact with robotic agents.

To highlight this distinction, we consider our three examples again but from the perspective of *social* HRI:

1) Is the average person willing to trust their life to an autonomous vehicle? What if something goes wrong? How can manufacturers convince sceptics?

   An autonomous vehicle also removes control from the driver. How does this affect the "mythos" and pride associated with skilled driving or the "freedom of the open road"? Does a trip in a fully autonomous electric car have the same romance as a road-trip across Route 66 in a gas-guzzling, ground-rumbling Ford Mustang? "Car culture", itself a relatively recent development, is firmly embedded in Western society and raises the question: even if the technological and legislative hurdles of autonomous vehicles are soon overcome, would the general public even want them?

2) Studies have already shown that the introduction of a robot vacuum cleaner (a distinctly high-tech device) in a household has a tendency to shift regular cleaning responsibilities towards the males of a family (Forlizzi & DiSalvo, 2006) (Sung, Grinter, Christensen, & Guo, 2008). Whereas vacuuming was historically a task for housewives, the proper maintenance and programming of a Roomba is now more akin to programming a VCR or servicing the family vehicle. Stereotypes aside, there is a social disruption at work here that bears investigation and study.
3) While proponents of robotic warfare argue that UAVs and devices like the PackBot save lives by taking soldiers out of harm's way, detractors fear that this "robotization" of violence lessens the psychological cost of waging war (e.g. the loss of soldiers' lives); making waging wars easier to justify and skewing this advantage towards richer and more powerful nations that can afford these high-tech weapons.

   As an example: many of the U.S.'s UAVs that are flying missions in the Middle East are remotely piloted by soldiers from bases in the American Midwest. These soldiers are able to "log in" to the UAV's control feeds, fire their missiles, and then return home to their families for dinner that evening. How do these soldiers' experiences differ from those who have been deployed to the front lines (for tours lasting many months), who experience death and violence in person rather than through a computer screen?

These examples highlight some of the psychological and sociological phenomena that straddle the boundary between traditional HRI research and *social* HRI research and are already an active area of research. As robots begin to take on increasingly personal and autonomous roles in society, the need to understand how we interact with them as social agents becomes ever more important.

2.4.1 Examples of Social HRI Research

"Paro" (Paro Robots U.S., Inc.), a robot that resembles a baby harp seal (Figure 2 - An elderly woman interacting with "Paro", a care-taker robot modelled after a baby harp seal), has been in use in Japan and throughout Europe since 2003. Employed primarily in care giving roles (e.g. homes for the elderly, hospitals), *Paro* invites intimate physical interaction through its movements, vocalizations, and artificial intelligence. *Paro* has been shown to reduce patients' stress (Wada, Shibata, Saito, & Kazuo, 2002) (Saito, Shibata, Wada, & Tanie, 2002) and improve their general happiness similar to visits from live animals such as cats and dogs. While the *Paro* robot may like some of the agility and lifelike energy of a truly live animal, it also allows for interaction that was previously impossible without robotic technology. E.g. *Paro* is hypoallergenic, continues working so long as its battery remains charged, allows care givers to monitor patients discreetly and remotely via embedded sensors such as cameras and microphones, etc.

Figure 2 - An elderly woman interacting with "Paro", a care-taker robot modelled after a baby harp seal (Paro Robots U.S., Inc.)

While *Paro's* internal mechanics required careful engineering and the system interface by which caregivers are able to control the robot required careful design, the field of social HRI is primarily concerned with whether and how the patients interact with and respond to the robot. E.g. How natural do they find the experience and how accepting are they of *Paro* knowing that it is a robot? Are *Paro's* vocalizations and movements appropriate and do they contribute to the robot's sense of character and intelligence or do they just seem to be random? Can *Paro* deliberately cheer someone up through its programming or is this affect achieved simply by its appearance? Etc.

In a similar vein, the Keepon robot has been used to study autism-spectrum disorders (ASD) in young children (Kozima, Nakagawa, & Yasuda, Children-robot interaction: a pilot study in autism therapy, 2007) (Kozima, Michalowski, & Nakagawa, Keepon: A Playful Robot for Research, Therapy, and Entertainment, 2009). Keepon is made of a soft, yellow, squishy material with only two eyes and a nose. The eyes are each tiny digital cameras and its nose is a microphone. The motors in its base allow Keepon to twist, lean, and bob smoothly. What is particularly powerful about the Keepon robot is that it allows researchers a unique perspective into how these children with ASD interact.

Figure 3 - A young girl interacting with *Keepon* (BeatBots LLC)

In many cases, it is difficult or uncomfortable for these children to interact socially with other humans because they find the tremendous variety of subtle emotion cues (eye gaze direction, eyebrow position, head tilt, lips and teeth position, eyelid, etc.) too overwhelming to synthesize all at once. Keepon is able to circumvent these problems by presenting the children with a drastically simplified and much more abstract "face". By using its limited set of motions, Keepon is able to express shared attention, recognition, and perform basic communicative gestures by bobbing at appropriate times.

By observing and recording Keepon's interactions with children through the robot's in-built cameras and microphone, researchers are now able to study the growth and social interaction of these children in a setting that is more comfortable for them. As a social HRI study, Keepon's focus is on the developmental psychology of the children, not on the robot platform's specific engineering or control system.

As a final example of social HRI research, work from Bartneck et al. presented participants with a very simple light-following robot toy and a flashlight (Bartneck, Mubin, & Al Mahumud, To kill a mockingbird robot, 2007). In one case, the robots were unaltered and were fairly competent in following where the participants directed the flashlight on the floor. In the second case, part of the robot's light sensors were disable and the robot travelled around the floor in a seemingly random fashion. After having the participants play and interact with the robot for a few minutes, the experimenters handed the participants a hammer and instructed them to quickly "kill" the robot; claiming that it employed a special learning algorithm that the researchers could not afford to let spread to the rest of the robot population.

Figure 4 - The implements of Bartneck's "mockingbird robot" experiment: a hammer, flashlight, and light following toy robot (Bartneck, Mubin, & Al Mahumud, To kill a mockingbird robot, 2007)

While at first glance a somewhat odd and seemingly nonsensical experiment, the experimenters' results are somewhat surprising: those participants with the unaltered robots took significantly longer to smash the robot, struck it fewer times, and claimed they felt it was "more intelligent". Alternatively, those with the broken robots struck hard, fast, and repeatedly. The experimenters theorize that this discrepancy is a result of our human empathy with intelligent creatures. E.g. While most people do not think twice when crushing a spider, many people will go out of their way to help a dog who is suffering.

Viewed as a whole, social HRI incorporates elements from human-computer interaction, engineering, psychology, sociology, cognitive science, and even cultural anthropology. All of these disciplines come together in an entirely new field of research; one that has its own unique preconceptions, twists, and methodologies distinct from its component parts.

Social HRI research is also a relatively new field in many academic circles and, although practiced at research institutions around the world, is largely unheard of by the general public. Given its novelty and combined with the imminent importance of understanding how these disruptive robotic technologies will affect our society and culture in coming years, we have taken this time to provide a brief overview of social HRI's history and context. Having established this understanding of the larger field of social HRI research, we now describe the specific aspect of social HRI upon which this thesis focuses: *emotive motion.*

2.5 Emotive Motion

Having provided the reader with a brief history, context, and motivation leading up to our work, we now introduce our goal: Over the course of this thesis, we explore the emotional effect of motion in social HRI. Specifically, our goal is to investigate whether and which types of emotional reactions can be elicited by the motion of robotic entities and to begin to understand what additional factors, such as visual appearance or working context (e.g. what task is the robot performing, where is it performing it) might play a role in that interaction between emotive robot motion and human observer.

Although these were not the specific goals of the studies we described previously, we argue that *emotive motion* plays a critical part in almost all social HRI experiments and thus must be paid specific attention when designing such experiments. In the case of Paro, the robot's motions must closely mimic those of a real baby harp seal: generally docile and slow unless the seal is hungry or in distress. Both Keepon's and the Bartneck "mockingbird" robot's only means of expression is via motion. Keepon responds to children through bobbing and "dancing" and the light-following robot's ability to follow the participant's flashlight (or not) is claimed to be a directly correlation with that robot's perceived intelligence.

While other social interaction phenomena may be the direct focus of a social HRI experiment (e.g. is the robot performing a task correctly), we argue that the characteristics of that robot’s motion (e.g. amplitude, frequency, direction, timing, consistency, reactivity, smoothness, speed, etc.) will play an important role in how human observers interpret, interact with, and perceive these robots. For example, while shuffling a deck of playing cards, is the robot doing so in a brisk, upbeat manner conveying that it is eager to play a game or are its movements slow, steady, and monotonous? Is a security robot patrolling its area slowly and cautiously (perhaps even resembling a hunting leopard), constantly scanning its “head” around with an air of high-strung menace so as to deter any would-be intruders or is it simply rolling from hallway to hallway much like a cleaning robot might?

We now spend the remainder of this thesis exploring the concept of *emotive motion* in social robots; its characteristics, its limitations, and discuss how it can be used as a powerful tool in future social robot design. In chapter 2, we briefly discuss related efforts in the field of social HRI. In chapter 3, we introduce a taxonomy which we use throughout this thesis in which to frame our various works and discussions. Chapter 4 details a variety of early prototype robot platforms that we developed to explore the concept of emotive robot motion. In Chapters 0and 7, we describe two major user studies that we conducted and discuss their results. We conclude our discussions in Chapters 0 and 9 and reflect on what we have learned through our efforts, their larger implications on social HRI, areas where our investigations could be improved, and future work.

3 Related Work

We believe our work is some of the first to explore the concepts of robot motion's style and character directly. In later chapters we discuss our work and focus on the general concept of *emotive motion* but in this chapter, we present a brief overview of some related works in the field of social HRI that address parallel ideas: studies that demonstrate both useful applications of emotive robot motion in specific working contexts and others that address the expressive characteristics of specific robots.

3.1 Emotive Motion Applied in Working Contexts

Numerous social HRI studies focus on specific tasks or different cognitive science and sociological phenomena otherwise not directly focused on *emotive motion* but which still demonstrate the expressive power of robot motion anecdotally. This "means to an end" effect can be seen in the light-following robot example from the previous chapter: Although Bartneck et. al. focus their attention on the perceived intelligence of the robot and the participants' hesitancy to smash the robot, the sole expression of the robot's "intelligence" is by way of its alternately purposeful or random motions (Bartneck, Mubin, & Al Mahumud, To kill a mockingbird robot, 2007).

An experiment by Hoffman and Breazeal (Hoffman & Breazeal, 2008) focuses on using robots as cooperative work partners. In this study, a robotic desk lamp and a human partner are tasked with reading a prescribed sequence of words from a set of signs arranged throughout a room and repeating each spoken sequence multiple times. In one condition, the robot lamp anticipates the human participant's motions and points towards the next sign ahead of the human partner's arrival and in a seemingly semi-intelligent fashion. In the alternate condition, the robot lamp merely follows the human directly with no anticipation and it is up to the human participant to remember which pedestal is next in the sequence without any assistance from the robot.

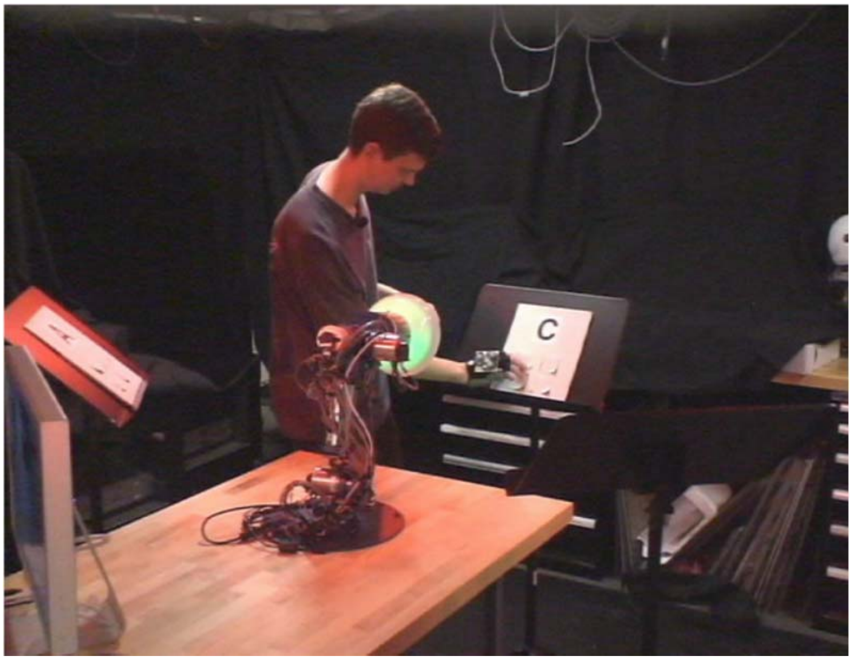


Figure 5 - A study by Hoffman and Breazeal has participants cooperate with a robotic desk lamp (Hoffman & Breazeal, 2008)

In this study, the experimenters' focus is on developing a flexible and intelligent anticipation system for robot collaborators. The robot lamp is able to assist its human partner by intelligently timing its motions and gesturing to the next sign in sequence. The results of the study demonstrate the emotional power of even these simple robot movements: participants felt that the anticipatory robot was more intelligent and more competent. Some participants even felt anxious about not wanting to "disappoint" their robot co-worker. Again however, we observe that the lamp's apparent intelligence, or lack thereof, was expressed solely by its movements and the way these related to the task.

Work by Cory Kidd (Kidd C. , 2008) and his spin-off company Intuitive Automata Inc. (Intuitive Automata Inc.) explores the concept of motivating long-term weight loss by personifying a digital statistics tracking system as a small, social robot. Their premiere robot product, called "Autom", consists primarily of a large, interactive touch screen with a mildly anthropomorphic "head" mounted on top (Figure 6). Users are encouraged to input information about their diet and exercise routine every day and the robot logs and analyzes their progress. Using its text-to-speech style voice synthesis capabilities, the robot responds with words of praise or gentle encouragement with phrases such as “Together we can reach your goal.” and “I want to help you lose weight.”

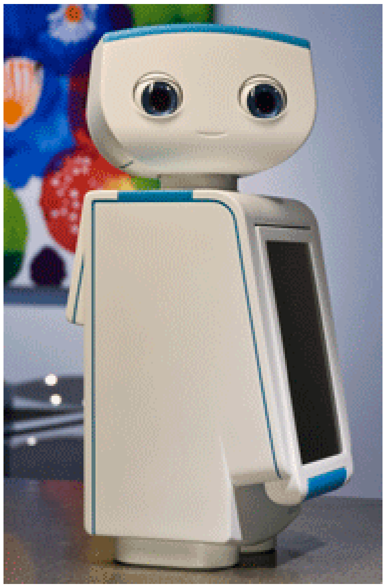


Figure 6 - Intuitive Automata Inc.'s "Autom" weight-loss training robot (Intuitive Automata Inc.)

Autom’s body does not move however and its head and upper eyelids are only capable of rigid, slow motions. While the concept of using a social robotic agent to motivate behaviour change is promising, largely unexplored territory, we feel that *Autom’s* extremely limited movement capabilities drastically reduce its effectiveness. In this case, we propose that the robot’s purpose is undermined by a *failure* to properly leverage *emotive motion:* We are left with the impression of a touch-screen computer (having sacrificed the benefits of an alternatively lightweight, mobile device) and only limited signs of a personality rather than a lively social robot with which we might emotional bond and cooperate.

As interesting as these projects are, the work is presented with a strong focus on specific task scenarios (that is, anticipation and cooperation with a robot helper). The robots’ motions are discussed in terms of *what* movements the robot performed in order to achieve its task. The specific qualities of *how* those motions were perform (e.g. smooth, repeating, rapid, etc.) were not the focus of the study and are mentioned tangentially, if at all.

3.2 Instances Focused of Emotive Motion

Other studies treat the concept of *emotive motion* with a stronger focus. For example, Mutlu et al. projected a collection of abstract moving geometric shapes onto a display (Figure 7) with the intent of eliciting specific emotional responses such as happiness, nervousness, or fear by animating the displayed shapes according to designated patterns. (Mutlu, Forlizzi, Nourbakhsh, & Hodgins, 2006)

Figure 7 - Mutlu et al. projected abstract shapes onto a wall and studied how various motion patterns could elicit different emotions (Mutlu, Forlizzi, Nourbakhsh, & Hodgins, 2006)

While the findings showed that this interactive display was successful in eliciting recognizable emotional responses via deliberate motion patterns, it was limited to the virtual display only, without any physical embodiment beyond the screen, and without physical movement. Work by Kidd and Breazeal indicate that the physicality and manifest presence of a robot, versus a virtual, on-screen entity, significantly affect a person's perceptions of these social entities. (Kidd & Breazeal, 2004)

The Puppet Master study (Young, Igarashi, & Sharlin, Puppet Master: designing reactive character behavior by demonstration, 2008) (Young, Ishii, Igarashi, & Sharlin, 2010) investigated how the motion paths of on-screen characters and iRobot Roomba-based robot platforms, could be used to express different robot personalities and intents. Using a unique puppet-based teaching method, novice users could demonstrate to the robot how to act “aggressive”, “happy”, “shy”, etc. For example, “attacking an intruder” would have the robot rapidly approach and make physical contact with the person and always attempt to stay in front of them to block their path. A computer algorithm would then take the robot’s speed and proximity information from these demonstrations and synthesize them into dynamic motion instructions for the robot to perform as a new participant walked around and interacted with the robot.

One of the experimenters’ conclusions (besides the ease of use of the authors’ puppeteer teaching method when compared to traditional hand-coding) is that each of the resultant motion patterns were generally recognizable, even for participants who had never seen or taught the robot prior. This demonstrates that, even with a robot platform as relatively simple as a Roomba vacuum, varied and recognizable emotive expression can be made just by employing the robot’s inherent motion capabilities (in this case, locomotion).

The focus of the Puppet Master work was primarily on the ease and effectiveness of the novel teaching method. While *emotive motion* played a key role in the author’s results, the nature of the motion algorithm is tightly coupled with this specific context and implementation. It is able to synthesize dynamic motion patterns based on simple speed and proximity relationships, but it does not address more complex issues such as the passage of time (e.g. has the robot done this before), the logical relationship between the robot and human (e.g. the robot’s owner vs. a stranger), or the situational context of where and why the human and robot are interacting (e.g. in public vs. in a private home). The study’s participants are focused on the style and character of the robot’s motions, but the author’s results do not discuss how these expressions might by designed or applied outside of the specific “demonstrate and display” context of the Puppet Master scenario.

A study by Saerbeck and Bartneck (Saerbeck & Bartneck, 2010) investigates *emotive motion* as a concept even more directly. In these experiments, participants were shown two different robots. In the first case, a Roomba travelled a circular path along the floor. In the second case, participants sat in front of a Philips iCat robot (Philips Electronics) (Figure 8) and watched as it looked between two objects set on the table in front of it and then returned its head to a neutral position facing the participant. (It should be noted that although the iCat's facial features are capable of changing to express emotions such as "fear", "sadness", or "happiness", they were keep in a neutral configuration throughout the study.) In both cases, participants were asked to rate their emotional responses as the experimenters varied the acceleration and curvature of the robots' motions. These motion paths were measured with respect to the Roomba's physical location as it traveled around the floor and the tip of the iCat's nose as it panned and tilted its head, respectively.

Figure 8 - The Philips "iCat" robot head. Resembling a cartoon cat, the iCat's facial features can change to express various emotions. (Philips Electronics)

The experimenters found that all of their participants "had been surprised by the variety of emotions expressed by the devices". Participants described the changes in the Roomba's movements as going from "careful" to "moving like a cat that wants attention" and the iCat as changing from "falling asleep" to "calm and relaxed". These are powerful results as they allude to a direct link between deliberate changes in a robot’s motions and its different emotional expressions.

The experimenters go on to claim that there was no significant difference in emotional interpretation between the two robot platforms and, while they attempt to make general statistical assertions correlating physical acceleration and curvature and emotional arousal and valence, they also admit that the underlying source of these relationships is unclear based on the current experiments.

In light of our work, which we discuss in subsequent chapters, we are inclined to agree that the use of *emotive motion* as a design tool in social Human-Robot Interaction is not nearly as simple as modifying a basic acceleration value to increased how “happy” a robot seems. Their results are also intrinsically tied to their two choices of robot embodiment: a cartoonish cat head and a domestic vacuum cleaning robot. We feel that the visual form of these robots carries with it important emotional connotations (that is, it is significant that the iCat is “shaking its head” and not it’s “foot” or “torso”). In our work, we endeavour to study *emotive motion* in a more “pure” sense; as free from visual connotation and affordances as possible.

In each of these instances, *emotive motion* plays a critical role but is not the core focus of the research. Our work attempts to take a more comprehensive approach to exploring and subsequently understanding the concept of *emotive motion*: we considering its design, influence, and side effects in isolation, in application, and in the presence of external influences such as recognizable visual form.

3.3 Conceptual Foundations of Emotive Motion

With the goal of gaining a deeper, more fundamental understanding of how the style and characteristics of robot motion affect its emotional expressivity, this section discusses a trio foundational works which we use in the next chapter to develop a conceptual taxonomy for exploring *emotive motion.* Where previous work may have employed emotive robot motion in service to an applied task or in a specific context, we use these works to understand *emotive motion* in a base, abstract sense.

3.3.1 The Liveliness of Motion

A seminal 1944 experiment by Heider and Simmel underscores the apparent affective capabilities of moving, non-living, abstract objects. In their study, participants were shown a short film wherein abstract geometric shapes (e.g. circles, rectangles, and triangles) were animated against a blank background (Heider & Simmel, An Experimental Study of Apparent Behavior, 1944). An example of this sequence is shown in Figure 9. (Given the importance of the film's animation, readers are also encouraged to try to watch the film online (Heider & Simmel, Video - An experimental study of apparent behavior)). Once the film was finished playing, the participants were asked a very straightforward question: "Describe what happened in the film?"

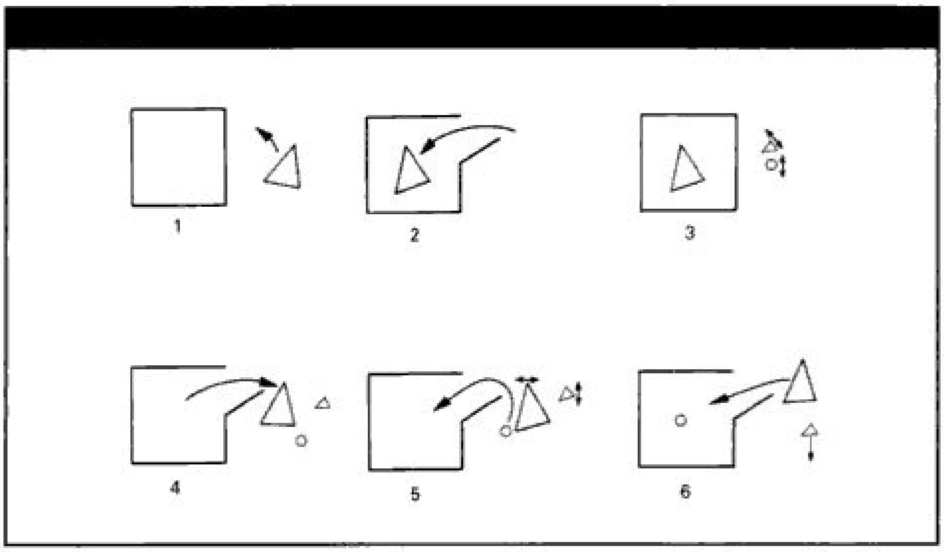


Figure 9 – Diagrams describing some of the movements of the shapes in Heider and Simmel's film about apparent behavior (Heider & Simmel, An Experimental Study of Apparent Behavior, 1944)

The remarkable result here was that the great majority of the participants interpreted the moving abstract geometric shapes as purposeful beings; for example, describing an argument between two men over a woman. Only one participant described the film in purely factual geometrical terms. (e.g. "A large solid triangle is shown entering a rectangle.") In effect, the majority of the participants attributed emotion and social intent to completely abstract but *animated* geometric shapes without specific prompting.

In their analysis of their results, Heider and Simmel highlighted apparent correlations between different motion patterns and their subjects' emotional responses. When the abstract shapes exhibited movements such as "simultaneous motion with sustained contacted", subjects' viewed this as "pushing or pulling"; "simultaneous movement without contact" as "following or leading", "impacts and reactionary movements" as violence or hitting; and so on. The subjects' specific descriptions varied based on factors such as which shape initiated the motions, their spatial context and the relative spacing of the various shapes, and whether or not patterns were observed to be repeating.

The concept that we take away from this is the fundamental correlation between certain motion characteristics (e.g. timing, speed, direction, proximity, reaction) and recognized emotional expressions; even in the absence of familiar visual form or anthropomorphic characteristics such as eyes, a face, or limbs. These results allude to an innate ability (or perhaps even tendency) for humans to attribute intelligence and purpose to the movement of abstract objects; a psychological phenomenon that lays the foundations for *emotive motion* as a design tool in social HRI.

3.3.2 Treating Digital Devices as Social Agents

In their book "The Media Equation" (Reeves & Nass, 1996), Byron Reeves and Clifford Nass describe a series of experiments they conducted which explored how people treat media artefacts such as computers, videos, and photographs in a similarly social manner as they treat other people. For example, when asked to criticize a fact-teaching computer program (consisting solely of a keyboard, monitor and text display), subjects were more polite when the computer asked them directly "Was this advice helpful?" than when a second computer asked the participant's opinion regarding the first. This parallels sociology studies showing how people can be more judgemental of someone when that person is not present to be offended. Further experiments from Reeves and Nass explore concepts of personality, character, morality, arousal, and gender (among others) and find similar human-media behaviours as those observed during live inter-personal interactions.

Reeves and Nass' titular claim is that "media experiences = real life experiences"; that we treat computers and other media as social actors (as far as our emotional reactions and interactions are concerned) despite their being artificial, non-living entities.

Some critics of The Media Equation argue that the phenomena at work are not quite as simple as original claimed, however. In his review of The Media Equation (Dourish), Paul Dourish proposes that the participants were reacting to the implicit *authors* of the various experiments' media. E.g. Responding to the *programmer* of the fact-teaching computer programmer, the *director/cameraman* of a video clip, or the *photographer/subject* of a given photo; rather than the media artefacts themselves.

While the true cause of the Media Equation phenomena is debatable, Reeves and Nass demonstrated that the observed results were consistent across many different media and social situations. For the purposes of social HRI research and exploring emotive robot motion then, this is a powerful result that mirrors Heider's and Simmel's findings: robot's are an even more life-like entity than simple computer terminals and it is highly likely that social robots will benefit from this subconscious human attribution of social characteristics onto artificial entities.

3.3.3 The Interplay between Visual and Motion Familiarity

While robots can be designed to be different sizes, shapes, and forms based on what is most suitable for their given purpose/task, one form in particular carries with it unique social connotations and emotional opportunities: that of human replica robots or "androids". One of the unique strengths of androids, as regards social HRI and emotional expressiveness, is that because of their very similar visual appearance and human-like features they can leverage all of the same social mannerisms and behaviours with which we are already naturally familiar. For example, shrugging their shoulders in confusion, or expressing anger with narrowed eyes and grimacing teeth.

Modern android development has even begun to approach this ideal. For example, it can be difficult to tell the difference between Hiroshi Ishiguro and his "Geminoid" counterpart

(Sakamoto, Kanda, Ono, Ishiguro, & Hagita, 2007). (Figure 10) The Geminoid has a very life-like appearance including individual hair follicles, eyelashes, and soft, flexible skin.

Figure 10 - Hiroshi Ishiguro (left) and his android twin, "Geminoid". The word Geminoid is a combination of "Gemini" and "android". (Sakamoto, Kanda, Ono, Ishiguro, & Hagita, 2007)

The Geminoid is also actuated by many different pneumatic "muscles"; allowing it to use its head to look around, move its jaw when speaking, blink its eyes and even make breathing motions with its chest. The Geminoid cannot move its arms and legs however: The robot's power source is an external air compressor, with hoses running up through the Geminoid's seat, preventing the robot from being able to stand up and walk around. The precision of these "pneumatic muscles" is also limited which makes it difficult for the robot to perform extremely subtle motions, such as squint its eyes or gently tilting its head to the side in a convincing manner.

The end results is that, while the Geminoid and similar android may look remarkable in still photographs and can be semi-convincing when limited to seated conversations, after a prolonged period of interaction many usually gets the eerie sense that there is something "wrong" with it/him. Having had an opportunity to "meet" the Geminoid in person, we can say that one is quickly left with the impression of talking with a quadriplegic person who, while looking very much like the human standing next to him, seems to be suffering from some sort of degenerative neuromuscular condition as it sits twitching.

In his 1970 paper “Bokimi no Tani” (originally 不気味の谷, the paper was translated by Karl MacDorman and Takashi Minato as “The Uncanny Valley”) (Mori, MacDorman, & Minato, 1970), Japanese roboticist Masahiro Mori wrote a commentary on the advance of robots that he had observed during his career. Mori hypothesized that as robot and android technology progressed, there would be a distinct correlation between the degree to which a robot visually resembled a human and the degree to which human observers would find them familiar, pleasant, emotionally expressive, and comfortable with which to interact. For example, a “perfect android” that was visually indistinguishable from a live human would be more pleasant to interact with than a robot that only possessed *some* humanoid characteristics such as the robot C-3PO from the film Star Wars. In turn, a C-3P0 style robot would be more appealing than a robot that did not resemble a human at all; such as a Roomba. Mori presented this trend using the graph in Figure 11. An example spectrum of increasingly human-looking robots is shown in Figure 12.

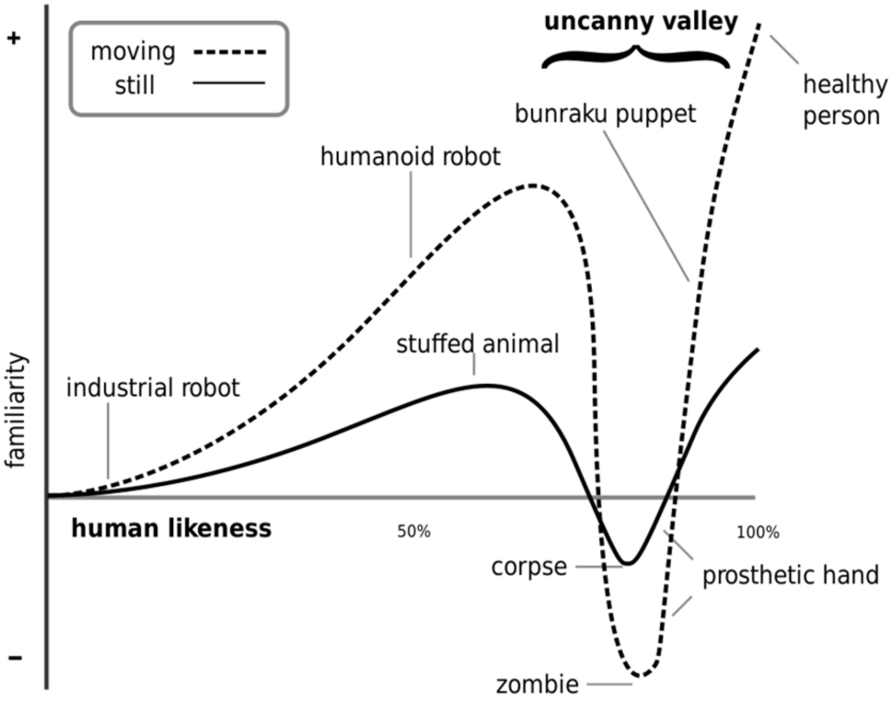


Figure 11 - Mori's graph of the "Uncanny Valley" (Mori, MacDorman, & Minato, 1970)

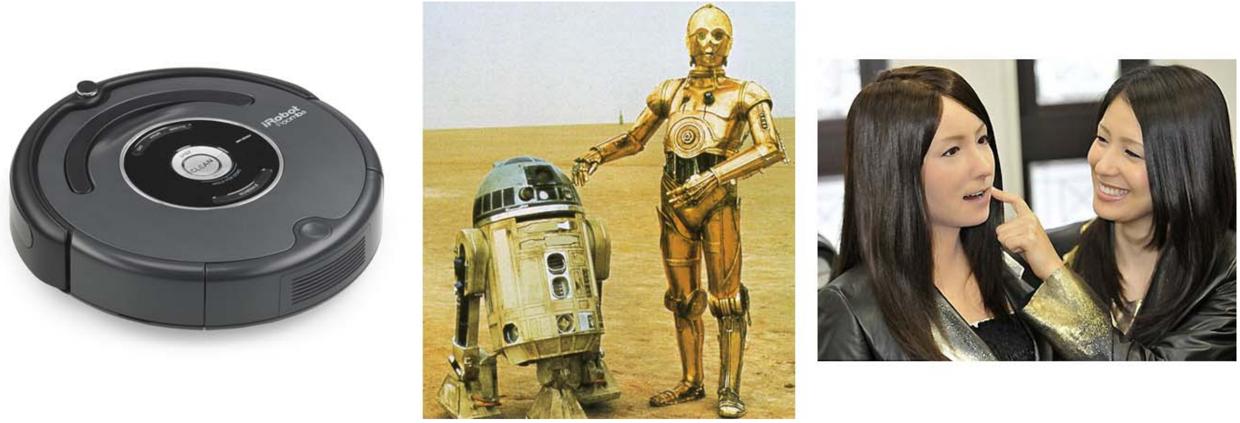


Figure 12 - A spectrum of different robot forms. A highly mechanical Roomba (left); R2D2 and C-3P0 from the film Star Wars, robot that incorporate anthropomorphic features (center); “Geminoid F”, an android with a very human-like appearance and the woman it was modeled after (right)

The titular “valley” occurs where Mori highlighted a distinct drop in how comfortable people would feel interacting with a robot that very nearly approached true-to-life human appearance but without quite reaching true, indistinguishable fidelity. This “Uncanny Valley” is where anthropomorphic robots take on a distinctly unsettling appearance (e.g. zombie-like) and where *less* humanoid robots would actually be preferred.

Figure 13 shows Ishiguro’s “Telenoid R1”: a tele-presence robot (i.e. a remote user can assume control of the robot and speak, sense, and gesture as if physically present) which was specifically designed to have a “minimalistic human” appearance (Guizzo, Telenoid R1: Hiroshi Ishiguro's Newest and Strangest Android). In this way, the visual appearance of the robot would not interfere with the character of the person “dialling in”. While the Telenoid’s androgynous, ageless, and featureless appearance is designed to suit its purpose, many observers have claimed that they are quickly put off and feel uncomfortable when interacting with it. Many feel this “almost but not quite human” look places the Telenoid firmly at the bottom of the Uncanny Valley.

Figure 13 - The “Telenoid R1” tele-presence robot (Guizzo, Telenoid R1: Hiroshi Ishiguro's Newest and Strangest Android)

The “Uncanny Valley” theory has since become well known in both academia and popular culture: being the subject of numerous studies, appearing in popular TV shows (Mancuso, 2008), influencing video game design, and even being proposed as the cause of failure of several major Hollywood animated movies (Gutierrez).

Despite its widespread popularity however, the “Uncanny Valley” theory remains controversial; particularly in its original field of android science. Numerous researchers refute Mori’s original conjecture; claiming that either the model is too simple, failing to capture all of the many social nuances involved in human-robot interaction by focusing almost exclusively on a robot’s visual appearance (Ishiguro, 2005), or that the theory is outright incorrect, claiming that initial feelings of revulsion can quickly be overcome by acclimatizing to an uncanny robot’s unique appearance (Potel, 2008). More ambitiously, android creators such as David Hanson and Hiroshi Ishiguro argue that we should dive headlong into the depths of the Uncanny Valley so as to discover exactly what it is that makes interacting with these not-quite-human robots so uncomfortable. In overcoming these obstacles and building ever more life-like androids, they propose that we will hold up a mirror to ourselves and learn more about what it means to be human. (Guizzo, Who's Afraid of the Uncanny Valley, 2010) (Macdorman & Ishiguro, 2006)

One of the strongest arguments against the Uncanny Valley theory is that it is too simple a concept to encompass all of the complexities of human-robot (and human-android) interaction. For example, rather than existing as a simple direct correlation between a robot’s visual fidelity and the pleasure with which a human observer perceives that robot, many claim that the Uncanny Valley exists more as a complex, multi-dimensional relationship between observer comfort and numerous other characteristics such as quality of speech synthesis, perceived intelligence, capability, working context, etc.

It is also important to note that Mori proposed the Uncanny Valley as a theory only. Despite the scientific appearance of his popular graphic, Mori’s original paper had no empirical backing and his choice of “pleasantness” as a dependant measure (vertical axis) is highly ambiguous at best. The value of a particular robot design, considering both its visual and motion familiarity, could alternatively be measured by fidelity of emotive expression, energy efficiency while communicating, consistency, etc. We use “pleasantness” here in the sense of a hypothetical, general-purpose social robot which is designed to interact with an average citizen on a day-to-day basis. In a different design context (e.g. military robots), “Clarity of Communication” or “Speed of Interaction” might be a more suitable metrics for measuring the effectiveness of the robots’ *emotive motion* expressions.

This leaves us free to speculate about some of the potential underlying complexities of this “eeriness” effect. Based on how current androids tend to evoke a sense of eeriness only once they begin to move, we hypothesize that *emotive motion* may represent one of these additional, orthogonal axes of design. Despite decades of discussion and robot designs that have skirted around and dove into the supposed valley, there are very few theories that provide any more concrete research directions than an implicit consensus that *something* unpleasant emerges when android reach “almost-but-not-quite-accurate” level of visual/motion familiarity.

It is only recently that substantial “proof” has emerged to support Mori’s original hypothesis. A study by Saygin, Chaminade, and Ishiguro (Saygin, Chaminade, & Ishiguro, 2010) used a functional magnetic resonance imaging (fMRI) machine to monitor the brain activity of 20 participants as they watched three different videos. In all three videos, a subject performed a set of mundane actions (e.g. picking up a cup, waving their hand). In one video, the subject was a human woman. In the second, the subject was an android modeled on the same women (I.e. a machine with a human-like appearance). In the third video, the subject was the same robot but with its “skin” stripped away to reveal its mechanical base. (E.g. metal frame, wires).

The researchers found that only when viewing the android video, a large portion of the subjects’ parietal cortex “lit up” with activity. This section of the brain is in part responsible for visual-spatial reasoning and “spatial empathy; that is, our “monkey-see, monkey-do” response that allows us to visualize performing the same bodily motions as someone else who we are watching. The researchers propose that the eerie feeling commonly associated with the Uncanny Valley may have its roots in the incongruence between a robot’s appearance and its movements. E.g. If a robot looks like a human and moves like a human, there is no problem. Similarly, if a robot looks like a robot and moves like a robot, there is no problem. However, if a robot looks like a human but moves like a robot many people have trouble reconciling this failure of expectations and feel uncomfortable.

This connection between visual form and motion is alluded to in Mori's original paper: Included on the original Uncanny Valley diagram (though often removed when the graph is republish) is a second, dashed line which proposes how a robot's *motion* would have an amplifying effect on the uncanny qualities of its appearance (Recall Figure 11). That is, a moving "uncanny" robot would be perceived even more negatively than just a motionless one and, alternatively, a moving "perfect android" would be even more appealing than a motionless one.

Mori does not elaborate on this point but, combined with the concepts of "the liveliness of motion", our tendency to treat media experiences as social experience, and this recent brain-imagining data linking our expectations between visual and motion familiarity, we begin to get a sense of the multi-dimension complexities inherent in social Human-Robot Interaction design. In particular, that *emotive motion* may play an integral and almost subconscious role in how humans interpret and interact with social robots.

In the next chapter, we formalize this design space and present our taxonomy for exploring the concept of *emotive motion.* We will then use this taxonomy to frame our work in subsequent chapters and to help explain our approach to exploring the impact of a robot's motion in social HRI.

4 A New Taxonomy for Exploring Emotive Robot Motion

In the previous chapter we presented an overview of related research in social HRI that deals with *emotive motion*; both in application and as a more direct topic of study. Beginning with this chapter, we begin to discuss our original research and contributions. Here, we develop a conceptual taxonomy to more fully explore the underlying mechanisms, strengths, and weakness of *emotive motion* as an element of design in social HRI. That is, where previous work may have employed emotive robot motion in service to an applied task or in a specific context, we endeavour to understand *emotive motion* in a base, abstract sense.

4.1 Visual Form and Motion Expression as Linked Characteristics

As we have seen with the related works in the previous chapter, *emotive motion* is a complex concept that is affected by many factors such as the robot's visual form or the working context of the interaction (E.g. What task is being performed?)

While Mori's Uncanny Valley hypothesis is heavily debated, it serves as an excellent focal point for discussion and helps simplify a complex concept into a more easily understood framework. Consider the following:

Our focus in this thesis is *emotive motion,* but we see a robot's visual familiarity and motion fidelity/capabilities as linked characteristics. Even irrespective of neuro-cognitive phenomena, in order for a robot to express itself through motion, *something* must be moved; whether that is the robot's "head", one of its limbs, or through the entire robot's locomotion. That *something* carries with it an inherent visual form.

In terms of familiarity and designing for a more appealing interaction then, this link gives rise to four general scenarios:

1. Where both a robot's visual form and motion is familiar.
   (e.g. "a perfect" android)
2. Where a robot's visual form is familiar, but its motions are unfamiliar.
   (e.g. Geminoid)

3. Where a robot’s visual form is unfamiliar, but its motions are familiar.
   (e.g. a visually abstract, but highly articulate robot such as C-3P0)
4. Where both a robot’s visual form and motion are unfamiliar.
   (e.g. a Roomba)

This presents social HRI designers with a challenge: While robots designed with anthropomorphic and zoomorphic forms can more easily employ common social conventions by way of their familiar appearance (e.g. recognizable “eyes” can express attention focus or a wagging “tail” can express contentment) there is a much larger class of robots that’s distinctly non-humanoid forms make them more effective at their designated tasks. (E.g. the squat, puck-shaped Roomba vacuum is able to easily fit underneath couches and tables whereas a general purpose android cannot.)

To focus our discussion, we arrange these two design axes as Table 1 and we see that our four general design scenarios are represented at the four quadrants. Scenario 4 encompasses the vast majority of current robotic platforms: robots that are purpose built, non-social “machines” which are design for a singular task with no regards for social implications such as visual familiarity or *emotive motion* expression.

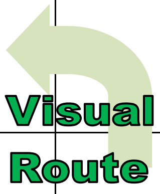
Table 1 - Motion Familiarity vs. Visual Familiarity

	Familiar Motions	**Unfamiliar Motions**
Familiar Form	Scenario 1 e.g. “Perfect” android	Scenario 2 e.g. Geminoid
Unfamiliar Form	Scenario 3 e.g. C-3P0	Scenario 4 e.g. Roomba

In their attempt to reach the ideal of a “perfect” social robot, we argue that the current generation of androids and more advanced social robot designs generally pursue a strategy of enhanced visual complexity; incorporating elements such as expressive “faces”, human-like hands and limbs, and so on. We call this design strategy the "Visual Route" (Table 2) and these types of robots typically fall into Scenario 2: visually, they closely resemble humans but once they begin to move, they quickly become eerie.

Table 2 – Visual Design Route: Pursuing enhanced visual familiarity

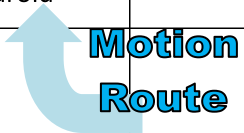
	Familiar Motions	**Unfamiliar Motions**
Familiar Form	Scenario 1 e.g. "Perfect" android	Scenario 2 e.g. Geminoid
Unfamiliar Form	Scenario 3 e.g. C-3P0	Scenario 4 e.g. Roomba



This imbalance stems from how modern androids and anthropomorphic robots are constructed: The technique used for creating their silicone rubber skins, artificial hair/eyes, and life-like colourings all come from film and theatre special effects backgrounds. (E.g. Prosthetic noses and wigs used in Hollywood movies.) While years of evolution have led to extremely visually convincing props, these false noses, ears, chins, and faces have historically been worn by live actors not animatronic machines. As such, current androids are visually convincing, but are stymied by unnatural motors and actuators that have a longer history in manufacturing and industry than in being designed to replicate the strengths and subtleties of living muscle.

Table 3 – Motion Design Route: Pursuing enhanced motion familiarity

	Familiar Motions	**Unfamiliar Motions**
Familiar Form	Scenario 1 e.g. "Perfect" android	Scenario 2 e.g. Geminoid
Unfamiliar Form	Scenario 3 e.g. C-3P0	Scenario 4 e.g. Roomba



Now consider the alternative design strategy of a “Motion Route” (Table 3). Given their generally more practical capabilities, we instead turn our attention to robots that have highly mechanical appearances and ask the question: Can these robots leverage their fundamental motion capabilities to communicate emotion despite their unfamiliar and unnatural appearances? (Scenario 3 in Table 3) If so, these robots might benefit from *emotive motion* as an additional communication channel while maintaining the practical advantages of being “purpose built”; in effect bypassing the Uncanny Valley entirely.

4.2 Bypassing the Uncanny Valley

To help map out this exploration of *emotive motion* and visual form, we develop a new design taxonomy. Figure 14 shows how the trends of Mori’s original graph demonstrate a familiar mapping between what we call “visual familiarity” and “pleasantness of interaction.”

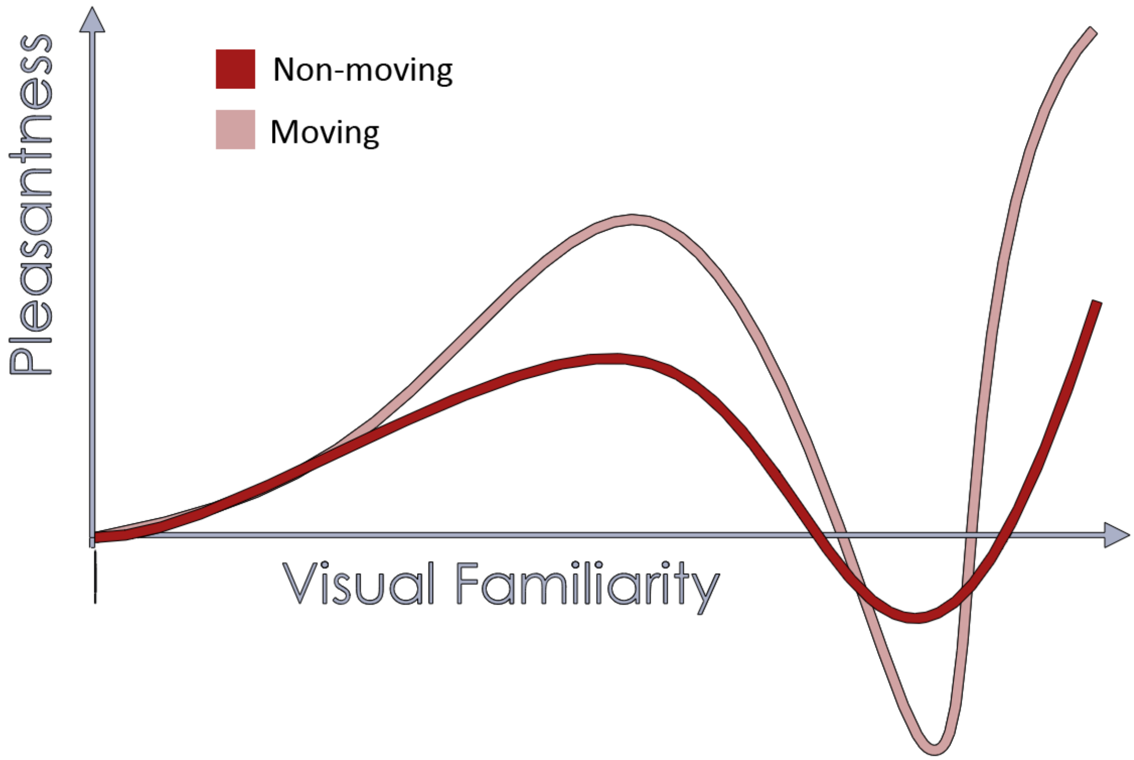


Figure 14 - A 2D graph mapping "visual familiarity" to "pleasantness", based on Mori's original graphic. The trend for non-moving robots is shown in red, while the trend for moving robots is shown as pink.

In order to account for the influence of *emotive motion* on social HRI experiences, we extend Mori’s original two-dimensional concept by introducing the third dimension of “motion familiarity" as a new axis. In Figure 15 we can imagine that Mori's "moving robot" trend line, with its amplified peaks and valley, actually occurs farther along the "motion familiarity" axis. Assuming one could resolve the movement issues that plague current generation androids and improve their motion fidelity (and therefore travel further and further along the "motion familiarity" axis), one might predict the gradual disappearance of the Uncanny Valley and a return to the originally hypothesized (i.e. a layman's naive assumption) linear relationship between visual familiarity and pleasantness. (Blue and Yellow lines)

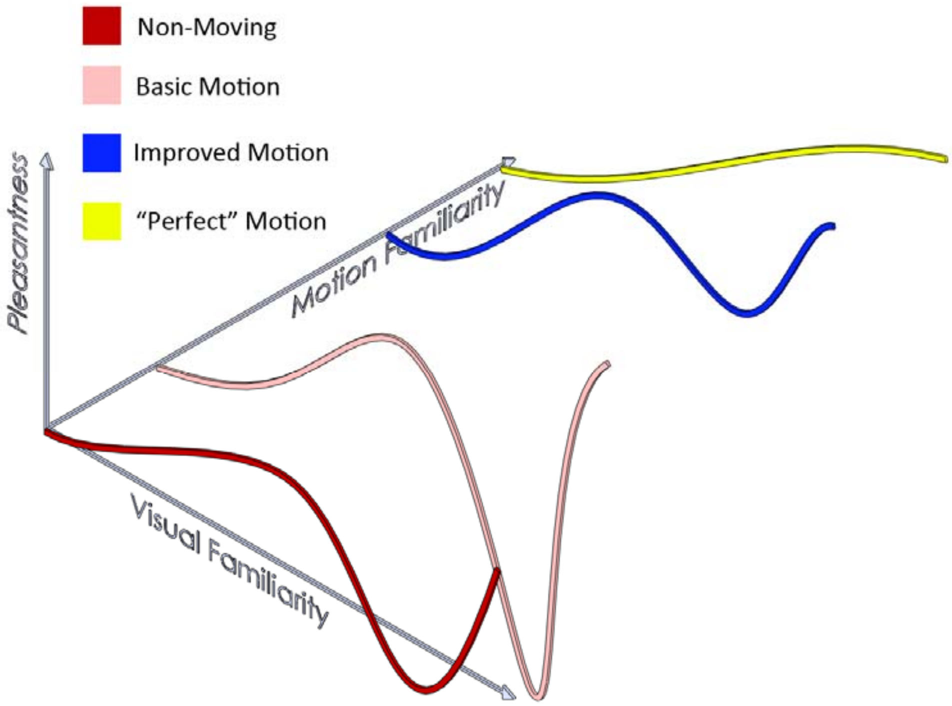


Figure 15 - Our taxonomy introduces "motion familiarity" as a third design axis. We can now visualize Mori's "motionless robot" vs. "moving robot" trends as extending backwards into the "depth" the design space volume. As a robot's motion characteristics improve (e.g. trends lines change from red, to pink, to blue, to yellow), there may exist potential reduction in the severity of Mori's valley.

The additional curves introduced in Figure 15 are pure speculation, however. There is currently no evidence to suggest that even if a visually near-perfect android could achieve more life-like motion that it's still zombie-like appearance would not still be off-putting. More importantly, both our extended 3D graph and the traditional 2D Uncanny Valley graph are presented solely as a conceptual taxonomy that will allow us to tie our subsequent discussions together as a coherent whole.

It is this unmapped surface which we endeavor to explore throughout the remainder of this thesis. Rather than travelling along the dimension of "visual familiarity" as modern android creators have done, we propose to explore along the dimension of "motion familiarity". Conceptually, this can be visualized as selecting a point along Mori's original graph (e.g. selecting a set visual form) and then exploring sideways along the plane of different motion characteristics as in Figure 16.

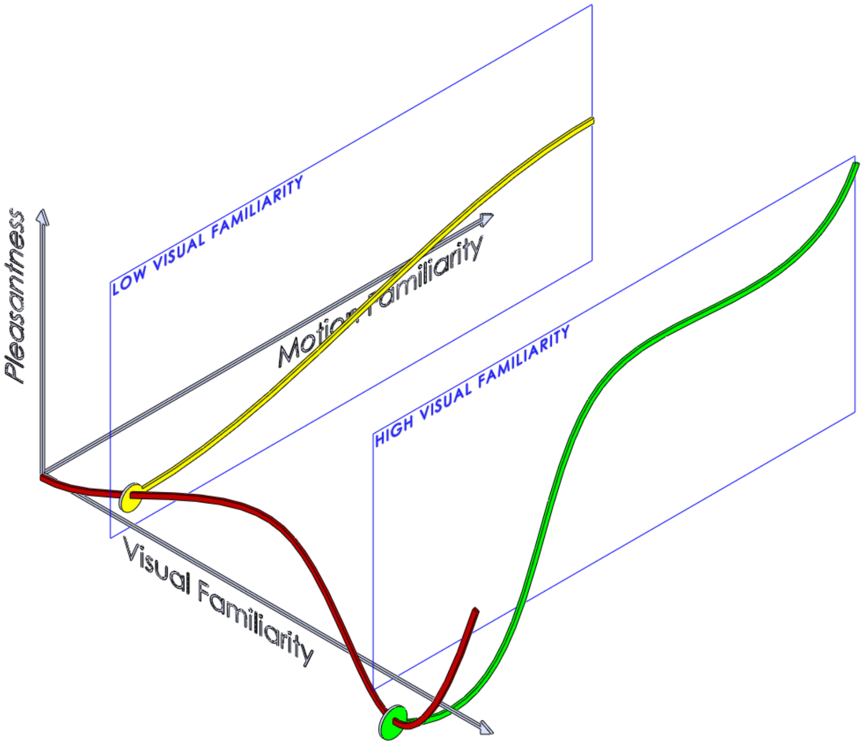


Figure 16 - Extending Mori's 2D graph into the "motion familiarity" dimension

Considering this new exploration space, we are presented with many unique, unanswered questions:

d) What does it mean to travel along the "motion axis"? Is it strictly a matter of more closely approximating the movements and gestures of whatever creature your robot resembles? What specific motion characteristics can be altered?

e) Are there similar "uncanny valleys" to be wary of when a robot's *motions* almost match their ideal but still fall short?

f) What "ideal motions" might a distinctly non-anthropomorphic or non-zoomorphic (e.g. low visual familiarity) robot be designed to strive towards? E.g. How can a Roomba's motion be made more familiar or more expressive?

g) Is there inherent emotive content within robot's motion regardless of visual form? Can we uncover a "base language" of emotive motion that generalizes across many different visual forms?

h) What other factors (e.g. other dimension) might affect the interaction between a robot's visual form and its motion expressions?

4.3 Summary

In this chapter, we discussed three foundational concepts (The Liveliness of Motion, Treating Digital Devices as Social Agents, and The Interplay between Visual and Motion Familiarity) around which we developed a new taxonomy for exploring *emotive motion.* In the next chapter, we describe a series of prototype robot platforms that we developed while attempting to find an appropriate vehicle for our exploration.

5 Prototype Robot Platforms

In this chapter, we discuss four robot prototypes that we designed in order to explore the concept of *emotive motion* and its various facets. Over the course of our investigation, the development of our early ideas resulted in several different physical robot platforms which we prototyped as well as a set of associated evaluation techniques and hypothetical applications.

While some of these prototypes were more fully developed and/or were conceptually more fruitful than others, each effort helped shed light on a unique aspect of *emotive motion* in the context of social HRI. In this chapter we discuss those specific prototypes which served primarily as early technical explorations (e.g. "Teeter"), that underwent only preliminary design critiques (e.g. "eMon"), or that served as experimental stepping stones (e.g. "The Tentacle" and "Stem Jr.") leading towards the in-depth user studies we discuss in the next two chapters.

5.1 Designing Motion

In order to study and come to understand *emotive motion* in a more "pure" sense, we began our prototyping efforts by considering some of the fundamental qualities of motion and how we humans react to it.

In order for a person to observe and interpret motion, *something* needs to be moving. However, any moving "something" would require at least *some* visual form and even non-anthropomorphic visual form brings with it some degree of meaning. Seldom is the visual appearance of an object in direct opposition with its function (Gibson, 1979). For example, larger objects tend to be perceived as heavier or stronger, slender objects tend to be perceived as faster or sharper, and we typically assume that these forms correlate to the object's function and purpose. Thus, despite our focus on *motion,* we would still need to be mindful of the size, shape, configuration, and materials out of which we would construct our prototypes.

We also considered the fundamental characteristics of motion that we could interpret: speed and direction. In combination with form, these basic characteristics lead to ideas of rotation, curvature, proximity and approach, gesturing vs. locomotion, repetition and frequency, response and hesitation, and numerous other qualities that we might attempt to examine and gauge.

On top of observing and interpreting motion in isolation, we felt that there was a distinct and complimentary aspect of expressing emotions that should be considered: interactivity. Expressing emotion is often meant to communicate our feelings within the context of a target audience whether we consciously recognize it or not (Parkinson, 1996). For example: crying, as an expression of sadness, can be a means of attracting sympathy from our loved ones; dancing can be a means of sharing joy not just with our dancing partners but with everyone around us; and so on. In this way, the audience becomes an integral component of (and a subconscious, almost instinctual motivation for) expressing emotion; particularly in how and whether or not the audience respond to those expressions.

From this perspective, expressing emotions becomes a two-way, interactive communication. We argue that in an exploration of how emotion is expressed and interpreted in an abstract sense, interactivity will also play an important role alongside visual form and purposeful movement.

With this design space in mind, we set about exploring different aspects of *emotive motion.* We now discuss a set of exploratory prototypes which we designed, briefly touch on their perceived strengths and weakness and discuss this sequence of prototyping efforts eventually led to our two users studies in Chapters 0 and 7.

5.2 Teeter

“Teeter”, our first prototype, borrowed its inspiration from the moving geometric shapes in the foundational Heider and Simmel experiments (Section 3.3.1, (Heider & Simmel, An Experimental Study of Apparent Behavior, 1944)) and considered the emotive qualities of locomotion. Placing a uniquely robotic spin on this concept, we chose to explore the “inverted pendulum” style of locomotion which is popularly associated with the “Segway” personal transportation vehicle (Segway Inc.)

We feel the movement of inverted-pendulum robots present an interesting dichotomy. On one hand, they are “unfamiliar” in that there are no creatures in nature that demonstrate this specific style of rolling, “single-legged” locomotion. This balancing technique also requires advanced sensor technology and internal computational power to maintain stability; making it a very technical and “robotic” style of movement. Yet these robots are also vaguely biological/animalistic in that their smooth, gradual swaying is largely at odds with the stereotypical jerkiness and rigidity of many traditional robotic systems. Most inverted pendulum robots are impressively elegant when moving and their demonstrable ability to react to external disturbances (e.g. when kicked) conveys a sense of dynamic intelligence.

Figure 17 - The Segway (left, (Segway Inc.)) and Honda UX-3 (right, (Honda Motor Company Limited)) personal transporter devices. Both vehicles utilize an "inverted pendulm" style of locomotion

Numerous advanced robotic platforms utilize this style of locomotion (E.g. Honda’s U3-X unicycle (Honda Motor Company Limited). (Figure 17). This is partly due to the smaller “standing footprint” of a 2-wheel robot as compared to a 4 (or more) wheel robot. This allows these self-balancing platforms to operate and navigate through tighter, human-occupied and “designed-for-humans” spaces such as restaurants and sidewalks.

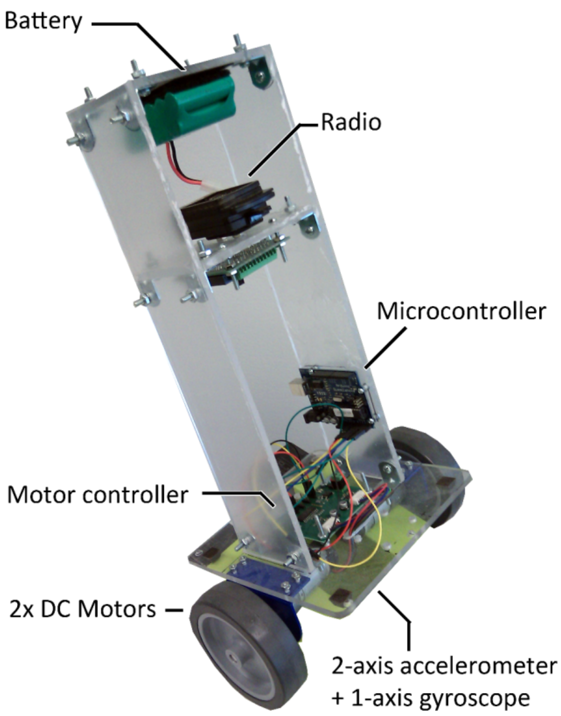


Figure 18 - The *Teeter* prototype robot

In contrast to these commercial vehicles, our early *Teeter* prototype (Figure 18) was very unstable; due primarily to the limited strength of its motors. While it could maintain a rough balance for dozens of seconds at a time, it quickly became increasingly unstable and would eventually fall over if not caught by a human observer. While properly resolving these instabilities would require a more complex stabilization system, *Teeter's* dependence on human care and intervention had already presented us with an interesting ideas regarding the expressive power of *emotive motion:* everyone who encountered our wobbling robot was immediately concerned for its safety. If one ignored the fact that they were actually watching a less-than-perfect robot roll around on the floor, the looks of simultaneous excitement, humour, and anxiety on these people's faces would be equally suited to a crowd watching a toddler take its first steps.

Now imagine a tour guide robot that utilizes an "inverted pendulum" style of locomotion: could a *purposefully* unstable robot (e.g. seemingly about to fall over but always just on the edge of control) use this perpetual expression of imminent disaster as a means of attracting attention (or even sympathy)? If a second robot that was visually identical but instead balanced perfectly was contrasted with the first, might the wobbling, teetering platform be viewed as more juvenile or less capable; much like that imaginary toddler just learning how to walk or a drunken hooligan stumbling down the sidewalk?

These were interesting questions that highlighted some of the potential design implications of emotive robot motion and how it might be purposefully applied to real-world scenarios. However, in the specific case of the *Teeter* prototype, early design critiques made it clear that there was a clear technical challenge in implementing a “perfect” balancing robot that we lacked the time, resources, and engineering expertise to pursue. Additionally, *Teeter* was viewed as too task specific: we felt there was little practical reason for a locomotion system to be anything but as stable as possible. In the case of both a human-transportation vehicle like the Segway or a human-centric working context such as a tour guide robot in a museum, anything less than a perfectly controlled robot would likely be too much of a liability to offset whatever emotive expressiveness might be gained. The pursuit of a higher-fidelity *Teeter* prototype was abandoned before the concept could deliver an effective test bed for *emotive motion.*

As a vehicle for exploring our “visual/motion familiarity” space, we felt the question of “instability vs. stability” was too tightly coupled with questions of “practical vs. Impractical” or “intelligent vs. dumb”. Although we imagine it would be better received than a perpetually unstable *Teeter,* we felt that the motion capabilities of a perfectly stable *Teeter* would still be conceptually limited.

Viewed from the perspective of our conceptual taxonomy (recall Chapter 4), *Teeter’s* limited possible scope of exploration is reflected in the close spacing of the two “exploration areas” seen in Figure 19 and their limited coverage of the full “motion familiarity” axis. We hypothesize that motions of a “perfectly balanced” *Teeter* would be both more familiar and more pleasant that a perpetually unstable *Teeter* and this is reflected in the slightly taller exploration area in the graphic.

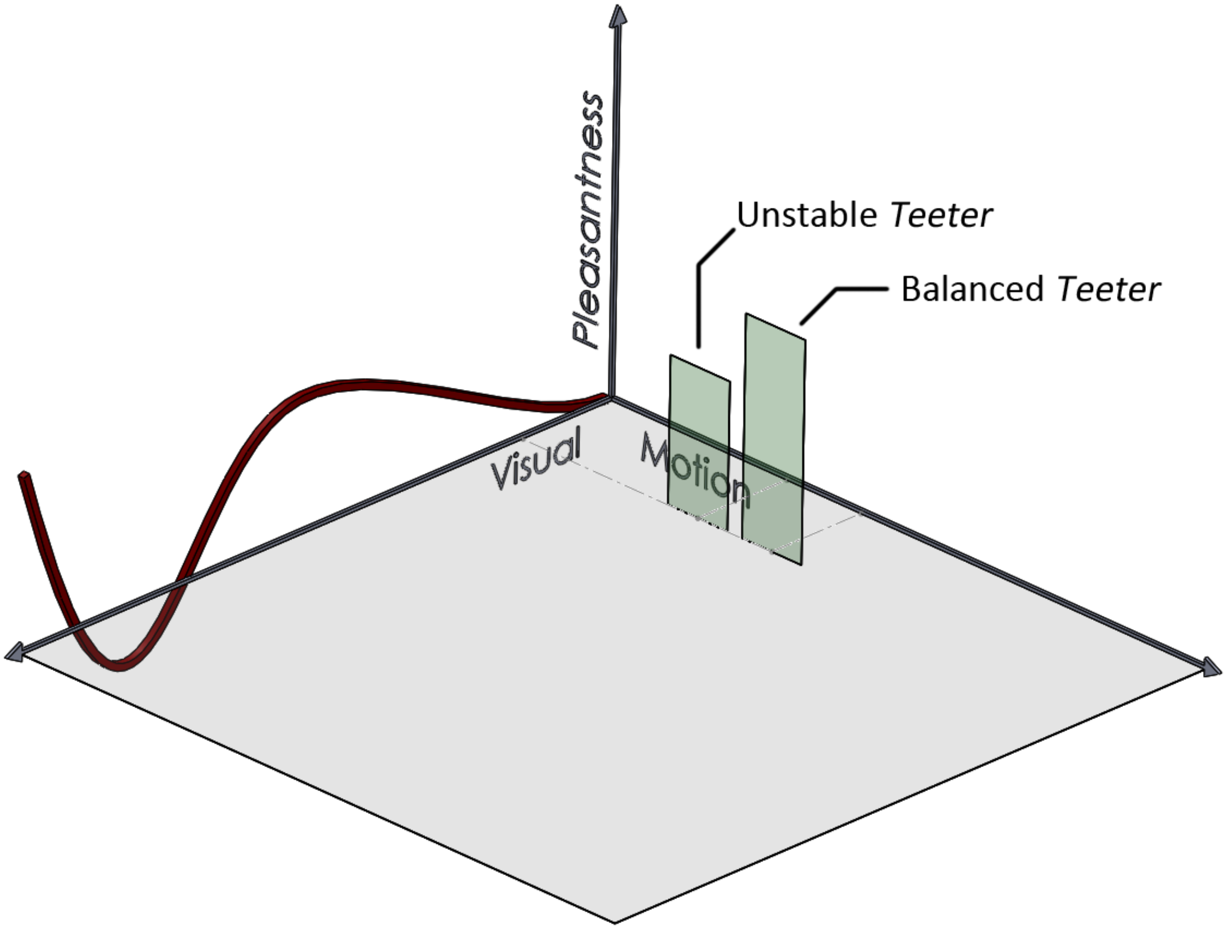


Figure 19 - The theoretical "pleasantness" of an unstable vs. stable *Teeter*

As we stated when first developing our taxonomy, the spacing, size, and positioning of our various robot prototype platforms within our conceptual taxonomy volume is largely subjective and is meant primarily as a means of guiding our exploration and framing our discussions. As we progress through this and the next two chapters, we will add more and more instances to our conceptual space and the value of our taxonomy will emerge in its ability to compare and contrast the effectiveness of our various robot prototype platforms.

5.3 eMon: A Robot Tree-Hugger

Our next prototype was motivated by a more applied, task-centered perspective. We considered "For what task might *emotive motion* in a social human-robot interaction scenario be more effective where a less expressive robot or traditional graphical/audio interface would falter?" *Teeter* had revealed a link between seemingly helpless robot motion and a subsequent human urge to want to care for them. Although using *emotive motion* to elicit sympathy proved challenging in the context of "inverted pendulum" and service robots, we considered what other applied contexts might be able leverage this apparent emotional need to care for emotive robots.

5.3.1 Concept

One of the application areas we considered in our work with our next robot prototype, "eMon", was Sustainable Interaction Design (SID). SID is a growing HCI research domain that challenges interaction designers to make environmental sustainability a fundamental component of their designs. This extends beyond "classical" sustainability concerns, such as what types of physical materials are employed, and instead considers the ways these systems are used in real-world settings and to the behavioural attitudes those interactions reinforce. (Blevis, Sustainable interaction design: investion & diposal, renewal & reuse, 2007) (Blevis, Two Digital Divides and Four Perspectives, 2008)

The goal of SID is to promote pro-environmental behaviour change over the long term by educating users and providing them with interactive systems that support their efforts. These systems have traditionally taken the form of high-visibility water meters (Arroyo, Bonanni, & Selker, 2005) and electricity gauges mounted directly to appliances (Gustafsson & Gyllensward, 2005) or social networking websites (Mankoff, Matthews, Fussell, & Johnson, 2007) and mobile device applications (Froehlich, et al., 2009) that leverage "social norms" as a motivator for behaviour change.

Work by He, Greenberg, and Huang (He, Greenberg, & Huang, 2010) demonstrates how the same methods of promoting sustainable behaviour often do not generalize across people with different levels of environmental awareness. For example, many energy monitoring devices employ a variety of information feedback methods in an attempt to cater to different personal value systems. (E.g. numeric readouts of power consumption in kilowatts, projected economic cost, or even visibly glowing in proportion to energy usage) While these devices may work as an excellent means of providing relevant energy usage information to those people who are already concerned about their environmental impact, these artefacts may be ineffective in motivating those people who have not yet make a decision to change their habits or who are outright unconcerned with conservation.

Recalling Kidd's "Autom" weight-loss robot (See Section 3.1), this prompted us to consider whether an engaging social robot could leverage *emotive motion* as an alternative (and potentially more potent) means of applying Sustainable-Interaction Design principals. We viewed this as a unique intersection of multiple research domains: not only would a robotic agent have access to all of the same sensor data and computational abilities as traditional water/energy/pollution monitoring devices but its unique ability to form a social and emotional bond with its users might appeal to those people who are not usually motivated by graphical, statistics based energy monitoring devices.

To explore this concept, we envisioned a small, desktop robotic agent which would monitor a user's energy efficiency and respond to their behaviour using emotionally meaningful gestures (Figure 20) (Harris & Sharlin, 2010).

Figure 20 - A concept sketch of our "tree-hugger" robot whimpering on its user's desk (Harris & Sharlin, 2010)

If a user was being particularly wasteful by leaving many lights on even when absent or was driving excessively when walking, biking, or public transit would be preferable, the robot could begin to act increasingly distraught; moving lethargically, moping, whimpering and repeatedly gesturing towards the offending lights or the user's neglected bicycle. Alternatively, if a user was meeting their behavioural goals, the robot could express happiness by moving energetically, rhythmically bobbing, and making cheerful noises.

This approach takes advantage of the idea that although some people may not express concerns about global climate change, many people automatically (or perhaps instinctually) cringe and feel uncomfortable when viewing scenes of human/animal distress. In this way, the robot's "happiness" would be directly tied to its owner's environmental habits and, if the robot could be made to be sufficiently emotive, perhaps the user's motivation to alter their behaviour could be offloaded from "concern about kilowatts/dollars" and onto "concern for a 'suffering' companion".

5.3.2 Implementation

Dubbed "eMon", short for a "living **e**nergy **mon**itor", the resultant prototype can be seen in Figure 21. The robot possessed 13 degrees of freedom and a smart phone "face" that displayed a simple pair of abstract "eyes". During testing, *eMon* would be tethered to a nearby computer and remotely operated by a hidden human operator using a video-game style controller.

Figure 21 – The resultant robot prototype. “eMon”: a living emotive energy usage monitor

eMon sat on two wheels which allowed it to travel forward, backward, and spin in place. These wheels were mounted to a pair of “ankles” which allowed the robot to perform whole body movements such as jittering, shaking, and even small hops.

eMon’s torso was surrounded by four “wings” which served as abstract “limbs”. These wings could be commanded to rhythmically rise and fall (e.g. as if approximating a breathing rib cage), remain stationary, or else be manually “fluttered” in unison. The amplitude and frequency of the robot’s “breathing” could also be controlled. This gesture was designed to portray *eMon* as a “living, breathing entity” and served as the primary indicator of *eMon’s* ambient “stress level”. (e.g. rapid, shallow breaths when agitated and slow, long breaths when calm)

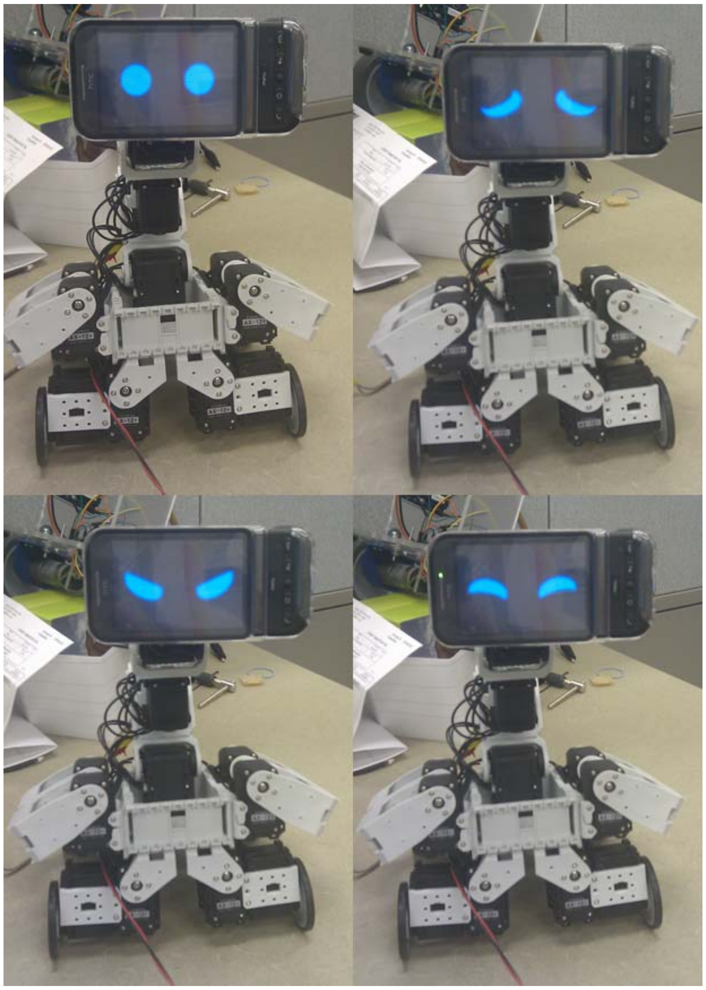


Figure 22 - *eMon's* four facial expressions. Clockwise from top-left: neutral, sad, happy, angry.

eMon’s “eyes” could be set to one of four expressions (Figure 22). The robot’s eyes would remain stationary relative to its face, save for an automatic “blinking” animation that would occur at randomly spaced intervals.

eMon’s “face” was mounted to a trio of motors which allow the robot to look up and down, side to side, and roll its head (e.g. as a human touches their ear to their shoulder). Finally, *eMon’s* “head” was situated atop a long “goose neck” which allows the robot to move its entire head forward and backward as well as up and down with respect to its body.

Anatomically, the *eMon* prototype could be said to vaguely resemble a “strange sort of robot duck on wheels”.

5.3.3 Evaluating *eMon*

In order to explore the expressive capabilities and persuasive impact of our environmentally-concerned robot prototype, we conducted a preliminary evaluation of *eMon* via a small scale design critique with two different audiences.

In the first scenario, we invited comments and observations from our colleagues during open interaction sessions around a lunch table. As we tested different combinations of motion from the robot's various motors, observers began to identify and describe what they interpreted as some of *eMon's* more recognizable gestures. For example: his ability to "hop" and rock side-to-side on his ankles, seeking attention by rapidly fluttering his wings, cautiously exploring the tabletop while breathing calmly, and so on. Common comments included phrases such as "He's quite cute!", "He's very lively for such a small robot!" and "It's a little goofy looking, isn't it?"

From a puppeteer's perspective, we were able to gain a better (if entirely informal) sense of how *eMon* various expressive capabilities might be better leveraged to form a coherent sense of "character" and attempt to elicit some degree of emotional bond. One of the most noteworthy lessons from these lunch table interaction was the very strong influence that *eMon's* "eyes" had on how the robot's motions were interpreted. Depending on whether *eMon's* eyes were "happy" or "angry" the same rapidly fluttering of the robot's "wings" would either be interpreted as "celebratory cheering" or "frustrated condescension" respectively.

In the second instance, we invited two external participants (personal acquaintances from outside the university) to interact with *eMon* in a mock usage scenario. The participants were seated at a desk in a darkened room. On the desk we placed *eMon*, a desk lamp, and a work sheet with a set of basic arithmetic problems. The participants were introduced to *eMon*, and told that he was a prototype household robot. They were then asked to sit down, solve the math problems, and then leave the room when finished.

While the participants were working through the written problems, *eMon* would slowly roll from place to place and contentedly explore the desktop around itself. As the participants rose to leave, both of them neglected to turn off the desk lamp. In response, *eMon* would begin to hop and wave its wings frantically, roll towards the lamp and gesture at it with its head; upset that they were being wasteful with the lamp's electricity. Both participants were initially confused by *eMon's* sudden flurry of activity but quickly realized *eMon's* intent and shut off the lamp.

5.3.4 Discussion

In order to elicit a sufficiently strong emotional connection, we attempted to design *eMon* so that it had both strong visual familiarity and strong *emotive motion* capabilities with the intent that sufficiently expressive traits in both design axes would result in a more emotionally powerful robot prototype. From the perspective of our conceptual taxonomy (Figure 23), this corresponded with a mid-range level of visual familiarity (focusing on the peak area of our original zoomorphic-but-unrealistic visual trend line) and a wide range of complex motion articulation (covering a wider span near the top end of the *motion familiarity* axis). Our preliminary evaluation showed that *eMon* was more expressive and generally more pleasant to interact with than *Teeter* and so we see that *eMon's* exploration area is significantly taller when compared to those in Figure 19.

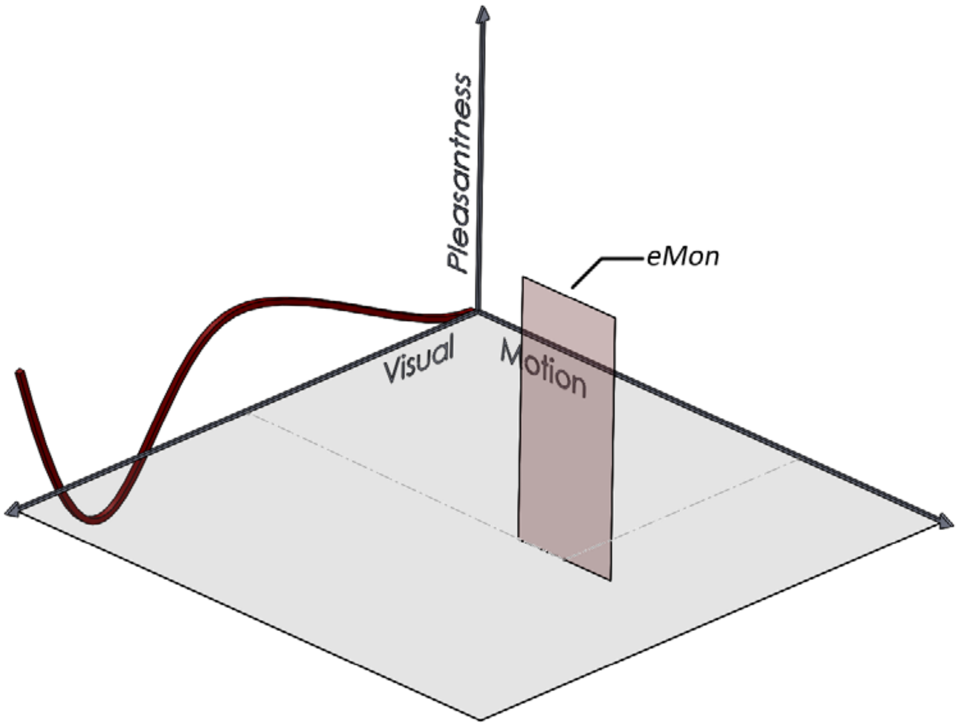


Figure 23 – ***eMon's*** **conceptual design goals represented within our design taxonomy**

While it is clear that that these were heavily engineered scenarios and both were rife with experimental confounds, we felt that the *eMon* concept showed promise as a demonstration of the expressive power of *emotive motion*. (E.g. In the spirit of exploration, we ignore the seeming incongruence of using a relatively high-power robot to ensure that single light-bulbs are turned off.) However, we feel the fact that numerous participants were actually compelled to sympathetically coo at *eMon* when it became upset (e.g. "Aww... Do you want me to turn this light off, little guy?") is unique; regardless of whether these feelings were genuine for them or merely a reaction to the novelty of such a robot.

We believe that the challenge of more thoroughly exploring this phenomenon arises from the long-term nature of the relationship between this type of robot and its owner. If *eMon's* goal is to promote pro-environmental behaviour change (or any type of long-term behaviour change) by forming a sympathetic emotional bond with its owner, we imagine that a sufficiently strong (and thereby persuasive) bond would need to be developed over the course of many months or years.

We also think that the current *eMon* prototype being a single-purpose robot is also potentially problematic; in the same way that traditional, dedicated energy monitoring devices are typically ineffective in motivating change in people who have not already made a conscious effort to alter their habits. Anyone that would purchase a single-purpose *eMon* robot would likely also benefit from a more traditional energy monitoring device. Instead, we envision *eMon's* persuasive behaviours as being only one facet of a more general-purpose system: We imagine the *eMon* robot would also need to be a helpful cleaning robot *and* a security robot *and* a babysitter *and* an entertainment device, and so on, in addition to its "behavioural coaching" role. In this way, *eMon* would have ample time and opportunity to both become an indispensible daily tool (e.g. as current smart phone devices can be) and to endear itself to its owner (e.g. such as learning the personality and habits of a household pet). If such a general purpose, and generally personable robot could be achieved, then *eMon's* potentially annoying initial attempts to alter its owner's level of environmental conscientiousness might be somewhat offset by deep-rooted concern for "disappointing" or "neglecting" their otherwise indispensible companion.

Our early explorations with *eMon* reinforced our belief in the expressive power of emotive robot motion. Even with a consistent visual form, *eMon's* motions alone were able to convey a variety of emotions including fear, surprise, happiness, and anger. Even despite his heavily robotic appearance, observers tended to treat the robot as a pet/creature rather than a machine.

However, the robot's working context (e.g. promoting long-term behavioural change) and the strong influence of its "face" made isolating the specific affects of *eMon's* different motion characteristics difficult. Anecdotally we could infer how some of the puppeteer's intentions were being translated and expressed through *eMon's* movements, but we wondered if we could investigate these phenomena in a less convoluted and more systematic way?

At this point we turn the focus of our explorations away from applications of *emotive motion* and towards the study of the concept itself. To provide ourselves with more structure, we chose to adopt a fundamentalist approach; stripping away concerns of visual form and functional context and approaching the concept of “abstract motion”.

5.4 The Tentacle

Our next prototype robot platform focused on the extreme visual abstraction component of Heider and Simmel’s “animated shapes” experiments (Heider & Simmel, An Experimental Study of Apparent Behavior, 1944). Our goal was to develop a robot motion evaluation platform that possessed a rich, expressive set of motion capabilities while being almost purely abstract in form and displaying very limited visual affordances.

Our first prototype in this vein was “*The Tentacle”.* This robot consisted of a central flexible column and four small winch mechanisms attached at the robot platform’s base. (Figure 24) The winch cables ran up and along the interior of the central spring column and were affixed at its top. When an individual winch cable was tensioned, the central spring would bend over in the direction of the tightening cable. By coordinating the motions of each of the four winches, *The Tentacle* could be made to lean in all four directions, with its movements resembling that of an earthworm or undersea tentacle.

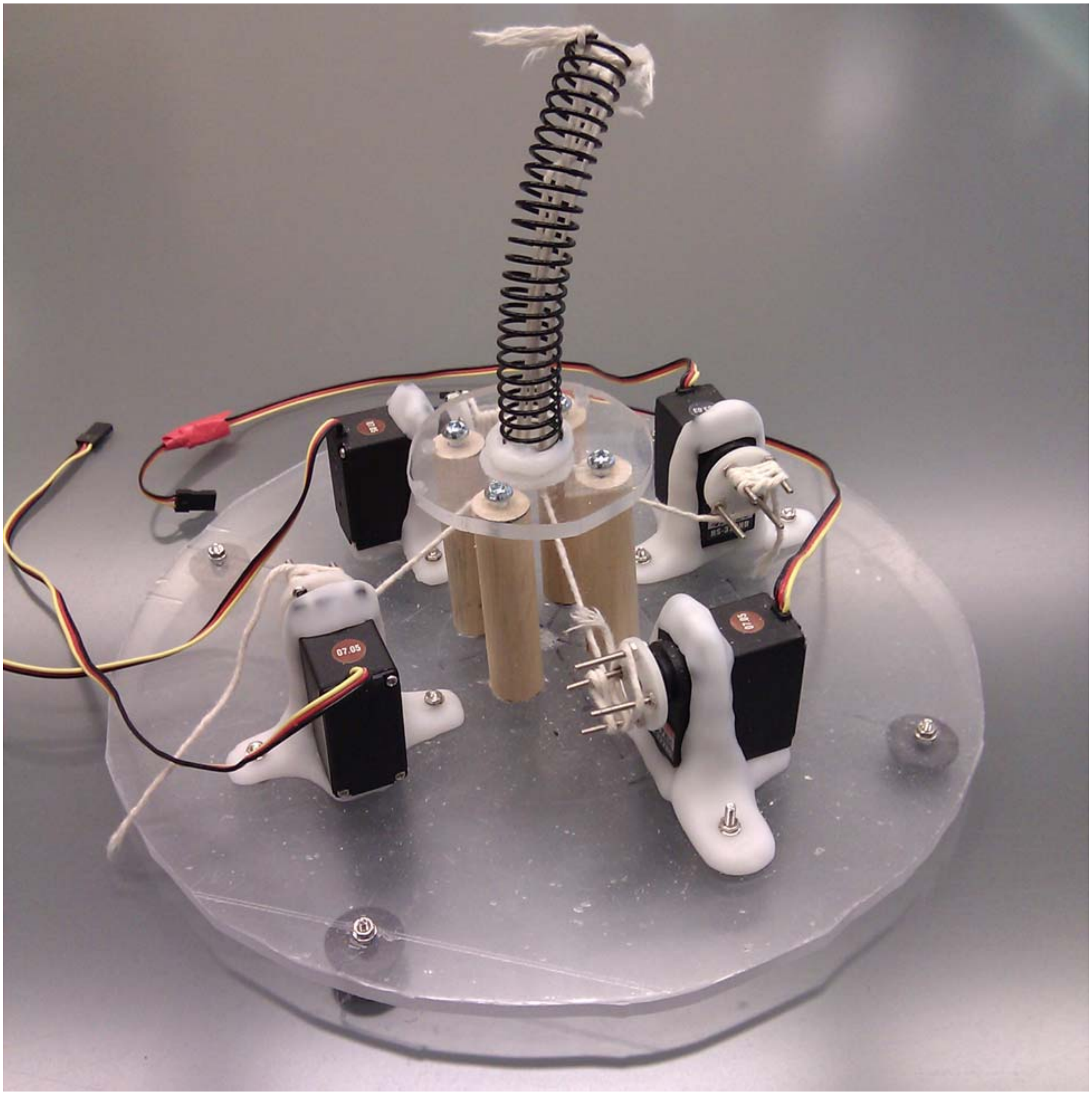


Figure 24 -"The Tentacle" robot prototype

While this mechanism succeeded in obfuscating the simple rotary motion common with typical electromechanical motors and proved very interesting visually, the flexibility of the central spring and general unpredictability of the winching mechanisms proved very difficult to control and not sufficiently repeatable for a controlled experiment. Further, despite our efforts to avoid visual familiarity, the emotive connotations of *The Tentacle's* eel-like motion style were deemed too overt and it was feared that any deeper investigation into the emotional expressions of such a platform would be immediately overwhelmed by these semi-familiar animalistic qualities. This limited range of exploration can be visualized by *The Tentacle's* narrow exploration area (e.g. small span along the *motion familiarity* axis) in our conceptual taxonomy (Figure 25).

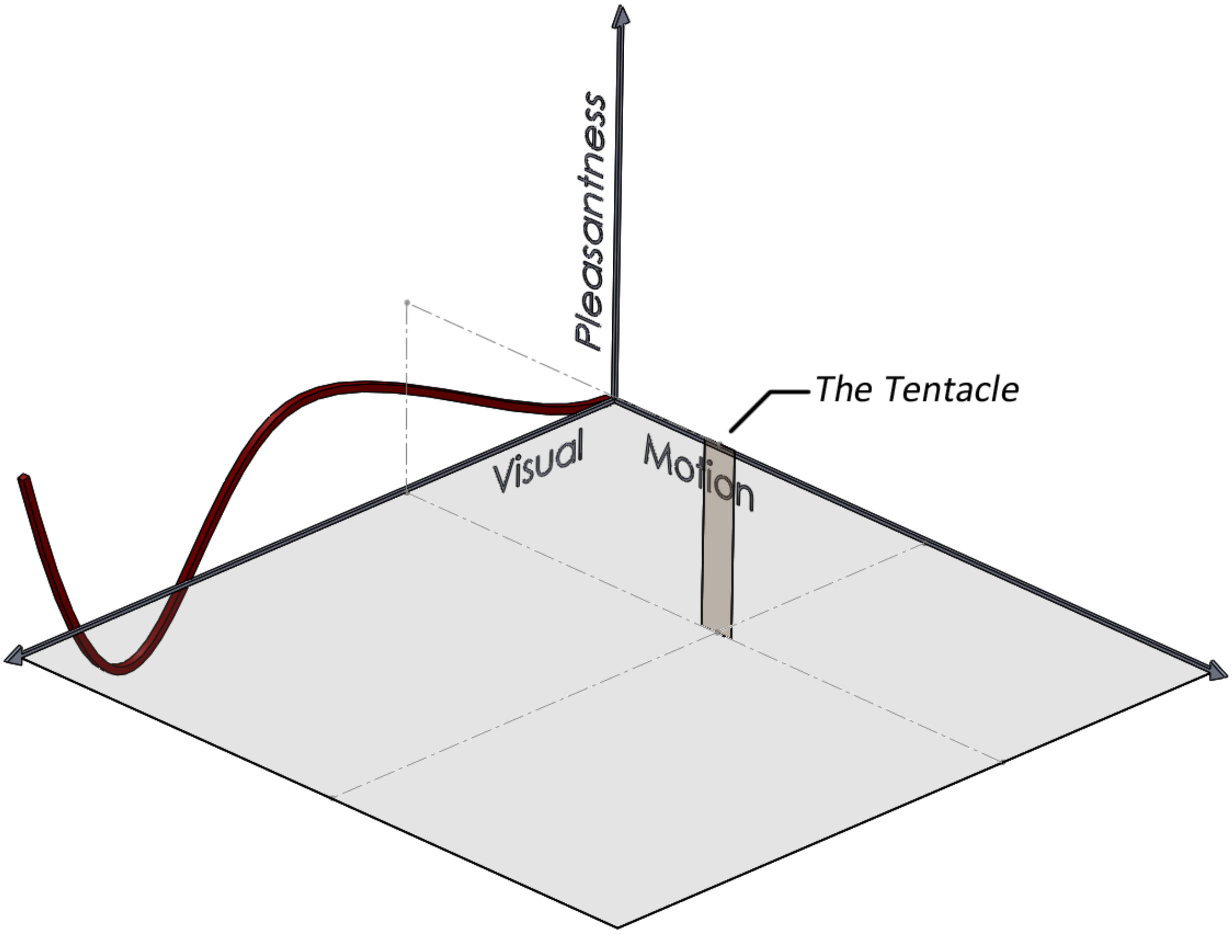


Figure 25 – Our impression of the limited exploratory range of *The Tentacle* platform

5.5 Stem Jr.

While difficult to control, *The Tentacle's* visual simplicity and abstract appearance (while stationary) proved promising however, and a variation of this design was evolved into *Stem Jr.* Rather than use a flexible spring and unpredictable winch system for control, *Stem Jr.* consisted of a thin central wood shaft and only three motors; all attached directly to one another in series. (Figure 26) The three motors were arranged in such as way so as to approximate a “spherical joint”; allowing the wooden shaft to yaw, pitch, and roll around a common base point and provide maximum freedom of motion. As such, *Stem Jr.'s* shaft could spin in place, travel in large or small circles, tap the table beneath it, and a wide variety of additional motions; all with varying amounts of speed, fluidity, and repetition.

Figure 26 - The *Stem Jr.* prototype robot

We felt that *Stem Jr.* also succeeded in minimizing its visual familiarity in terms of resembling a human being or animal. With its ample degrees of freedom of motion, excellent repeatability, and ease of control we felt had achieved a highly articulate, highly abstract robot prototype platform capable of addressing our goal of exploring *emotive motion* in a basic, "pure" sense. Not only did we feel this would allow us to explore the extreme low-end of our "visual familiarity" axis, but our ability to consistently actuate *Stem Jr.* in a wide range of styles afforded us the freedom to explore a wide area along our "motion familiarity" axis. (Figure 27)

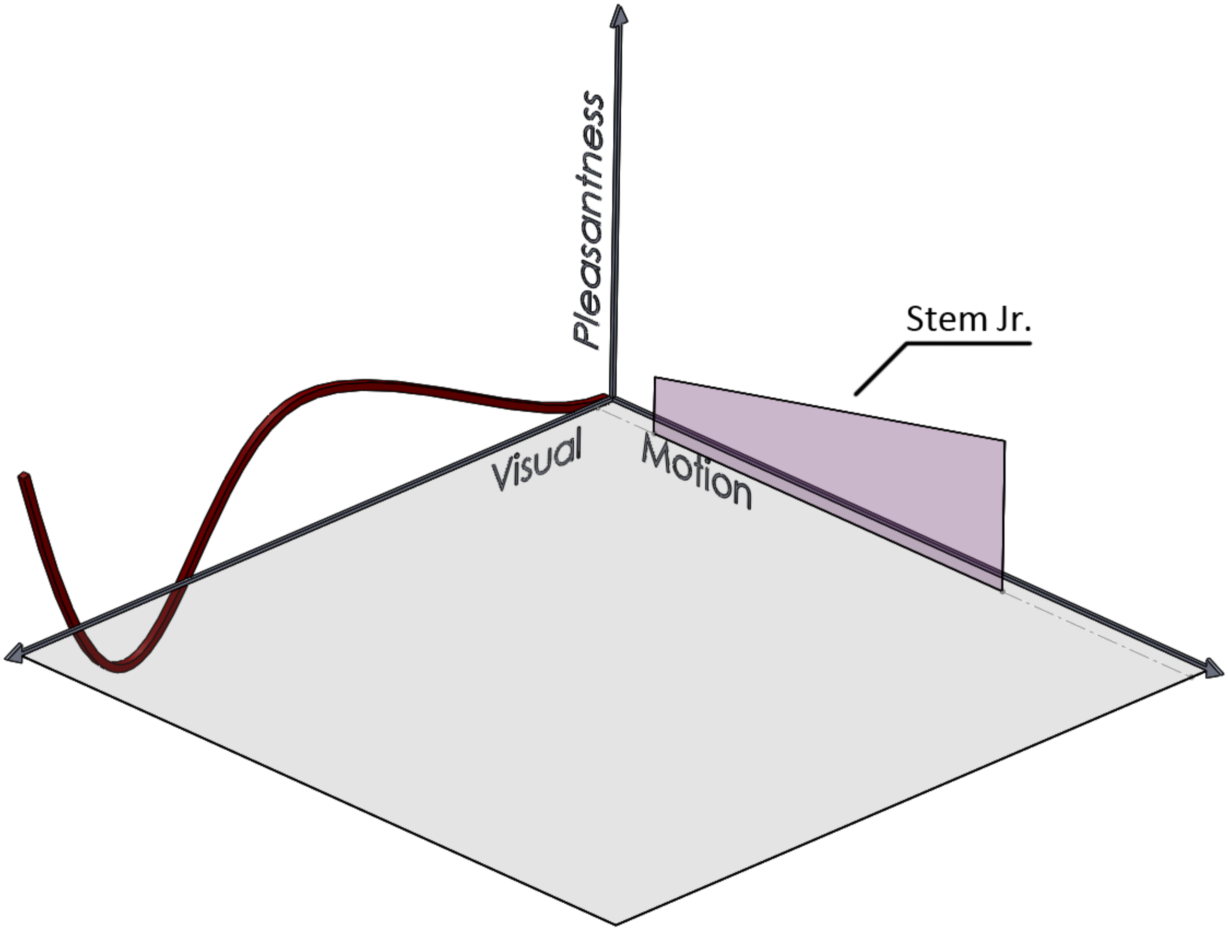


Figure 27 – *Stem Jr.'s* low visual familiarity and wide area of exploration along the "motion familiarity" axis made it an excellent platform for exploring "pure" *emotive motion*

Stem Jr.'s primary shortcoming was its small size. Measuring only 6cm x 10cm x 35cm, the prototype had little more physical presence than a desktop toy. As a result, the range of its expressive impact was limited. (E.g. it would be difficult for such a small robot to express emotions such as "anger" and "intimidation" without coming across as "ineffectual" or "harmless".)

5.6 Summary

In this chapter we presented four prototype robot platforms that we developed in order to explore the various facets of *emotive motion. Teeter* and *eMon* both addressed possible applications for emotionally expressive motion in social HRI highlighted promising areas of future investigation but the scope of their evaluations were limited by specific implementation challenges.

We next focused our efforts on addressing *emotive motion* in a “pure” and abstract sense; free of familiar visual form and working context. We discussed how the development of *The Tentacle* and then *Stem Jr.* resulted in a highly articulate, but visually abstract experimental platform which closely approached this goal but were limited by aspects of their appearance.

In the next chapter, we address *Stem Jr.’s* primary shortcoming by scaling up the *Stem Jr.* prototype to a human-sized platform which we simply called *The Stem.* We then discuss the full user-study that we conducted using this new experimental platform.

6 The Robot Stem

In the preceding chapter, we described a set of prototype robotic platforms that were developed to explore different aspects of emotive robot motion; including different mechanical means of expressing motion (*Teeter, Tentacle)* and how such expressive motion might be applied in order to achieve a desired goal (*eMon*). In this chapter, we describe the first of two in-depth user studies that were conducted to more fully test some of these concepts. We describe how our "*Robot Stem*" experiment attempts to establish a baseline for completely abstract emotive motion, the robot platform we developed to test these limits of visual abstraction, the experiment we used to evaluate this concept, and a discussion of the experiment results.

6.1 Design

As we discussed during the development of *Stem Jr.* our design goal with *The Stem* was to explore the concept of *emotive motion* in a more direct and "pure" sense; with as minimal visual familiarity and connotations of recognizable working context as possible. With this new approach, we hoped to establish a baseline understanding of how social robots might be able to generate expressive motion, what specific characteristics of motions relate to which emotional interpretations, how people interpret those motions in the absence of all other affordances, and how (by gradually reintroducing external influences such as recognizable visual form in Chapter 7) we might come to understand more about the interplay between robot motion, robot appearance, and emotional interpretations of those robots.

The Stem experiment employed two distinct approaches simultaneously: alternating between an entirely abstract experiment and one that prompted the participant with questions specifically relating to emotional interpretations. The goal was to present each participant with a moving robotic entity as devoid of visual connotations as possible and to query the participant about their interpretations while introducing as little bias as possible.

6.2 Implementation

6.2.1 Robot Platform

We designed the robot platform to approximate the visual simplicity of the Heider and Simmel experiments by modelling it after a straight, moving line; fixed at one end and with no other distinguishing visual features. Named *The Stem*, the robot (Figure 28) consisted of a 1m long, 2.5cm square balsa wood shaft and a trio of servo motors arranged as a “spherical joint”; allowing the wooden shaft to roll, pitch and yaw about its single base point. The motor assembly was mounted onto a stationary 1m cubic aluminum frame.

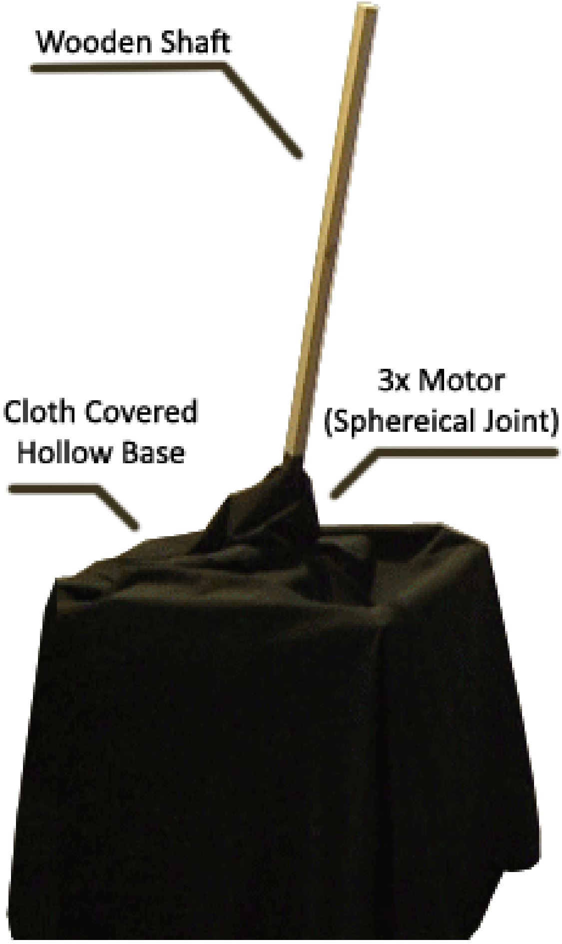


Figure 28 - *The Stem.* Consisting of a 1m long, square-sided wooden shaft, 3 servo motors at its base arranged in a spherical joint configuration, and sitting atop a cloth covered $1m^3$ hollow, aluminum base platform.

A square sided shaft was purposefully chosen so that as *The Stem* rotated, the various facets of the shaft would catch the light and shadow of the environment; allowing observers to notice the yaw rotation more easily than, for example, if they could only observe the minute wood grain patterns and monotonous shadowing of a rotating cylindrical shaft.

Each of the robot's motors allowed for direct position control over a 300 degree range of motion. When combined with the length of the wooden shaft, *The Robot Stem* had a significant range of motion in all three axes as well as a significant "reach" within its immediate surroundings.

Both the motors and base were covered by a black cloth skirt. This obscured the inner workings of the robot platform and focused observers' attention on the presented movement of the wooden shaft.

Between its overall height and large base, *The Stem* was designed to have a substantial physical presence and was deliberately constructed to be viewed from eye-level and in close proximity in an attempt to maximize its physicality and the impact of whatever emotions its movements might elicit.

Regarding the physical risks of interacting with *The Stem*, while the motors that were used were powerful, the leverage provided by the long length of the wooden shaft meant that the tip of the shaft travelled with a high speed but relatively little force. Balsa wood was chosen for *The Stem's* shaft because of its extremely low density; resulting in a total weight of less than 150 grams. Together, this meant that being struck by the shaft, a scenario that never occurred during the design or evaluation of the robot, would result in nothing more than a gentle bump. The arm operating at full power could easily be pushed back even by a young child.

6.2.2 Study Environment

The study environment in which *The Stem* and participant were situated was also setup to be as devoid of distractions as possible (Figure 29). *The Stem* was positioned in the corner of an empty white room. The participant was seated 2 meters away from the robot with a screen placed directly behind them to block out the rest of the room.

Figure 29 - The study area used for *The Stem* experiment

A single spotlight was placed within the ceiling above the robot and all other room lights were turned off. The spotlight was pointed straight down and positioned slightly behind the robot in order to draw the participant's attention directly to the robot, enhance the visual contrast on the various facets of the wooden shaft, and cast a shadow from the moving shaft down to the floor; all meant to further highlight the motion of *The Stem*.

Participants' spoken comments were recorded via wireless lapel microphones. Each participant also wore a set of over-ear, closed-can headphones for the duration of the experiment. These headphones played a continuous white-noise sound meant to prevent the participants from hearing the sounds that the robot's motors would make when they moved. This avoided introducing emotional connotations associated with the varying motor noises and allowed participants to focus on only the motion of the robot. (E.g. more rapid motor movement would be accompanied by a high pitched "whirring" noise, potentially perceived as similar to a growl.)

A video camera recorded each session from behind and to the side of the study area; outside of the participants' immediate field of view. The study administrator was seated behind the participant, hidden behind a barrier from the chest and downward; preventing the participant from seeing the administrator's control actions but still allowing the administrator to clearly observe both the participant and the robot platform. The administrator used a laptop computer and a joystick-style controller that exactly mirrored *The Stem's* degrees of freedom to either trigger the robot's pre-scripted motions or assume direct manual control over the robot's motions as necessary.

As a result, during all sessions the participant (with blocked ears) was left in an empty, silent room with just *The Stem* under a single spotlight, and the hidden administrator.

6.3 Evaluation

In the following sections we detail the phases and experimental conditions of the study, and the individual motions that were performed by *The Stem*. The study was divided into two conditions: 1) the "Mechanical" condition and 2) the "Organic" condition with interactivity.

Note that throughout the study, participants were only told that each experiment phase would contain "a set of motions", and were never made aware of the "titles" of the motions, nor their total number or variety.

6.3.1 Mechanical Condition

In designing the robot's various motion patterns, we adopted a two-tiered approach, with the study participant's reaction to the first experiment condition informing the design of the second condition.

6.3.1.1 Mechanical Motion Patterns

The set of motions in the "Mechanical" condition were designed as an abstract baseline. The motion characteristics of "frequency" and "direction" were systematically varied in an attempt to survey the realm of possible movements. Each Mechanical motion consisted of a combination of sinusoidal movement performed by each of the three axes of motion (roll, pitch, and yaw) resulting in relatively simple, repetitive motions.

While the robot's motors were technically capable of travelling through a range of 300 degrees, the Mechanical set of motions was limited to arcs of approximately +/- 35 degrees. This was primarily due to the inertia of the wooden shaft when it performed some of the more vigorous movements and the practical need to maintain sufficient force to affect rapid direction changes. By limiting the motors' range of travel, different frequencies of motion could be tested without limiting the amplitude of a given motion. That is, beyond 35 degrees, *The Stem's* motors were not powerful enough to perform both wide, arcing motion *and* fast, rapid motion.

Following is a list of the 11 Mechanical motion patterns. During the experiment, each motion pattern repeated itself for 45 seconds. For brevity, similar motions descriptions are grouped together (along with their abbreviations).

#1, #2, #3, and #4: "Front to Back" Fast/Slow (F2B F/S) and "Side to Side" Fast/Slow (S2S F/S)*:* *The Stem* is pitched toward and away from the observer or rolled from side to side; rep*eating t*his pattern cyclically at either fast or slow pace.

#5 and #6: "Twist" Fast/Slow: Standing straight upwards, the robot's arm yawed about the vertical axis; twisting fast or slow to either side.

#7 and #8: "Circle" Fast/Slow: At an angle of approximately 35 degrees, the top of the *The Stem's* shaft traced a complete circle (if viewed from above) either fast or slow.

#9: "Figure Eight": *The Stem* traced an "infinity" symbol (if viewed from above).

#10: "Nodding": *The Stem* rapidly pitched forward and backward while at the same time slowly rolling from side to side.

#11: Motionless: *The Stem* was motionless, holding a vertical position.

The core of the initial experiment consisted of two phases. In the first phase, participants were invited to observe and openly reflect on *The Stem* and its motions. In the second phase, participants were asked to complete a Likert-style survey asking how they would rate the robot's motions in relation to opposing pairs of adjectives. At the conclusion of each study session, a semi-structured interview was conducted; with each participant being queried about their thoughts on *The Stem,* their interpretations of its motions, and the study in general.

6.3.1.2 Mechanical Condition, Phase 1: Open Reflection

In order to allow each participant to be as reflective and open-minded as possible and to avoid biasing their responses towards a strictly “emotional” agenda, each experiment session began with a period of open, unstructured reflection on the robotic motion. During the recruitment process, participants were informed only that they would be participating in a “human-robot interaction experiment”, with no details given as to the nature or purpose of the study.

The participants were asked to sit in front of “the robot” and were told that the robot was going to be “performing a series of motions” while they were tasked with “simply observing it and speaking aloud whatever thoughts or feelings come to mind”. The critical component of this phase was that, while these instructions specifically mention that the robot would be performing motions, it did not instruct the participants as to what they should be reflecting on or what the experiment’s “true purpose”.

While participants were told that the administrator would be leaving them alone in the room with the robot to allow them to reflect on its actions for this first phase of the experiment, in reality the administrator would walk to a distant corner of the room, behind and out of sight of the participant, such that they could still directly observe interaction. This deception was an attempt to allow the participants to feel as reflective and open minded as possible without feeling guarded about sharing their inner thoughts with a stranger in an unfamiliar scenario.

During this phase, *The Stem* would perform the complete set of 11 motions. The sequence of motions was randomly generated for each participant. Each motion would last approximately 45 seconds before smoothly transitioning to the next distinct movement pattern. Once the complete set of motions was performed, the experimenter would “return” and provide instructions for the second phase of the experiment.

6.3.1.3 Mechanical Condition, Phase 2: Survey Phase

Having attempted (during the open reflection phase) to allow participants' reactions to emerge without biasing them towards an emotion-centric perspective, the Survey phase of the experiment was designed around a Likert-style emotional survey: a compromise that had both a more easily quantifiable structure and presented the participant with a more overt directive.

Figure 30 - A participant records their answers during the survey phase of the experiment

In this phase, the participant was instructed that the robot would "perform another series of motions" (in reality, the same set of motions as the first phase, but with a new random ordering) and they were asked to complete one page of the survey for each motion. On each page of the survey was a set of 7 Likert Scale style questions (See Appendix Section B.1). Each question asked the participant to rank (with the scale 3-2-1-0-1-2-3) how applicable a pair of adjectives was for the motion the robot was currently performing. Ranking an adjective pair as 0 was labeled as "Neutral".

The seven adjective pairs were:

- Mechanical Vs. Organic
- Dumb vs. Smart
- Shy vs. Outgoing

- Bored vs. Interested
- Sad vs. Happy
- Tired vs. Energetic
- Enemy vs. Friend

While the functional meaning of each adjective pair was chosen to be in opposition, the use of positive vs. negative numbers was specifically avoided so as not to associate either of the adjectives with an overtly “negative” connotation. Instead, the magnitude of the numbers was meant only to correlate with how applicable a participant felt a given word was in each case.

Participants were given an unlimited amount of time to observe each motion and complete each survey page. When they completed a page, they would say “Next” or “Finished” and the experimenter would command the robot to transition into the next motion and so on until all 11 motions had been performed and all 11 survey pages had been completed.

6.3.2 Organic Condition

Over the course of conducting the experiment sessions under the Mechanical condition, a set of common themes were noted in the participants’ responses; specifically their rapid recognition (and subsequent disinterest in) the repetitive nature of the Mechanical motion patterns and the general belief that *The Stem* was a strictly demonstrative robot and that it (disappointingly) did not react to any of the participants’ actions. In order to explore these emergent themes, a second experiment condition was designed along with a new set of motion patterns. Labelled the “Organic” set, this experiment condition was design to explicitly enable *The Stem* to express more purpose and a higher level of intent in its movements and to build on some of the more general themes that emerged out of the simpler Mechanical motion patterns.

6.3.2.1 Organic Motion Patterns

Recall that the “Mechanical” motion patterns systematically explored what emotions were elicited by a set of simple motions that varied only in frequency and direction; in essence, asking the question “What might each of the various combinations of axis X, Y, and Z, express?”

In contrast, the “Organic” motion patterns were designed to be more focused and considered “How expressive can an abstract robot platform’s *deliberate* motions be?” by selecting the motion themes that emerged from the “Mechanical” motion condition (e.g. “approach suggests aggression”) and designing specific motion themes around them.

For example, a common participant response from the mechanical condition was that rapid approaching motions might suggest aggression. Given that theme, a motion was developed which specifically emphasized rapid, approaching movement. This “Organic” set of motions consisted of pre-recorded sequences that were manually authored via a miniature joystick interface that exactly matched the degrees-of-motion of the larger, original *Stem* robot.

Unlike the “Mechanical” motions, the “Organic” motions were also intended to by acyclic and thereby more complex. Each motion lasted approximately 45 seconds (the same duration as the “Mechanical” motions).

These motion sequences are briefly summarized as follows:

#1: “Angry”: Emphasis on aggressive, rapid pitching motions towards the observer, relatively little roll or twist, and maintaining constant, high energy motion.

#2: “Bear Swipes”: Emphasis on low-height, high-speed, horizontal sweeping motions separated by periods of withdrawing away from the observer. The intent was a “defensive posture” which attempts to maintain a safe distance from the observer.

#3: “Sad/Moping”: A low-energy sequence characterized by *The Stem* leaning almost 90 degrees over to one side, moving only to occasionally slowly rise a few degrees and then fall back down slowly as if “letting out a large sigh”.

#4: “Wailing”: A high-energy sequence consisting of continuous random, high-amplitude, sweeping motions.

#5: “Working”: A semi-periodic sequence with *The Stem* leaning over to one side (the “filling” side), bobbing and twisting for approximately 7 seconds and then arcing up and over to its far side (the “deposit” side). Here it performs one large bobbing motion and then arcs back over to the “working” side to repeat the sequence. The metaphor is that *The Stem* is filling an imaginary bucket and then emptying it elsewhere.

#6: “Conversation”: Mimicking a spoken conversation, *The Stem* stands nearly vertical (with minor side to side rocking) while periodically responding “Yes” or “No” by either quickly pitching forward and backward by approximately 10 degrees (nodding in agreement) or by quickly rolling/twisting side to side by 10 degrees (shaking its “head”).

#7: “Inspection”: *The Stem* leans towards the participant and rolls to each side; staying there for short periods before switching sides as if trying to get a better view of the participant through a magnifying glass.

#8: “Surprised”: *The Stem* leans in random directions, sweeping an arc around its perimeter before periodically jumping back to vertical and then slowly, “cautiously” leaning in again and repeating the sequence in a new direction. The intended expression is that *The Stem* is timidly exploring its surroundings like a young child in the dark.

#9: “Searching”: A high-energy sequence that combines quick leans in random directions followed by rapid bobbing motions before *The Stem* leans in a new direction. The metaphor is that *The Stem* is searching all around it for a lost item.

#10: “Happy”: A high-energy sequence emphasizing rhythmic rolling motions while avoiding aggressive pitching motions. *The Stem* also occasionally pauses to perform a series of rapid twists before resuming its rhythmic rolls.

#11: “Fidgeting/Idle”: Rather than remain completely motionless like the “Mechanical” idle motion, *The Stem* remains essentially vertical while making subtle pitching and rolling motions of no greater than 10 degrees. The intent is to mimic the idle fidgeting motions performed by most living creatures while stationary. (E.g. breathing, scratching an minor itch, shifting weight to a different foot)

The sessions in the “Organic” condition began with the same “open reflection” and “survey” phases as in the “Mechanical” condition but, prior to the concluding guided interview, a new, fully interactive “open interaction phase” was introduced.

6.3.2.2 Organic Condition, Phase 3: Open Interaction Phase

In order to explore our theories on the importance of interaction in expressing emotion, the open interaction phase enabled the participants to immerse themselves in direct interaction with *The Stem.* Participants were asked to stand up and “freely interact with the robot” for 5 minutes.

As a slight deception, and to reinforce the participant’s sense that this phase would be different from the observational Reflection and Survey phases, the administrator would move behind T*he Stem’s* base platform, reach beneath the obscuring black cloth, and pretend to adjust some imaginary switches. The administrator would then instruct the participants that “I’ve just turned the robot’s sensors on. It will now be aware of you when I turn on its artificial intelligence.” Neither what kind or number of “sensors” had been activated nor the nature of the new “A.I. algorithm” was disclosed. No further instructions or prompting were given.

Figure 31 - A participant "dancing" with *The Stem*

The administrator would then return to the administration desk and proceed to directly control the robot via a “Wizard of Oz” technique. This control was hidden from the participant by an obscuring barrier in front of the desk. This is the only portion of the study where *The Stem* was under manual control.

The experimenter would puppeteer *The Stem* according to a simple “emotional state machine” based on the set of Organic motions used in the Reflection and Survey phases. In short, *The Stem* would “wake up” (similar to “Sad” and “Surprised”) and would then transition between Happy, Scared, Angry, or Sad behaviours depending on the participant’s interaction.

The “intelligence” and state transition logic of The Stem’s personality were informally modeled after a small household pet. For example, *The Stem* attempted to act as if it:

- Enjoyed gentle, close contact
- Became frightened by sudden, unexpected movements

- Became bored if the participant would either repeat the same actions or did nothing for an extended period of time
- Became angry if the participant became overly aggressive

After 5 minutes, the interaction was stopped and the participant was instructed to take a seat in preparation for the concluding semi-structured interview.

6.4 Results

In total, 30 participants were recruited for the *Robot Stem* study. The experimental conditions were studied between-participants, with a gender distribution of 9M/6F in the “Mechanical” condition, and 7M/8F in the “Organic” condition. All participants were recruited from the local campus community and were financially compensated for participating in the study. The participants’ ages ranged from 19 to 56 with a median age of 23.5. The participants’ professional training varied; including history majors, medical professionals, engineers, and computer scientists, among others.

Each session lasted approximately one hour and was recorded via both audio and video; allowing the study administrator to review both verbal reflections as well as non-verbal expressions such as body language, facial expressions, and physical gestures throughout the experiment.

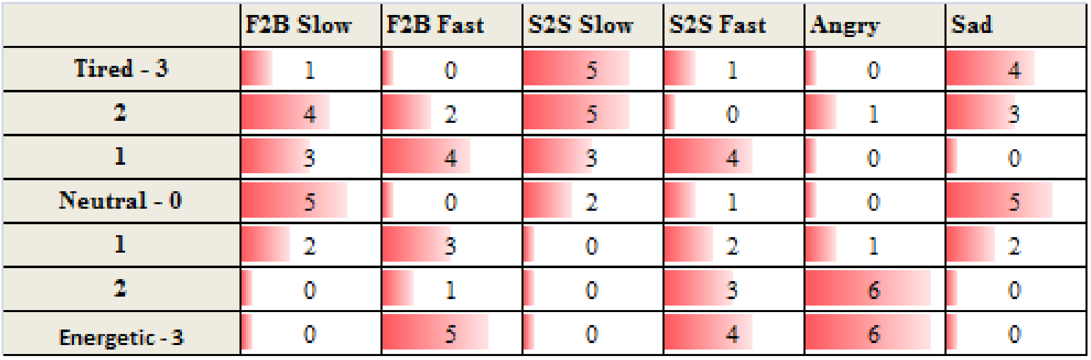
What follows is a high-level analysis of the study results. Given the largely open-ended and exploratory nature of the study, the current analysis presented here should be viewed as an attempt to gain insight on the major trends, rather than a final and exhaustive examination of the data. While we believe a more fine-grained analysis of the recorded data would likely reveal further interesting findings, we feel that the larger themes that were exposed demonstrate the validity of my approach and are overall good early indicators of the potential of exploiting the affect of abstract motion in social HRI.

6.4.1 Quantitative Results (Survey Phase)

The results of the survey phase were aggregated and compared as histograms. The major emergent trends are presented below. The histogram numbers represent how many participants rated *The Stem's* motions with a given adjective and to what degree (e.g. "Very Tired", "Somewhat Tired")

Table 4 shows how strongly participants felt either the word "tired" or "energetic" applied to certain motions. For the "Mechanical" condition, most "fast" motions showed a marked tendency towards "energetic" when compared to their "slow" counterparts. For the "Organic" condition, visibly more energetic motions (e.g. Angry Vs Sad) were graded as such. That one might expect this correlation between the robot's speed and the participants' perception of increased "energy" alludes to at least some level of efficacy in the study questionnaire.

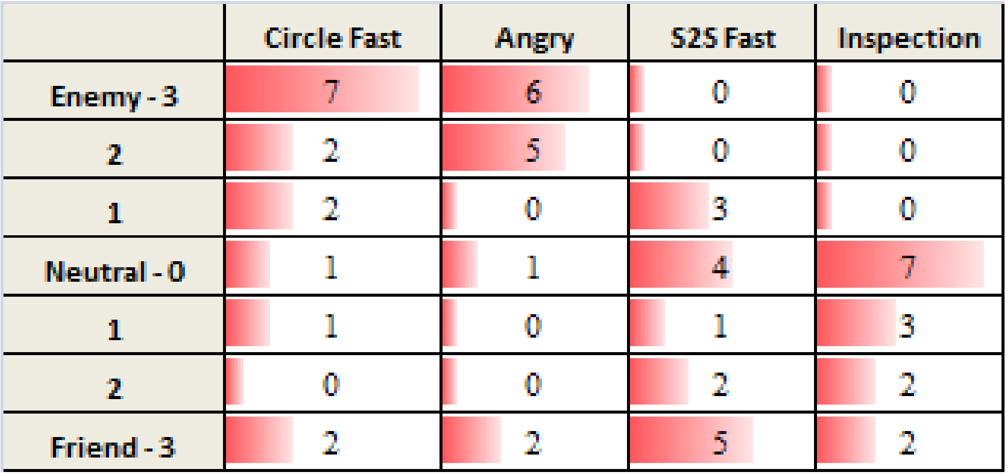
Table 4 - "Tired" Vs. "Energetic"



	F2B Slow	F2B Fast	S2S Slow	S2S Fast	Angry	Sad
Tired - 3	1	0	5	1	0	4
2	4	2	5	0	1	3
1	3	4	3	4	0	0
Neutral - 0	5	0	2	1	0	5
1	2	3	0	2	1	2
2	0	1	0	3	6	0
Energetic - 3	0	5	0	4	6	0

Table 5 suggests that motions that emphasized fast and advancing (towards the participant) movement tended to be graded more strongly as "Enemy" (e.g. "Circle Fast" and "Angry") while non-advancing motions were not; even if they had similar overall speeds to non-advancing motions. (e.g. "Side to Side Fast" or "Inspection")

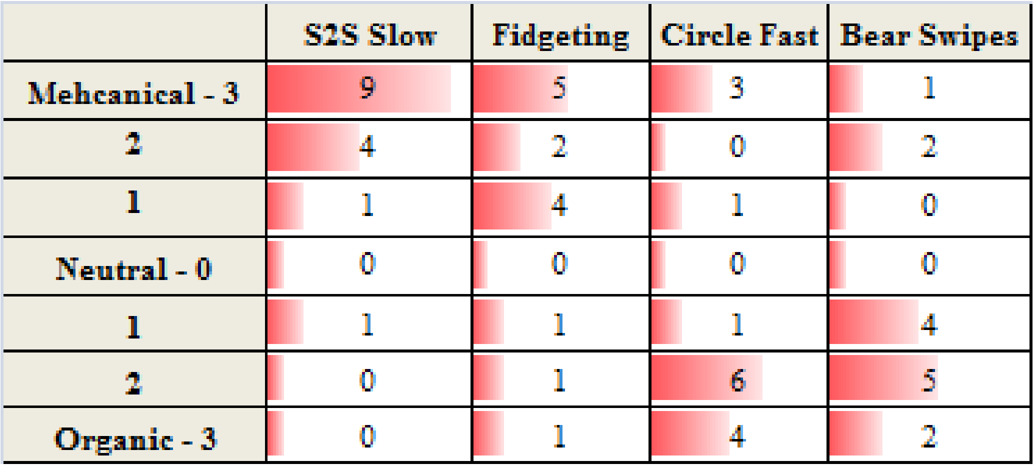
Table 5 - “Enemy” vs. “Friend”



	Circle Fast	Angry	S2S Fast	Inspection
Enemy - 3	7	6	0	0
2	2	5	0	0
1	2	0	3	0
Neutral - 0	1	1	4	7
1	1	0	1	3
2	0	0	2	2
Friend - 3	2	2	5	2

Table 6 suggests that when participants were asked to apply either the adjective “mechanical” or “organic” to their observations, motions that emphasized fast-moving, complex motions tended to be graded as more “organic” while slower, more repetitive motions were graded “mechanical”; regardless of which pre-determined motion set a motion belonged to.

Table 6 - "Mechanical" vs. "Organic"



	S2S Slow	Fidgeting	Circle Fast	Bear Swipes
Mehcanical - 3	9	5	3	1
2	4	2	0	2
1	1	4	1	0
Neutral - 0	0	0	0	0
1	1	1	1	4
2	0	1	6	5
Organic - 3	0	1	4	2

6.4.2 Qualitative Comments and Observation

Open coding analysis was performed on each participant's recorded video/audio data; revealing a number of prominent themes from the "Reflection", "Open Interaction", and "Interview" phases of the experiment.

1. ***The Stem* was dangerous**

At least 17 out of 30 participants said that they thought some of *The Stem's* motions felt dangerous, scary, intimidating, or that the robot was otherwise attempting to attack them (Figure 32). A number of participants also visibly recoiled away from the robot when it transitioned into certain aggressive motions. (E.g. "Angry" or "Front to Back Fast") In particular, one participant (Male, 26) withdrew his outstretched legs saying "The robot doesn't reach me, but its shadow does. Somehow I'm not even comfortable with its shadow touching me."

Figure 32 - A participant recoils from one of *The Stem's* more aggressive motions

2. ***The Stem*** **could dance**

At least 10 participants, mainly from the “Organic Condition”, claimed that The Stem was “dancing” during certain motions. These comments generally occurred as they were observing the “Happy” motion. Most participants would smile as they made this comment and many would begin to mimic *The Stem’s* rhythmic bobbing.

3. ***The Stem*** **faced towards the participant**

When asked “Which way is the robot facing?” at least two thirds of the participants responded with “Towards me.” When asked why they felt this, despite the symmetry of *The Stem’s* appearance, most participants could not provide a specific reason.

4. ***The Stem*** **had internal thoughts/intelligence**

A large majority of participants made at least one comment attributing an internal thought process or intentions to *The Stem*; at different times claiming the robot was “pensive… it’s thinking about something” (Female, 25), “enjoying this, sort of purring like a cat” (Male, 50), hiding something (Female, 20), bowing or greeting them (6 participants), drawing or painting (3 participants), looking for/inspecting something (10 participants), and so on.

5. **Very few viewed *The Stem* as nothing but a machine**

At least two participants described *The Stem’s* motions in essentially technical terms. E.g. “It’s now tilting about 40 degrees side to side every 2 seconds.”

6. **Repeating motions quickly become boring**

At least 11 participants exhibited boredom when faced with slow, repetitive motions; primarily under the Mechanical condition. Each appeared interested in observing the new motion when the robot transitioned from one to the next, but their attention quickly waned once they claimed to have “figured out the programming” (Male, 28).

7. **The robot was the box and the wooden shaft was a tool the robot was holding**

More than two thirds of all participants made some comment similar to “It looks like the robot is holding a sword or a baseball bat and is swinging it around” or that “the robot must be inside the box [the covered base platform] and is manipulating the stick”; implying that the wooden shaft itself was not the robot but merely a tool.

8. **The Organic condition was interactive, the Mechanical condition strictly observational**

When asked if they felt their experience with the robot had been interactive or strictly observational, 12 out of 14 participants in the “Organic” condition said they felt they had been interacting with the robot. Conversely, more than half of the participants in the “Mechanical” condition felt that their experience had been strictly observational.

9. **One participant appeared terrified of interacting with *The Stem***

One participant (Female, 24) remained essentially stationary during the entire 5 minute period of open interaction with *The Stem*. Visibly intimidated by the robot, she continued to mutter comments such as “Oh no… Oh no… Stop pointing at me… Oh God…”

10. **The study was enjoyable**

Despite individual motions appearing dangerous or intimidating, every participant claimed that they enjoyed taking part in the study. Many stated they felt it a uniquely thought-provoking experience.

6.5 Discussion

In this section, we briefly summarize our interpretation of our results and discuss their implications.

6.5.1 Speed and Direction

Relationships appeared to emerge between certain motion types and emotional characteristics. Most straightforward of these were the connections between speed-excitement and approach-aggression. That these trends tended to be common across all participants leads us to believe that there is some form of instinctual emotional interpretation at work rather than a learned interpretation based on previous experience.

6.5.2 Autonomy and Control

With so much of the experiment depending on presenting *The Stem's* motions in an unbiased fashion, there was some concern about the participant's implicit control over the robot during the survey phase. By allowing the participant to dictate when to move on to the next survey motion (e.g. by saying "Next!" or "Finished!"), the experimenter's control over the robot's motion was made transparent; rather than *The Stem* existing as an autonomous (and possibly intelligent/emotional) agent.

6.5.3 Physicality

Unlike on-screen, virtual representations of objects (e.g. computer graphics or 2D animation), we feel *The Stem* is quite viscerally "real" and present with its human observers; able to directly affect its environment through motion and physical interaction in more powerful (as well as more subtle) ways that strictly virtual displays. *The Stem's* physicality allows it to exploit our senses of depth perception, personal space, vibration, and even subtle air currents using its mass and rapid movement. We feel that the instinctual fear of being physically struck by *The Stem* itself is an important component of this experiment and a characteristic unique to HRI in general.

The importance of *The Stem's* physicality and the impact it had during the experiment (particularly during the Interaction phase) agrees with the conclusions drawn by Kidd and Braezeal. (Kidd & Breazeal, 2004)

6.5.4 Personal Space

Many participants responded to the rapid approaching motions (e.g. Front to Back Fast, Nodding, etc.) by expressing concern for their own personal safety; withdrawing into their seats and drawing their arms into their torsos.

Figure 33 - A participant retreats from *The Stem's* advances during the open interaction phase

During the open interaction phase, some participants made their own aggressive approaches towards the robot (e.g. suddenly jumping towards it and raising their arms above their head), saying they were "trying to see if I could scare it." As per the experimenter's protocol for controlling *The Stem* during this phase, the robot would in turn recoil from these motions, attempting to maintain a safe distance from the participant. Noting this, one participant remarked "Ah… I see it doesn't like that."

6.5.5 Purpose and Context

The "purpose" of the robot played a large role in how participants thought to interpret its motions. When asked to openly reflect on the experience of observing the moving robot, many participants repeatedly asked what the robot was meant to be doing or why it was moving. Before describing their thoughts on their interpretations, they wanted to place their ideas in a more concrete context.

We feel that it was almost guaranteed that, had participants been pre-biased by introducing *The Stem* as, for example, “a security robot on patrol” participants would be more likely to interpret certain motions as more aggressive than if they were to enter the experiment with a more open mindset.

Alternatively, the entirely freeform nature of the study’s reflective and open interaction phases may have left participants so bereft of official context that their reported interpretations of the robot, instead of being accurate reflections of their internal thoughts, were instead their best attempts to brainstorm *any* appropriate answer they could think of in order to comply with the experimenter’s instructions.

What is clearer is our participants’ apparent reflex to draw upon any and all of their past personal experiences in order to understand and explain the behaviour of a novel entity that they do not initially understand; whether that was having lived with household pets or formal engineering training.

6.5.6 Relation to our Conceptual Taxonomy

The three distinct conditions of *The Stem* user study forms an excellent baseline for comparison between *The Stem* prototype platform and the remainder of our experimental platforms. With an absolute minimum of visual affordances, *The Stem’s* wide variety of possible motion styles meant the robot was able to elicit a range of powerful emotions from its human observers; both positive (e.g. happiness, celebration) and negative (e.g. anger, sadness).

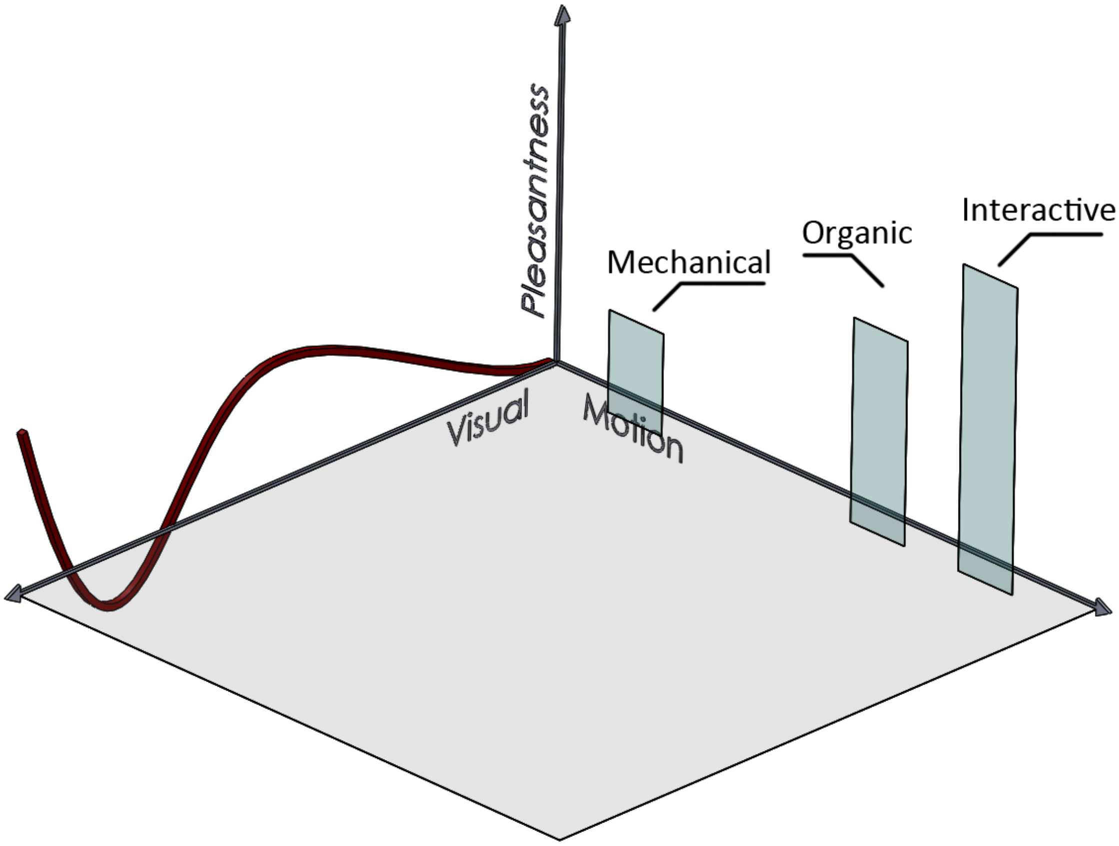


Figure 34 - Our conceptualization of the various degrees of emotive impact we feel *The Stem's* different motion styles expressed under each of its motion style conditions. (E.g. "Mechanical", "Organic", and "Interactive")

Figure 34 visualizes the flexibility of *The Stem's* motion capabilities from the perspective of our *emotive motion* taxonomy. *The Stem's* "Mechanical" set of motions were very linear, repetitive, and machine-line; resulting in a very unnatural and unexciting emotional experience for the participants in that condition (and hence the relatively low height of the "exploration area" in the figure for that condition). The smoothness and complexity of *The Stem's* "Organic" motion set place that conditions "exploration area" higher up the "motion familiarity" design axis. Numerous participants began to claim that someone was sitting inside *The Stem's* base and were wielding the wooden shaft as a weapon; demonstrating that *The Stem* had achieved a distinct level of life-like motion familiarity. Introducing reactivity to these complex "Organic" motions further enhanced their emotive impact and we see that the "pleasantness" of this experimental condition is higher than the previous two.

Remarkably, all of this was achieve with *The Stem's* minimum of visual familiarity.

6.6 Summary

This chapter detailed *The Stem* robot and an exploratory study we conducted using it. It was an initial exploration of some of the associations between robotic motion and the human emotions it can elicit even in the absence of recognizable visual form. In this case, we chose a basic, low level approach to the problem: looking at abstract robotic motions, avoiding form and affordances as much as possible, and requiring the user to focus on the motion alone rather than on a task.

We detailed our design philosophy and efforts, and presented the robotic platform we used in a full user study. We discuss our evaluation approach, a reflective meditation-like think aloud observation session as well as an interactive session allowing the users to relate directly, through their own actions, to the robotic motion.

We discussed our extensive user study and its results. While some of the mapping we observed between sets of motions to the emotions they elicited were, we believe, quite obvious (e.g. instinctually defending oneself in the face of an aggressive, approaching entity), we were also pleasantly surprised to see a strong level of user engagement emerging from our observations, despite *The Stem's* rudimentary appearance. Many of our participants engaged in seemingly emotional and unexpected ways with our very simple, almost purely abstract robot.

Having witness the users' ability (or was it need?) to be deeply engaged with abstract robotic motion, these powerful initial results prompted additional questions and further avenues of investigation:

1. We wondered if and how far can the insight gained from *The Stem* might scale to non-abstract robots? Recalling Mori's continuum of visual robotic form, we wondered if and how the level of emotional engagement would be affected by enhanced form?
2. How far could this engagement be carried on when the user was dealing with a valid task, supported with a progressive interaction flow? Would users still pay so much attention to the robotic motion when they need to perform a task, or perhaps the motion will move into the background, providing a sort of ambient interaction trait?

3. To what degree was the complete openness and entirely reflective nature of *The Stem* user study a confound itself? Would a different environmental context, perhaps one not so overtly “experimental”, affect participant’s perception of the robot? We wondered, if participants were to run into *The Stem* in a public space, would its abstract visual appearance and lack of functional context be less a blank canvas on which they could project their interpretations and more of piece of incomprehensible nonsense?

In the next chapter, we discuss a second user study we conducted that attempted to address some of these questions.

7 Calamaro: The Mac Hall Monster

In the preceding chapter, we described *The Stem*: a user study investigating *emotive motion* with an emphasis on extreme visual abstraction and performed in a controlled laboratory setting. While the quiet, reflective environment of *The Stem*'s study revealed interesting trends and highlighted the expressive power of robot motion during its interactions with participants, the extremely abstract nature of the study raised questions regarding the general applicability of the study's results to more real-world scenarios.

In this chapter we discuss a second study we conducted in order to address some of these new questions. We describe how we followed on from the *Stem* study, why we chose to take a radically different approach to the experiment, the unique robot platform that was created for it, our results, and a discussion of their possible implications.

7.1 Design Philosophy

7.1.1 Visual Form

Having explored the lower end of the "visual familiarity" design axis, we chose to center our next investigation of *emotive motion* on a robot platform with a more distinctly zoomorphic visual appearance. Having seen how even a basic wooden shaft could elicit a wide variety of emotional responses through just the careful use of its motion capabilities, we were now curious to see whether and how a robot's more familiar visual form could affect those interpretations.

We chose to strike a middle ground between the extreme visual abstraction of *The Stem* and the realism of life-like androids. This returned us to the "semi-zoomorphic" realm (e.g. in the middle of our "visual familiarity" spectrum) of robots like our *eMon* prototype and the animated robot character *Wall-E* (Stanton, 2008): robots with vaguely recognizable features such as a "head", "hands", or "wings" but with a still distinctly "robotic" appearance including glass, plastic, gears, and wiring.

7.1.2 Study Environment

Additionally, we chose to explore a wholly different experimental design than the Zen-like, free-form environment used during our *Stem* studies. Rather than seclude our participants alone in a serene and reflective but practically unnatural (i.e. in that daily life is rarely so peaceful) environment, we wanted to take an “in the field” approach to our second *emotive motion* study and instead approximate an ethnographic study of “robots in the wild”.

Our motivation here was to pursue a greater sense of how our results might generalize in daily life. E.g. Without the time and opportunity to open up and thoroughly meditate on their emotional reactions to our robot platform, would an average person in public be nearly as receptive or emotionally engaged as our previous study participants were in the darkened room with the *Stem*? What factors would human-human social interaction play? Would a group of friends interact differently with our robot than if they were to encounter it individually?

The importance of addressing these questions and understanding how social HRI experiences change when they move from the laboratory and into the “real world” has been highlighted by several HRI researchers, including (Sabanovic, Michalowski, & Simmons, 2009) and (Shiomi, Sakamoto, Kanda, Ishi, Ishiguro, & Hagita, 2008).

7.1.3 Emotive Motion Characteristics

In terms of the *emotive motion* characteristics we were to study, we chose to use the *Calamaro* study to focus on some of those themes that had emerged from the *Stem* study, but had either not been fully explored or *could not* have been explored using that platform: in particular, the concepts of speed, repetition, and the coordination of multiple “appendages”.

Part of the motivation for the creation of the “Organic” motion sequences during the *Stem* study was the perception that participants quickly became bored with the very simple, and quickly repeating “Mechanical” motion patterns of that study. Whereas the “Mechanical” motions would begin to “repeat” within seconds of starting, the *Stem’s* “Organic” motions consisted of unique patterns lasting more than 30 seconds each. The Organic motions were also never allowed to begin repeating and instead just stopped after the 30+ seconds had passed.

The *Calamaro* study would specifically address this question by deliberately exploring the concept of repetition with both short, rigid motion patterns and longer, more ornate motion patterns.

Regarding “coordination”, the *Stem* only had one shaft that it could actuate. In nature, many animals have many appendages that they can use in coordination to achieve specific goals. For example, humans can use both of their hands and arms to hold and manipulate objects; a horse’s four legs all work in unison to propel it while running; and the many dozens of legs on insects (e.g. spiders and centipedes) is often a source of discomfort and fear. Depending on the number of appendages and their type of coordination, the emotional expression associated with these animals’ motions can change. Conversely, many robots move their motors in a lock-step, sequential fashion; one axis at a time. (The same motion characteristic popularly associated with “Dancing the Robot” and “robot” mimes.)

Calamaro’s multiple distinct appendages (including wheel/legs, a 3-axis “head”, and eight individual arms with three degrees of freedom each) afforded us an excellent opportunity to explore the impact of these two distinct styles of motion.

7.2 Implementation

The Mac Ewan Student Center, informally known as “Mac Hall”, is a bustling center of activity situated right in the heart of the University of Calgary campus. Mac Hall incorporates many large, open spaces, multiple restaurants, lounges, offices, student club rooms, and a full-sized concert venue. It was quickly chosen as the ideal location to mount our study. Every afternoon, Mac Hall is typically host to a steady stream of people (including students, faculty, and members of the public) and, because vendors and unique events are a common occurrence throughout the year, we would be able to mount our study with minimal obstruction to the student centre’s normal operations.

During the initial design stages of our robot platform, it was simply referred to as the “Mac Hall Monster”. Designing this new robot platform proved to be extremely challenging and, like the series of iterative designs that eventually led to *The Stem*, we developed numerous early prototypes before arriving at our final platform. We describe the evolution of these prototypes and how they affected our study design next.

7.2.1 “The Jungle Snake”

In order to maximize the “naturalness” of our ethnographic approach, achieving a serendipitous interaction scenario between the visitors to the student centre and the robot platform was one of the primary goals of the Mac Hall Monster study. In searching for a suitable location within Mac Hall to deploy the robot, a large central atrium became an early leading candidate for a number of reasons:

1. It was situated in between the two primary walking laneways through which almost all of the MacEwan Centre’s visitors would have to pass.

2. It was surrounded by food court tables which would give passersby a natural reason to sit in direct proximity to the robot, observe, and potentially interact with it.

3. Beneath the atrium’s well lit skylights were two large potted plants. Because the trees were relatively small and thin compared to the large diameter of the pots in which they were planted, we felt this provided an excellent place to position the robot (e.g. in the pots at the base of the trees themselves) while naturally maintaining good sight lines for any video cameras we would use. The pots would also act as a crowd control device that would naturally maintain a safe distance between the robot and observers.

Inspired by this “forested” location, this led to our initial “*Jungle Snake*” robot prototype. An incremental evolution of the rigid *Stem’s* design, the *Jungle Snake* maintained the same long, single-shaft form but introduced the concept of a “face/head” area as well as a highly articulated body. With this, we could explore many of the same general motions as *The Stem*, but this time in a serendipitous public context as well as introduce motions involving curvature, contraction, and twisting.

Unfortunately, early hardware tests showed that as the length of the *Jungle Snake’s* articulated torso grew longer (Figure 35), the mechanical leverage required of the base motors quickly grew too great for the motors to maintain. If the robot was to be of any significant length, it would not be able to stand up straight. Even if it was mounted to hang down from the tree branches, we found that it would only be able to hang down essentially vertically and with only limited movement from side to side.

Figure 35 – Our motors proved too weak to form a sufficiently large chain for the *Jungle Snake* prototype's body

We felt this would greatly limit the *Jungle Snake's* expressive capabilities, limiting the motion space we could explore and pulling our study focus too far away from *emotive robot motion.* Instead, our study would be pushed too far towards a focus on the unique environmental context and public interaction scenario. The *Jungle Snake* concept was abandoned and a new robot design was sought.

7.2.2 "Strider"

The primary problem with the *Jungle Snake* design was that our available motors could not allow for a robot platform that had both the physical size/presence of *The Stem* and yet was also more articulated. *The Stem* achieved its large size by virtue of its extremely light balsa wood core. Mounting even a single additional motor along *The Stem's* length would have drastically increased its weight and reduced its motion capabilities severely. Therefore, for our next prototype, we chose to sacrifice scale for greater articulation and returned to the design concepts we experimented with during the development of *eMon*.

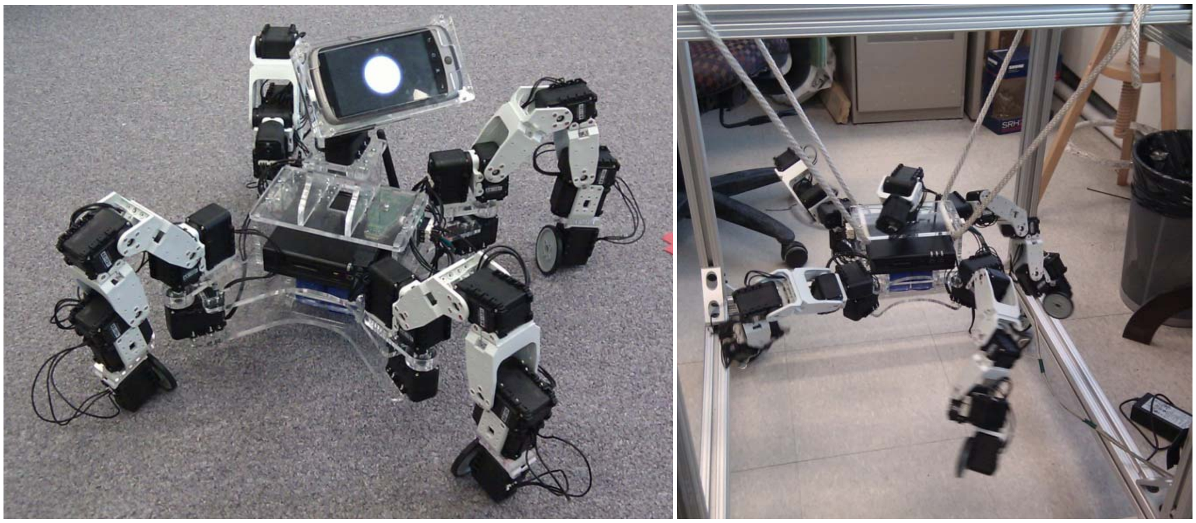


Figure 36 - Our "Strider" prototype (left) and its motion testing hardness (right)

Inspired by the fictional robot character “Tachikoma” (Kamiyama, 2002) this new, multi-legged design presented both new opportunities and new challenges. Nicknamed “Strider”, our new prototype no longer needed to be a fixed component of the student centre’s architecture. Equipped with wheels on its “feet”, *Strider* could freely travel amongst the food court visitors and roll along the many table tops.

Borrowing from our *eMon* design, the *Strider* robot was also equipped with an articulated smart phone “head”. This was added to provide a familiar focal point for observers, to suggest “gaze”, and to provide the robot some structural context. That is, with a “head” situated atop a proportionally larger “body”, *Strider’s* four highly articulated appendages were meant to be clearly interpreted as “legs” or “arms”. We felt that these visual affordances would push the Mac Hall Monster design even further along the “visual familiarity” spectrum, while it’s unique configuration and physical materials (e.g. glass, plastic, and wires) would ensure its immediate appearance remained clearly robotic.

With 31 degrees of freedom that allowed it to move its head, walk, roll, and shift its body position, we considered *Strider* our most visually zoomorphic and most physically expressive robot prototype. During early tests, *Strider’s* “wheel/feet” also proved very promising: allowing the robot to combine both rolling and walking motions as if wearing powered roller-skates.

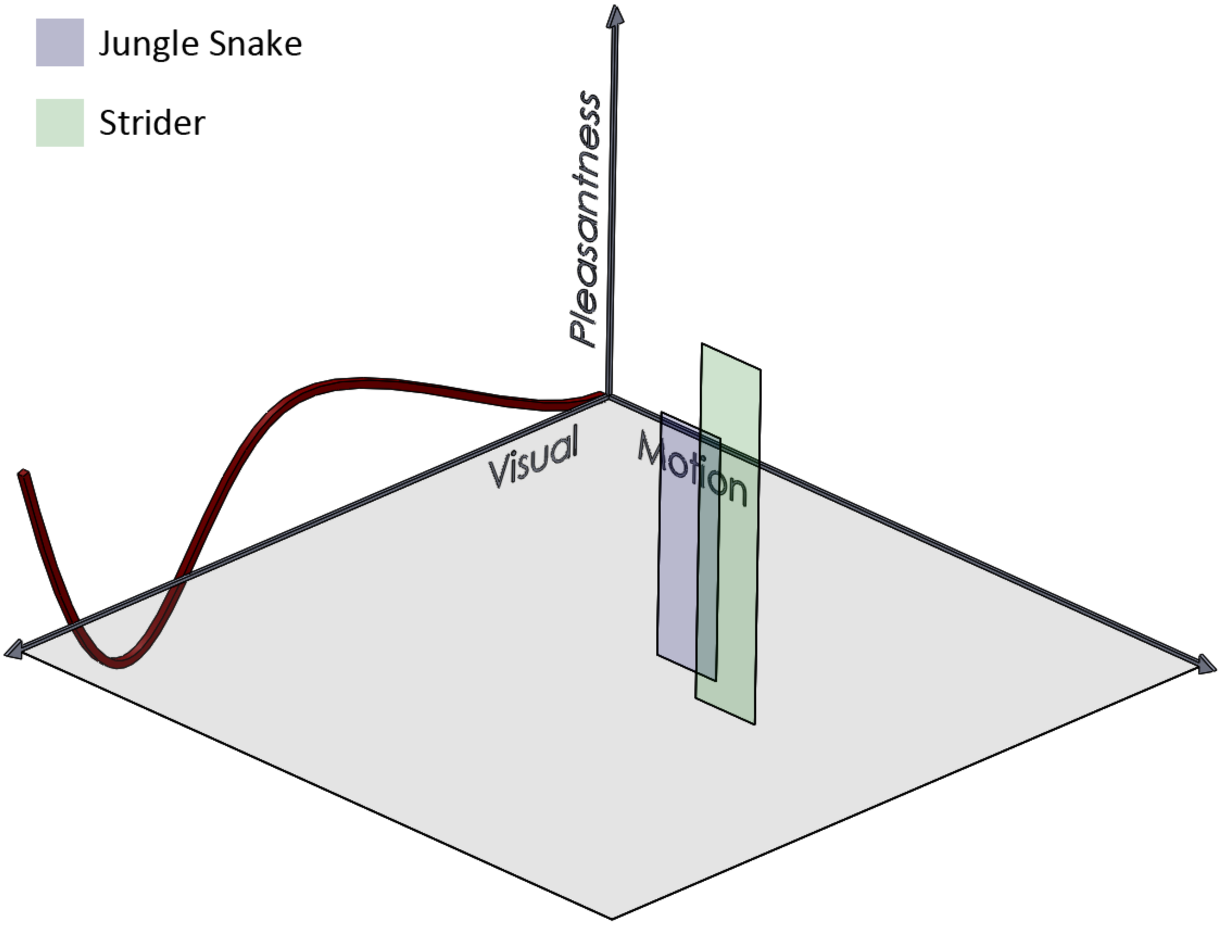


Figure 37 - Our conceptual impression of the *Strider* prototype design (green) with the failed *Jungle Snake* design concept in blue.

This prototype's nickname would prove to be something of an unfortunate irony however. Given *Strider's* many highly-articulated legs, early design critiques likened the prototype to a "strange sort of hybrid robo-spider". The robot was both something vaguely familiar and yet entirely alien. Many observers expected the robot to start walking around on its legs or even jumping from place to place; up and down on furniture. After much testing however, the available servo motors proved too weak once again and any attempts to have *Strider* walk quickly resulted in overloading torques on the robot's shoulder joints. This would cause the robot to collapse and constantly require hardware resets. Despite *Strider's* excellent range of *emotive motion* capabilities, we would require a much more reliable exploratory robot platform if we were to be able to conduct a field study for any significant length of time.

7.2.3 "Calamaro"

It was decided that *Strider's* most interesting feature, it's legs, were also the primary source of all that prototype's problems and, after much deliberation, the legs were replaced with much simpler wheels. The numerous leftover motors originally used for *Strider's* four sets of shoulders, knees and ankles, were converted into a set of eight 'arms' and arranged around the perimeter of the robot's base. Like the original *Stem's* base joint, these eight arms were "spherical joints" that allowed each individual arm to yaw, pitch, and roll around a single base point.

After heavy modification from our original vision, we had arrived at our highly articulated and highly reliable *"Calamaro"* robot prototype ("Calamaro" being the singular of the Italian word "calamari"; a food recipe involving squid). In line with our original design goal, this robot's visual appearance was vaguely animalistic (e.g. an octopus) while still being heavily robotic. (Figure 38)

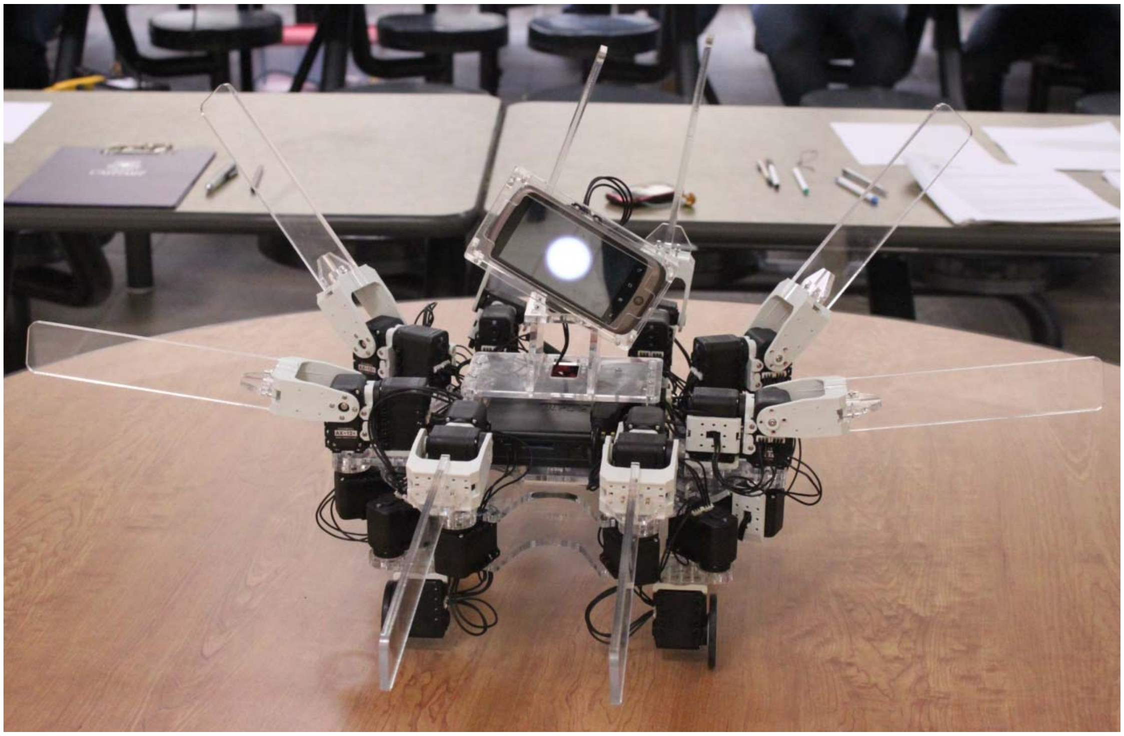


Figure 38 - The *Calamaro* prototype with its eight highly articulated arms

7.2.4 Motions Sequences and Styles

For the study, *Calamaro* was programmed to perform a set of 5 motion sequences using a combination of 3 different styles. In between each motion, the robot would return to a neutral position where its head was facing forward and all of its arms were evenly spaced around it, level, and pointing outwards like the spokes of a wheel. We attempt to describe each motion as clearly as is possible in text as follows:

1. **Simple Breathing** – *Calamaro's* arms would begin laid out flat in an evenly spaced circle around its body. They would then rise to +25°, fall to -25°, and then return to level. At the same time, the robot's head would rise and fall slightly. The desired impression was that *Calamaro* was taking a deep breath and then exhaling slowly.
2. **Defensive Cage** – The robot would look once from side to side, roll backwards, and then raise its arms around itself; turning them about their axis so as to form a defensive wall around the perimeter of its head and body. Once "caged", *Calamaro* would look around again before lowering its defensive wall and returning to its neutral position. The

desired impression was that *Calamaro* was guarding itself against some threat in front of it; as a boxer raises their hands to block incoming punches.

3. **Table Tap** – First, the robot would align all of its arms so that those four arms on its left side pointed directly left, all parallel, and the four arms on its right pointed directly to its right, also all parallel. It would then look over and down to its right and tap the table with its right arms and then return the arms to level. It would then repeat this tapping motion on its left side and then return to the neutral position. The desired impression was that *Calamaro* was "checking" the feel/sound of the table next to it.
4. **Ebb and Flow** – Similar to "Table Tap", but more closely resembling a smooth dancing manoeuvre. Without aligning its arms, *Calamaro* would roll sideways to the right while lowering its right arms and raising its left arms. Its head would roll into the slide and briefly dip down. It would then repeat this move to the left; lowering its left arms, raising its right, and dipping its head down and to the left before returning to its neutral position. The desired impression was that *Calamaro* was suavely sliding from side to side, as if dancing.
5. **Prairie Chicken** – *Calamaro* arranges is four rear arms like the tail feathers of a turkey or peacock; sticking straight up into the air behind the robot's head. The remaining four front arms (two pairs of two) are arranged like "wings" to the front and sides of its body. The robot then rolls forward while rocking all of its arms side to side repeatedly before retreating. The desired impression was that *Calamaro* was presenting an aggressive display and challenging its observers in front of it; much as a real bird might try to intimidate an opponent and scare it away.

Unlike *The Stem*, the content of *Calamaro's* motion patterns was not the primary focus of this study. Instead, we designed our experiment to study three different "styles" under which these motions would be performed. Each "style" had two attributes which were systematically combined in a 2 x 2 x 2 schema of conditions. Each motion sequence was scripted in such a way that there was only one sequence of steps for each and it was the combination of the different style conditions that would dictate how those steps were interpreted.

These styles are described as followed:

A. **Fast or Slow** – A given sequence of motion steps would be interpreted and performed either quickly or more slowly. Each condition was just as smooth as the other, with only the time taken for each step being elongated or shortened.

B. **Sequential ("Mechanical") or Simultaneous ("Organic")** – *Calamaro's* motion sequences consisted of discreet gestures. In the Sequential condition, these individual gestures would be performed separately, one after the other. (E.g. Raise arms, *then* turn head, and *then* roll forward.) In the Simultaneous condition, all of the distinct gestures would be performed at the same time. (E.g. Raise arms *while* turning head *and* rolling forward.) This style distinction also extended to individual gestures involving multiple motor axes working in unison and was especially evident with arm gestures. (E.g. either each of the eight arm motors would move one after the other until all of the arms were "raised" or the would all rise at the same time.)

C. **Repeating or Non-Repeating** – In the Repeating condition, once a complete motion sequence was finished, *Calamaro* would perform the same motion again and again. (E.g. Breathing, breathing, breathing...) In the Non-Repeating condition, *Calamaro* would randomly select a new motion each time. (E.g. Breathing, Defensive Cage, Prairie Chicken...)

Over the span of each study session, *Calamaro* was commanded to cycle between motion styles approximately every half hour. To ensure that participants generally viewed (and were subsequently interviewed about) only one type of motion style, the condition transition timing was flexible and the motion style was never changed while a participant was engaged with the robot. This resulted in some motion condition periods that lasting slightly longer than others. Over the course of all three study sessions, overall period of time that each motion style was performed was roughly equal however.

Calamaro's mechanical complexity was a compromise between our highly zoomorphic *eMon/Strider* designs and our more abstract *Stem/Jungle Snake* designs. Combined with a range of motion patterns and motion styles to explore, *Calamaro* would serve as an ideal vehicle for investigating *emotive motion* concepts in our public study. (Figure 39)

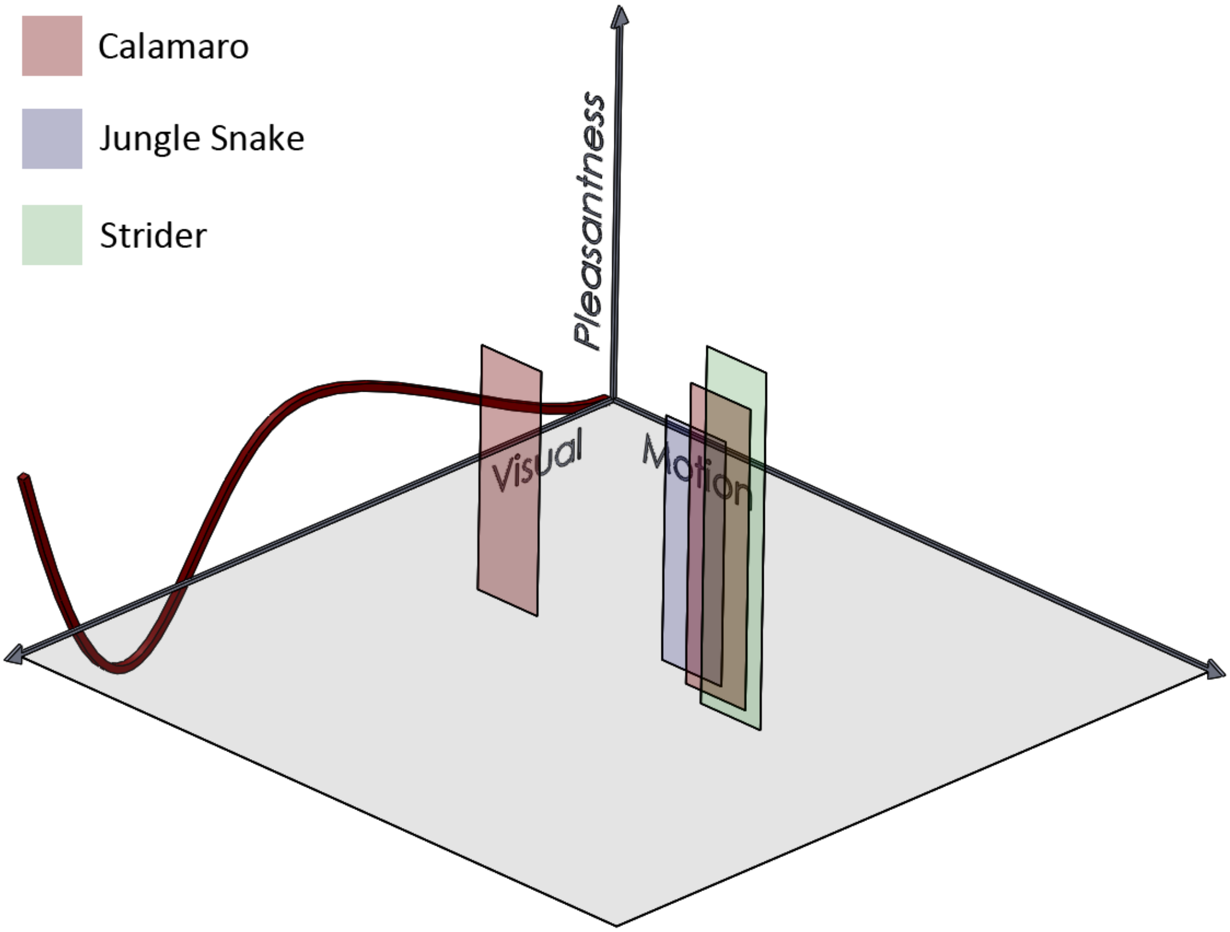


Figure 39 - *Calamaro's* visual form (red) compromised between our *Strider* (green) and *Jungle Snake* (blue) designs while its flexible motion capabilities offer two distinct areas of exploration.

7.2.5 Privacy and Ethical Constraints

One of our original goals in mounting the *Mac Hall Monster* study in a public setting was to maximize the serendipity of the encounters between the public and our robot. Over the course of negotiating with both the University of Calgary Conjoint Faculties Research Ethics Board (CFREB) and the Students' Union (owners and operators of the Mac Ewan Centre), we were required to make some compromises in terms of how we presented our robot to the public and how we recorded the resultant interactions.

Unfortunately, in order to take video recordings of our study space, the CFREB required us to display numerous large information posters describing how the area around the robot was under observation and advising those people who did not want to be filmed to avoid the area. This immediately dissolved any true sense of serendipity we might have hoped to obtain: rather than the robot being able to freely "roam" the various food court tables with the experimenters and video cameras nearby but cautiously hidden from sight, we would have to alter our experimental approach.

In addition, we were not allowed to (falsely) imply that our robot was fully autonomous. If specifically asked, we would be required to reveal that the robot was only semi-autonomous and was receiving occasionally control inputs from the experimenters via a wireless radio link. Given this "transparency" stipulation (and in light of our now mandatory information posters), we chose to abandon our "hidden experimenters" approach altogether.

7.3 Evaluation

Given the new constraints on our study design, we chose to maximize our ability to clearly record our participant's interaction by positioning our video and audio recording equipment front and center. We also chose to interview our participants during their interactions with the robot rather than relying only on video footage of their passing encounters.

7.3.1 Study Environment

The study was conducted in the food court area of the Mac Ewan Hall student centre in the heart of the University of Calgary campus (Figure 40). The *Calamaro* robot was placed in the center of a large, round, 150cm diameter wooden table. Attached to the front and mounted on stands to either side of the table were three large information posters describing that a research study was being conducted and that the study area was being recorded via both video and audio. Behind the table, a video camera was mounted on a large tripod so as to film the entire study space.

Figure 40 - An overview of the study area from the perspective of a passing observer in the Mac Hall food court. *Calamaro* performs its motions on a large wooden table (front center), flanked by large information posters, a video camera on tripod (rear center), interviewer (left center, solid black shirt), and survey administrator (left rear, striped shirt).

7.3.2 Methodology

Two experimenters were present with handheld audio recorders to interview passing visitors who expressed interest in the robot. In order to maintain some element of serendipity, these interviewers specifically avoided soliciting interest in the study and did not actively approach any passersby. If however someone chose to stop and examine the robot or speak with the interviewers, these people were then approached and questioned about their thoughts and impression of *Calamaro.* These people were classified as Category 1 participants.

Generally the participants would immediately begin a dialog with the interviewer. Otherwise, the interviewers would eventually prompt these participants with open-ended questions such as “What do you think of the robot?”, “What do you think it’s doing?”, or “Why do you think it is doing that?” The interviewers would then ask more focused questions such as

"What can you say about the way the robot is moving?" or "Do the robot's motions remind you of anything?"

When answering questions posed by the participants, interviewers would attempt to avoid biasing the participants; often by reflecting the participant's inquiries back at them. For example, if a participant asked "What is the robot for?" the interviewer would respond with "What do *you* think it's for?" Depending on how persistent a participant would be with their inquiries, interviewers would eventually defer to email addresses displayed on the information posters and assure the participant that their detailed questions could be answered at a later time. The purpose of this was to avoid revealing the purpose of the study to the general population. We wanted to avoid having new participants arrive, having been briefed by their friends, with a pre-conceived focus on the robot's motions; further destroying any illusion of serendipity.

It should be noted that, in respect for the privacy of the public patrons of the Mac Ewan Center, we were also required to blur all faces and identifying features of people in our collected photo, video, and audio recordings; including Category 1 participants. This "anonymization" of our footage was explicitly stated on our information posters.

After being interviewed, the Category 1 participants were invited to fill out an additional questionnaire that asked more specific questions about their emotional interpretation of the robot and its motions. These survey sheets also included a section asking the participants for consent to a) analyze their survey results and/or b) use their *un-blurred* recorded video footage for academic publications. If these people chose to fill out a questionnaire sheet, they were then classified as Category 2 participants and were led to one of the nearby cafeteria seats where one of the experimenters would explain and administer the survey.

7.3.3 Survey Questions

Having had an opportunity to observe and interact with *Calamaro,* Category 2 participants were presented with a single page of 23 Likert-scale style questions. Similar in nature to the questionnaire used during the *Stem* studies, the participants were asked to rate how applicable they felt different pairs of emotionally descriptive adjectives were to the robot and its motions.

Rather than create our own sets of adjective pairs as we had for the *Stem* study, for the *Calamaro* study we chose to employ the “Godspeed Questionnaire Series” which was recently developed by a team of prominent social HRI researchers (Bartneck, Kulic, Croft, & Zoghbi, 2009) (but of which we had previously been unaware). The Godspeed questionnaires were developed with the intention of providing a common set of measures for related social HRI phenomena that were being studied by numerous different researchers but that lacked a reliable means of comparing results. The Godspeed Questionnaires measured concepts such as anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots; all of which are concepts strongly related to *emotive motion* and its impact on social human-robot interaction.

Incidentally, some of the adjective pairs recommended in the Godspeed Questionnaires are the same (or close variation) as those used in our earlier *Stem* study. However, because Bartneck et. al. synthesized the Godspeed survey from a larger body of related works and experiments, they were able to better gauge the reliability and validity of their specific adjective pairs.

The Godspeed Questionnaire Series is broken down into the following categories:

1. Anthropomorphism
    a. Fake – Natural
    b. Machinelike – Humanlike
    c. Unconscious – Conscious
    d. Artificial – Lifelike
    e. Moving rigidly – Moving elegantly
2. Animacy
    a. Dead – Alive
    b. Stagnant – Lively
    c. Mechanical – Organic

  - d. Artificial – Lifelike (**repeated)*
  - e. Inert – Interactive
  - f. Apathetic – Responsive

3. Likeability
   - a. Dislike – Like
   - b. Unfriendly – Friendly
   - c. Unkind – Kind
   - d. Unpleasant – Pleasant
   - e. Awful – Nice
4. Perceived Intelligence
   - a. Incompetent – Competent
   - b. Ignorant – Knowledgeable
   - c. Irresponsible – Responsible
   - d. Unintelligent – Intelligent
   - e. Foolish – Sensible
5. Perceived Safety
   - a. Anxious – Relaxed
   - b. Agitated – Calm
   - c. Quiescent – Surprised

We presented each adjective pair as a 5-point spectrum, with “neutral” in the center. In order to avoid biasing the participants into assuming higher numeric values were associated with more positive responses (or negative values with negative responses), a symmetric graphical scale was used where the size of the mark was associated with how strongly they felt a particular word applied.

E.g.

	Extremely	Somewhat	Neutral	Somewhat	Extremely	
Unpleasant	0	0	0	0	0	Pleasant

Our survey removed the duplicate word pair (Artificial-Lifelike) and did not display category titles. Because of the wide variety of adjective types, we did not introduce any additional "dummy questions" (usually used to help mask the focus of the survey and avoid biasing participants answers based on the experimenter's perceived intention). For each participant, the order of each individual adjective pair was randomized (e.g. Alive-Dead and Dead-Alive), as was the ordering of all 23 adjective pairs within the list (e.g. the order of the first, second, third, word pairs would different randomly between participants.)

Having completed the questionnaire, Category 2 participants were thanked and then allowed to depart.

7.4 Results

The *Calamaro* study was conducted over the course of three sessions on separate days. Each session lasted from 11AM in the morning until 3PM in the afternoon; covering the high-traffic lunch hours of each day for a net total of 12 hours. Over the course of these three study sessions, hundreds of people observed *Calamaro* from afar; either watching it while walking through the Mac Hall food court or while sitting and eating. Of these, many dozens of people stopped to closely inspect the robot and talk with the experimenters about the study (Category 1). Of these, a total of 88 participants (70 male, 18 female) completed our written survey (Category 2). The average age of our Category 2 participants was 24.59 (standard deviation of 7.42).

Figure 41 - Small crowds gathered to observe *Calamaro* while passersby notice the robot from the background.

Part of the written survey asked participants to describe their professional or academic background. We grouped their responses into four major categories: robotics oriented (e.g. mechanical/electrical engineering, computer science), technical but non-robotics oriented (e.g. chemistry, astronomy), non-technical but creative (e.g. artists, musicians, teachers), and non-technical non-creative (e.g. secretary, plumber). (Figure 42)

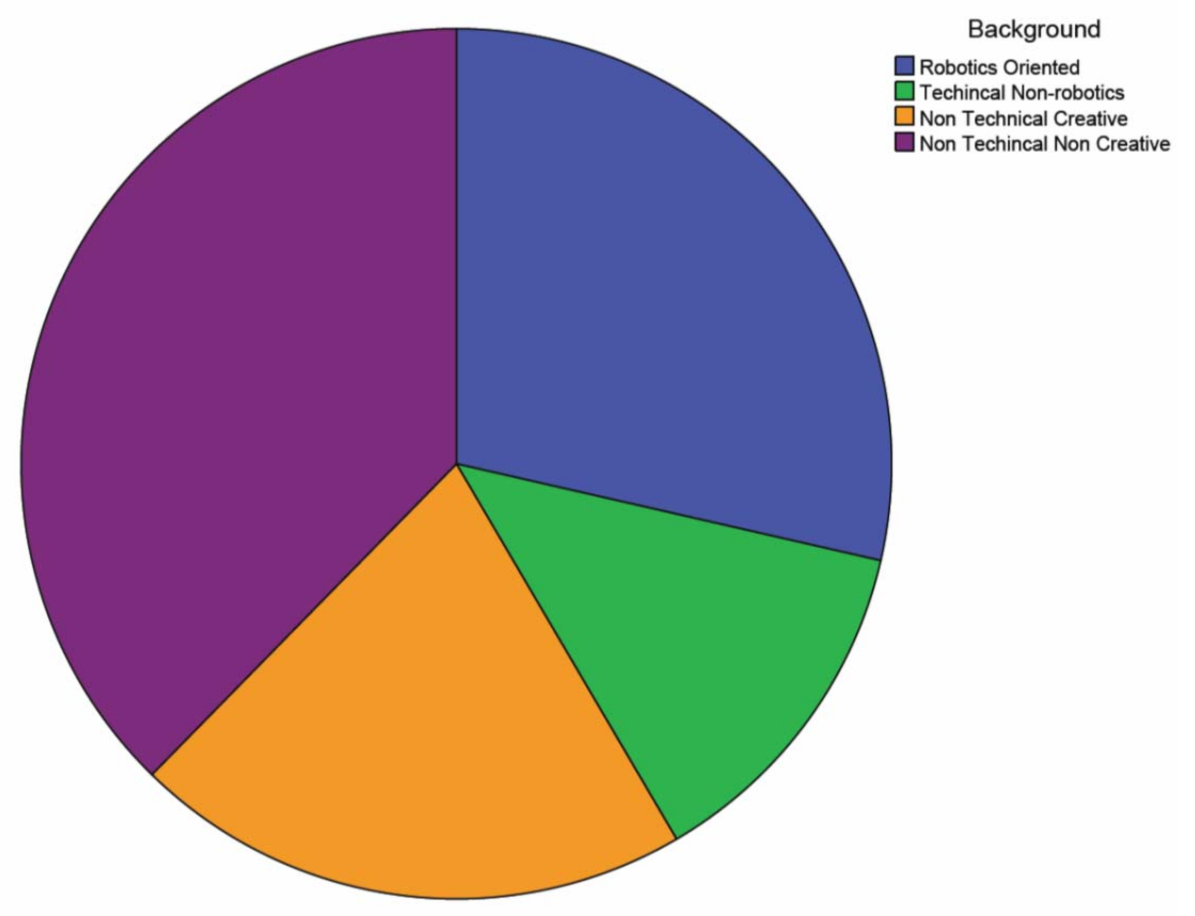


Figure 42 - A proportional breakdown of the survey participants' professional/academic backgrounds

7.4.1 Quantitative Results

We performed an analysis of variance (ANOVA) on our collected survey data and found multiple main effects and 2-way interactions between our movements style conditions. We chose to run a factorial analysis of variance (ANOVA) because we were interested in seeing in comparing the different conditions (movement, speed and repetition). Given the purpose of the study and the collected data, we felt the factorial ANOVA was the most appropriate analysis. A covariance analysis was not conducted as there were no significant correlations found between the data and the demographic data we collected.

We present these results here and discuss some of their possible implications in the next section.

7.4.1.1 Main Effects

1) Comparing the simultaneous (organic) condition to the sequential (mechanical) condition, the following main effects were observed:
    a) Participants rated the robot as significantly **more natural under the organic movement type condition** (*M* = 3.26) than under the mechanical movement type condition (*M* = 2.59) averaged over speed and repetition. *F*(88) = 4.95, *p* = .029.
    b) Participants rated the robot as significantly **more organic under the organic movement type condition** (*M* = 2.50) than under the mechanical movement type condition (*M* = 1.83) averaged over speed and repetition. *F*(88) = 5.41, *p* = .023
    c) Participants rated the robot as significantly **more interactive under the organic movement type condition** (*M* = 3.16) than under the mechanical movement type condition (*M* = 2.95) averaged over speed and repetition. *F*(88) = 5.25, *p* = .025
    d) Participants rated the robot as significantly **more kind under the organic movement type condition** (*M* = 3.82) than under the mechanical movement type condition (*M* = 3.33) averaged over speed and repetition. *F*(88) = 4.43, *p* = .039

2) Comparing the repeating condition to the non-repeating condition, the following main effects were observed:
    a) Participants rated the robot as significantly **more relaxed with repetition** (*M* = 3.80) than without repetition (*M* = 3.08) averaged over speed and movement type. *F*(88) = 4.46, *p* = .038
    b) Participants rated the robot as significantly **more calm with repetition** (*M* = 4.12) than without repetition (*M* = 2.82) averaged over speed and movement type. *F*(88) = 22.52, *p* = .000

7.4.1.2 Two-way Interactions

3) There were two-way interactions between movement style and repetition:
    a) For the fake/natural word pair, participants rated the robot as **more fake under the mechanical movement** type condition (*M* = 2.50) than the organic movement type condition (*M* = 3.79) **when there was no repetition**, *t* = 4.47, *p* = .026. There was **no significant difference in ratings found when there was repetition** between the mechanical movement type (*M* = 2.67) and organic movement type (*M* = 2.72) conditions.
    b) For the mechanical/organic word pair, participants rated the robot as **more mechanical under the mechanical movement** type condition (*M* = 1.53) than the organic movement type condition (*M* = 2.67) **when there was no repetition**, *t* = 4.10, *p* = .002. There was **no significant difference in ratings found when there was repetition** between the mechanical movement type (*M* = 2.13) and the organic movement type (*M* = 2.33).
    c) For the unfriendly/friendly word pair, participants rated the robot as **less friendly under the mechanical movement** type condition (*M* = 3.63) than the organic movement type

condition (*M* = 4.22) **when there was no repetition**, *t* = 2.15. The effect of movement type was not the same for all levels of repetition as with repetition, the participants rated the robot as more friendly under the mechanical movement type condition (*M* = 4.19) than the organic movement type condition (*M* = 3.61).

   d) For the anxious/relaxed word pair, participants rated the robot as **more relaxed when repeating under the mechanical condition** (*M* = 4.27) than when not repeating under the mechanical condition (*M* =2.75), *t* = 4.40, *p* = .001. There was **no significant difference found in ratings under the organic movement type condition** with repetition (*M* = 3.33) or without repetition (*M* = 3.41).

4) There were two-way interactions between speed and movement style:
   a) For the mechanical/organic word pair, participants rated the robot as **more mechanical under the mechanical movement** type condition (*M* = 1.56) than under the organic movement type condition (*M* = 2.83) **when the speed was slow**, *t* = 3.90, *p* = .001. There was **no significant difference** in ratings found between the mechanical movement type (*M* = 2.10) and organic movement type (*M* = 2.17) **when the speed was fast**.
   b) For the foolish/sensible word pair, participants rated the robot as **more foolish under the mechanical movement type condition** (*M* = 3.08) than under the organic movement type condition (*M* = 4.39) **when the speed was slow**, *t* = 4.35, *p* = .002. There was **no significant difference** in ratings found between the mechanical movement type (*M* = 3.42) and organic movement type (*M* = 3.03) **when the speed was fast**.

5) There were two-way interactions between speed and repetition:
   a) For the ignorant/knowledgeable word pair, participants rated the robot as **more ignorant with repetition** (*M* = 2.78) than without repetition (*M* = 3.62) **when the speed was slow**, *t* = 2.76, *p* = .042. There was **no significant difference** in ratings found between the with repetition condition (*M*= 3.67) and the no repetition condition (*M* = 2.82) **when the speed was fast**.
   b) For the agitated/calm word pair, participants rated the robot as **more agitated with repetition** (*M* = 4.50) than with no repetition (*M* = 2.11) **when the speed was fast**, *t* = 7.52, *p* = .000. There **was no significant difference** in ratings found between the repetition condition (*M* = 3.75) and no repetition condition (*M* = 3.53) **when the speed was slow**.

Figure 43 - A participant reaches towards the robot while *Calamaro* performs its "defensive cage" motion pattern

7.4.2 Qualitative Results

Over the course of the three separate sessions of the *Calamaro* study, a number of interesting interaction themes emerged. These are summarized as follows:

7.4.2.1 *A Sense of Entitlement*

An unforeseen consequence of this new study environment was a distinct “sense of entitlement” from many of the passersby. Often the very first question the experimenters received from many people was “Ok, so what’s this about?”, “What’s the story here?”, or “Ok, give me the spiel. What’s going on?” followed by the participant crossing their arms and waiting for an explanation. Unlike a more classical ethnographic field study (where the experimenters are almost completely hidden and attempt to never interfere with the population they are studying), our study was designed (and our ethics clearance necessitated) that the experimenters be present and visible at all times during each session. Together with the large, highly visible information posters, this turned the Mac Hall Monster experiment into more of a "kiosk" or "information booth at a convention" experience than a "natural encounter with a robot in the wild"-style experience.

7.4.2.2 Hands-on Interaction

While we felt a true "robot in the wild" experiment would be even more interesting, we learned over the course of preparing and mounting our modified *Calamaro* study that it would also take a tremendous amount of preparation and safety precautions (for both the participants and the robot) that we do not think would have been feasible given the resources available to us, in retrospect. *Calamaro* is a relatively fragile robot and, even with the experimenters present, the robot often came close to being man-handled and physically abused by the public participants to the point of being broken and needing to be repaired.

It appeared that these hands-on participants were generally interested in testing *Calamaro's* strength out of a natural sense of curiosity; similar to some of the participants than handled *The Stem.*

On one hand, it is highly unlikely that the current *Calamaro* prototype would not have survived for very long if participants were allowed free-reign of their physical interaction with it. This is primarily because the available motors and control programming did not account for extreme motor loads. *Calamaro* simply interpreted its motion scripts and performed its movements unthinkingly. If one of *Calamaro's* motors were to become obstructed, it would continue to push against the obstacle until either the blockage was removed or the motor overloaded and shut down. While rare, the nearby experimenters worked to avoid this scenario by asking particularly hands-on participants to treat the robot more gently and discouraged aggressive handling.

On the other hand, we find it interesting that so many participants at least *asked* if they could touch and interact with *Calamaro.* Despite its unfamiliar appearance, unknown purpose, and often rapidly moving appendages, relatively few people appeared to be afraid of the robot.

Instead, most participants seemed more to be intrigued, curious, or entertained by *Calamaro* and hence their desire to see just how closely they could interact with it.

We feel this level of comfort arose out of two possible factors: 1) The “information booth” appearance of the study area; complete with waiting “information attendants” (e.g. the nearby experimenters with microphones). 2) The small, pet-like size of the robot, its lack of physically intimidating presence, and its relatively slow locomotion speed. One could easily “escape” from the robot, if necessary, so people may have felt bolder in approaching it than they might have if the robot was more agile or had the same physical presence as *The Stem*.

7.4.2.3 The Affect of Background Training

As we had seen with *The Stem*, the academic or professional background of a participant often greatly affected the tone of their interview responses. Technically oriented individuals, particularly those with engineering backgrounds or work involving robotics, approached *Calamaro* by comparing it to their own work or analysing its construction. E.g. “So what did you use for the controller?”, “How powerful are the motors?”, “If it doesn’t have any sensors, then it’s just a toy.”

Alternatively, there were numerous non-technically oriented participants for whom *Calamaro* was an entertaining curiosity. These participants were more likely to ask about the robot’s name, refer to it as “Calamaro” or “he” as opposed to “it”, and generally treated is as something with character rather than just as a machine. These participant’s inquiries were more often directed towards the nature of the study and the experimenters’ motivations.

7.4.2.4 Public vs. Private Reflection

There was a distinct difference in the atmosphere of the *Calamaro* study when compared to our earlier *Stem* study. Much of this can be attributed to the obvious difference between the study environments (darkened private laboratory vs. bustling public cafeteria) but we found the resultant differences to be instructive when considering future study designs.

First and foremost, we felt that the quality of internally reflective comments from *Calamaro* participants was significantly reduced. When asked their impressions of the robot participants were generally quick to respond, as if being quizzed for a known answer, rather than pausing to reflect and present their own well-formed reflections. Part of this might be attributable to the high-pace nature of the Mac Hall food court: people are either there to study, eat or are passing through on their way to a different destination. Our most reflective Category 1 participants were those who specifically said that they had been observing our study from afar while finish their meals and made a conscious effort to investigate more thoroughly.

Some of the most popular comments from all of our participants were variations on “That’s cool!” or “That’s impressive!”; commenting on the robot and the study itself rather than their thoughts on the specific qualities of the robot’s motions or visual characteristics. That *any robot at all* was moving and gesturing in the middle of the Mac Ewan Centre food court was more noteworthy and more unexpected than details about the robot itself or its motions.

Figure 44 - A participant reaches out to interact with *Calamaro*

7.4.2.5 Group Reflection

Unique to the *Calamaro* study was the possibility for participants to reflect as a group. A number of groups (e.g. sports teams, groups of colleagues out for lunch, student club members, conference attendees, etc.) stopped to observe the robot and were subsequently interviewed as a whole. Individual comments would be proposed, reiterated, added-to, or countered by other members of the collective. Often this would lead to the formation of consensus (E.g. “Yeah, you’re right... it does kind of look like an octopus.”). We question whether this also had the effect of suppressing some of the less popular or more esoteric responses.

In other cases, in particular a group of robotic engineers and their non-engineer friend, this group deliberation led to subtle conflict: A set of engineering graduate students that were working on a search and rescue robot for the University of Calgary were particularly critical of *Calamaro.* They immediately regarded the robot as a machine with no intelligence or emotive impact and, once they recognized the relative simplicity of the robot’s mechanics and control technology, were visibly unimpressed with *Calamaro’s* technical aspects as well.

However, a single non-engineering-oriented member of the group who claimed to have no understanding of how either *Calamaro* or the search and rescue robot worked clearly expressed a dissenting opinion and drew laughs and mild indignation from his friends. This participant then went on to describe that, because *Calamaro* actually “worked” (e.g. continued to move and perform without outside intervention for dozens of minutes at a time, despite his not having been told what the robot’s “purpose” was), he was far more impressed with our robot than his companions’ more advanced, more capable, and more expensive platform that constantly suffered from technical problems which prevented it from consistently “working”.

“Reliability” was a characteristic that we had so far not considered in our experiment designs. Similar statements were also made by other participants with technically-oriented backgrounds. They complimentied us on how well *Calamaro* appeared to be functioning and expressed exasperation over how difficult it often was to keep robot prototypes in good working order; especially when operating “in the field”.

7.5 Discussion

One of the main motivations for mounting the *Calamaro* study in a public space was to create a specific counterpoint to the extremely abstract and Zen-like nature of the *Stem* experiment. Although participants shared many interesting stories and comments while interacting with *The Stem*, we worried if part of this had to do with their near total lack of instruction, that the study was too freeform, or that the participants were just making their comments up so as to satisfy the experimenter (and not waste the hour of their time that they'd committed to participating). By running a similar study in a public space, people that were not interested in sharing their thoughts now had the option of continuing to walk by and not participating at all. Running *Calamaro* as a field study was an attempt to bring some "real world legitimacy" to our abstract motion explorations.

Although we encountered unexpected challenges in terms of how we were able to mount our study and publicly portray our robot, we gained important insights into both different *emotive motion* characteristics, the differences between conducting controlled laboratory studies and experiments "in the wild", and how that difference in setting affects emotional interpretations of social robots.

7.6 Impact on Emotive Motion

The statistical analysis of our *Calamaro* survey results reinforced some of the themes we first uncovered during our study with *The Stem.* The impression of "boredom" we perceived during the more repetitious segments of the *Stem* studies was reflected in *Calamaro's* direct exploration of that motion style as being more calm and more relaxed. Regardless of the complexity or duration of a robot's motion pattern, once an observer has perceived it to have fallen into a predictable pattern, a sense of expectedness and calm arises.

Robot motion that is smoother and more complex (e.g. simultaneous coordination of multiple appendages) was generally interpreted as more natural, more organic, more interactive, more friendly, more intelligent, more calm, and more kind; all of which can be viewed as beneficial traits when attempting to design pleasant social interactions between humans and social robotic agents. In contrast, “typical” robotic motion (e.g. jerky, linear, rigid, sequential, and repetitious) may be failing to take advantage of the expressive power of *emotive motion.*

We view these themes as our most important experimental results: The quality and style of a robot’s motions, regardless of that robot’s purpose or visual form, carried with it important emotional weight and should be a deliberate focus when designing social human-robot interaction scenarios.

7.7 Impact on Social HRI Study Design

In contrast to the Zen-like experience of the *Stem* studies, our *Calamaro* study in the heart of the Mac Ewan Center lunch rush was significantly less personal and less reflective, but was also more “real” and more instructive what future robotic technology will need to be capable of handling. Social HRI researchers must be prepared for the practical challenges of bringing their robot prototypes out of the safety of the lab and into the unpredictable chaos of public spaces.

Most current robots are relatively fragile and largely helpless devices which require constant supervision and regular maintenance. However, if social robots are to become the ubiquitous, daily experience that many envision they will become, then they must be capable of dealing with overzealous humans (and potentially overt vandalism), mechanical failure, complex and dynamic public environments, and many other challenges.

Even in the semi-controlled scenario of an academic field study, researchers must be aware of the unique social interactions (e.g. group consensus, time pressures, public expectations) that are simply not possible to emulate in a laboratory setting.

7.8 Summary

In this chapter we discussed the development of our *Calamaro* robot prototype and the field study we conducted using it in the Mac Ewan Centre. The study’s results reinforced some of the same themes we first observed during our *Stem* user study as well as revealed some of the unique influences and challenges inherent with public social HRI.

In the follow chapters, we conclude this thesis; reflecting on our complete body of work and what we feel is one of the first in-depth investigations of the role of *emotive motion* in social HRI. We discuss our specific contributions and discuss further work which we hope to pursue in future.

8 Future Work and Alternative Areas of Exploration

Our initial investigations into the expressive capabilities of *emotive motion*, while we feel possesses significant breadth of exploration as well as depth of focus, remains far from exhaustive. Motion is just one design axis among many (e.g. visual form, working context, personal familiarity, academic/profession background, etc.). and was have already seen how this multitude of conceptual dimensions can contribute and interact to form subtle, complex social experiences.

We have only just begun to chart this tremendous multi-dimensional complexity and we discuss some of these new avenues of exploration in the following subsections.

8.1 Short Term

1) *A thorough, grounded-theory analysis of the Calamaro study video data:* Unlike the extremely expressive footage from the interactive *Stem* scenario (where participants were dancing, fighting, playing, etc.), essentially all of the *Calamaro* interactions were visibly more mundane; consisting mainly of spoken comments and the written survey results (which we have quantitatively analyzed.) Despite this, we would like to go back and perform a more thorough review of the *Calamaro* video footage so that we might perhaps uncover some more interesting, if subtle, trends.
2) *Swap evaluation methodologies for The Stem and Calamaro: Calamaro* and *The Stem* explore very different extremes of our "visual familiarity" axis (e.g. strong zoomorphism and extreme visual abstract, respectively). At the same time, their experimental methodologies excel at revealing different types of results (e.g. our Zen-like approach promotes deep personal reflection, while our field study approach generalizes better to real-world public scenarios and affords group interaction). We would be interested to see what sort of interactions might arise if the much larger, more abstract *Stem* were placed in the food court of the Mac Ewan center and the more recognizable, but smaller *Calamaro* were place in a darkened room with a lone study participant. Would participants be as reflective or open-minded when faced with the very "robotic"

Calamaro? Is the unexpected expressiveness of *The Stem* reliant on its uniquely reflective environment? Would either experiment uncover similar themes? And so on.

3) *A more locomotive Calamaro*: Although the robot had wheels, due to safety concerns about it accidentally rolling off the table, *Calamaro's* locomotion was extremely limited during our field study. Not only do we think a more mobile robot be more interesting (which the *Stem* was not, much to our participants' chagrin), but it would allow us to combine the elements of gesture (*Stem*) and locomotion (*Roomba*). In general, all of our robot prototypes were rooted in place or had relatively limited locomotion capabilities. Locomotion is an another entire aspect of motion that we did not really address in our current set of studies.
4) *An interactive Calamaro:* One of the most interesting parts of our studies was when participants were allowed to freely interact with the *Stem.* Although some participant still thought *Calamaro* was able to react to their presence and action, that robot never exhibited the true interactivity of *The Stem.* With its significantly more recognizable visual form, especially in a public setting, we think it would be immensely revealing (not to mention tremendously entertaining) to explore the role if interactivity in motion with the *Calamaro* platform.

8.2 Mid Term

1) *A more substantial eMon study*: Our explorations with *eMon* and the concept of Sustainable Interaction Design through *emotive motive* and social HRI were very limited. *eMon* also represents our only robot prototype with an specific application context beyond a direct exploration of *emotive motion*. Although it would require a significant and challenging longitudinal study, more thoroughly exploring *eMon's* potential would serve as an interesting "real-world" test bed of the power of *emotive motion.* Are the phenomena we witnessed limited only to abstract experimental scenarios? How does a person's emotional bond with a robot affect its expressive impact? Can *emotive motion* actually be used as a design tool to promote long-term behaviour change or will is only be perceived as a short-term (and eventually annoying) novelty?

8.3 Long Term

1) *Explore autonomous (e)motion*: The majority of our study conditions involved either pre-scripted animation sequences or relied on the Wizard-of-Oz technique for control. It would be a difficult challenge to program our robots to be autonomously (e)motive (e.g. an appropriate artificial intelligence), but I think that in attempting and working to overcome that challenge, we would learn quite a lot about other aspects of *emotive motion* such as the role of timing, context, interactivity and robot perception.
2) *Study correlation phenomena such as eMon's face effects*: During our informal design critique with eMon, we discovered that the emotional interpretation of his trademark "flapping" gesture would change dramatically based on what his facial graphic was showing. E.g. If his eyes were "happy", the flapping was an attention-grabbing expression of joy. If his eyes were "angry", his exact same flapping would be interpreted as frustration and condemnation.
3) Explore the impact of culture on *emotive motion:* In human-human interaction, cultural values can have a strong influence on how emotions, speech, and gestures are expressed and interpreted. For example, there can be heavy emphasis on social hierarchy, protocol, and communal well-being in Japanese culture (e.g. honourifics in language, a tradition of respect for elders) whereas North American culture is often viewed as more focused on individualism (e.g. "The American Dream", competition, and entrepreneurial spirit).

   Work by Wang et. al. (Wang, Rau, Evers, Robinson, & Hinds, 2010) has already shown that the impact of culture extends to Human-Robot Interaction as well. In their study, a highly expressive robot collaborator was seen as an energizing boon in one culture (United States) but that same robot was considered loud and obnoxious in a different culture (Chinese). We would like to investigate whether and how these cultural differences affect *emotive motion* specifically.

   For example: For those accepting of certain Shinto traditions, where the idea that all things have a spirit ("kami") which should be respected (e.g. rocks, trees, kettles, cars), the idea that a robot would have a "spirit" and could spontaneously move of its own volition might invite playful interaction and curiosity. Perhaps not coincidentally, robots have a long history of being portrayed as heroes in Japanese and East Asian culture (e.g. Doraemon, Astro Boy, Gundam). Conversely, many works of Western science-fiction focus on a terrifying "robot uprising" in the future (e.g. Terminator, 2001: A Space Odyssey, I Am Robot). As such, many Western people seem to react with caution and hesitation when encountering robots.

How then might these cultural differences affect the interpretation of *emotive motion*? Should a Western robot's motions be designed to be more predictable and docile? Should an Eastern robot express its "spirit" through joyous dance and playfulness?

4) Scary robots. The vast majority of social robots are designed for personal interaction. That is, they are polite, helpful, happy, and caring servants. Military robots, though violent in purpose, are usually clean and efficient; eschewing elaborate emotional/social interfaces in favour of robust, reliable efficiency. We think it would be interesting to explore an middle-ground between the two in the sense of "aggressive, unfriendly, and scary" robots. The idea here would be to deter people before having to get violent with them. E.g. A lumber jaguar-robot employed as a patrolling security guard. As a potential robber, am I more likely to think twice about my criminal plans if I see one of these things prowling around the grounds of my target factory? (This is sort of the "junkyard Rottweiler" effect.)

8.4 Alternate Areas of Exploration

We present this set of "alternate" areas of exploration separately because we feel that although they emerged as a result of our research into *emotive motion*, they are significantly divergent from that core concept as to warrant an entirely dedicated research effort of their own.

8.4.1 Exploration of Timing

Unsurprisingly, the majority of our participant in the *Stem* study, when asked if they felt the robot was reacting to them during the interactive phase, responded with "Yes, it definitely is."

A more subtle phenomenon sometimes occurred during the known "non-interactive" phases across all of our studies when participant initially tested for the various robot's reactivity: If the robot were to coincidentally change its motion pattern or otherwise alter its behaviour at just the same moment that, for example, the participant asked "I wonder if I do this…?" and waved their hand, they would also comment that they felt the robot was being reactive. In these cases, we begin to see the important role of *timing* with regards to the emotional interpretation of robots' motions.

Work such as Hoffman and Breazeal's robotic desk lamp (Hoffman & Breazeal, 2008) touches on the issue of *timing* in a very large grained manner: while performing a cooperative task, the robot help either completely pre-empts their human partner or is totally subordinate and follows behind. Dance partner robots(Kosuge, Hayashi, Hirata, & Tobiyama, 2003) touch on this concept in a more subtle way: where the robot allows itself to be "lead" by its human partner via gentle nudges, as would a human dance partner, reacting to these subtle inputs within milliseconds.

Timing clearly plays an important role when considering interactivity and reactivity. As these form some of the most interesting basis of human-robot interaction, a more in-depth exploration of timing would be prudent when considering future work in this area.

8.4.2 Developing Familiarity of Motion and Form

As the visual appearance of robotic entities becomes more detailed, complex, and potentially more "life-like", there will be more opportunities to directly leverage the tight coupling between what we, as humans, are familiar with in form with what we are familiar with in motion. E.g. a robot wishing to display ambient emotional cues could incorporate an expressive, dog-like tail specifically for that purpose.

However, the flexibility of design and the unique efficiencies of purpose-built robot forms also raise interesting questions and new possibilities. For example, Willow Garage's PR2 robot (Garage) employs cameras on its wrists to help achieve better visual acuity with the objects it attempts to grasps. That is, as it goes to reach for an object, it can achieve a better perspective on it from its hand than it can from its relatively distant and stationary “head”.

While this makes excellent functional sense, it may lead to interesting incongruence from the perspective of motion/visual familiarity: While functionally possible, does it make sense for the PR2 to “look around the room with its arm”? We imagine, upon first encountering such behaviour, the average human observer would be quite confused as to what the robot was attempting to do. (Perhaps it’s “eyes” are broken and it is attempting to feeling its way around in the dark?) That such a hand-camera-equipped robot was actually performing a searching task *more* efficiently than a “normal” animal might prove surprising at first.

Besides exploring this dissonance between familiar form and familiar motion, an immediate follow-up question arises: Would the odd sensation of this form/motion dissonance be quickly overcome once familiarity was achieved? If a human observer was already aware that a particular robot needed to “breath with its neck rather than its mouth” (a la fishes’ gills), both its form and its motion would be familiar and we wonder if the original “eerie” feeling would persist?

8.4.3 The Emergence of “Robot Whisperers”

After having expended significant effort individually authoring the (still very limited) set of motions for both the *Stem* and *Calamaro*, we begin to wonder what sorts of “practical” motion expressions might arise from these various robot platforms once they were given more legitimate tasks to perform.

Many human gestures develop as variations on actual, functional tasks. For example, saluting is said to have evolved from tipping one’s hat: soldier that wore heavy or strapped helmets that they could not easily remove began approximating the motion by just touching their hand to their temples. The expression of being tired or frustrated, where we slouch our shoulders forward and exhale sharply closely resembles actual human behaviour when overworked. We have come to recognize many of these expressions both over time and by virtue of their practical roots.

Is it possible then that a similar set of common robot gestures and expression might emerge over time even without those motions being explicitly designed or engineered? If a particular model of robot becomes popular for a given task, could those people trained to work alongside them not then become familiar with all of their behavioural quirks and their programming's unique "character"? Even if these robot gestures are not as obvious or explicit as a friendly human wave of the hand, is it possible that experts might become well versed in their subtleties?

We liken this concept to that of "horse whisperers": highly skilled horse trainers that have learned to recognize many of the subtle signals and expressions that horses perform (such as the position of their ears or a flick of their tail) which are largely unnoticed by novice observers, but otherwise allows these trainers to more easily understand the horses' behaviour/intent and thereby drastically expedite their training.

Much of the motivation for discovering more intuitive and natural ways for robots to communicate with humans is to help alleviate the difficulty of understanding each different robot's methods of operation and control. Even with the relatively simple Roomba robot vacuum clean, many people become confused when they must troubleshoot an atypical scenario (e.g. the robot's drive motor is broken or the vacuum as become clogged). Rather than require extensive training and a thorough understand of the Roomba's manual to understand its standard series of error beeps and LED flashes, one of the goals of HRI design is for an average person to be able to control and trouble-shoot a basic Roomba vacuum clean right out of the box by having the Roomba adopt *our* communications traditions (e.g. speech, gestures).

Assuming that not every robot need be fitted with a natural language interface and advanced artificial intelligence, could a level of natural expression akin to a dog not also be efficient? Just as a dog whimpers when sad or bounds around with its tail wagging furiously when happy, is there an intermediate (though still dog/robot specific) language of expression that could bridge this gap between human understanding and limited robot capabilities? We wonder if the practical limitations of robot expression/communication might then give rise to a new breed of "robot whisperers"?

8.4.4 On Mechanical Limitations

Throughout this thesis, there has been much discussion about the distinction between robots with machine-like/zoomorphic/anthropomorphic qualities and more human-like androids. In our introductory chapters, we observed that although current android have very lifelike visual appearances, their motion capabilities were not sophisticated enough such that their underlying movements had an adverse effect on how people interpreted them; making them feel uncomfortable once the androids began to move. Hardware limitations (e.g. underpowered servo motors) have also presented us with challenges when designing the robot prototypes discuss in the body of our thesis. Our *Jungle Snake* and *Strider* designs were even completely undermined for lack of sufficiently powerful motors. Both problems stem from the current limited capabilities of robot hardware.

Unlike the exponential rate of increase in raw processing power that has propelled the advancement of digital computing technology over the past half-century, robot-specific hardware (e.g. motors, sensors, and battery technology) has been advancing at a markedly slower pace. Current robots are heavy, slow, move jerkily, and require recharging only after a few hours. Although some more exotic forms of actuation exist (e.g. electro-active polymers, air muscles) they are often only useful in very specific use cases and their operating characteristics still do not compete with basic electromagnetic rotary motors.

Although our work demonstrates that more fluid and complex motion is often more expressive and preferred by participants over rigid, jerky, “mechanical” motion, our most “organic” robot motions still fall far short of true, life-like smoothness and subtlety. Current robot hardware is simply not capable of matching the same range of speed, power, subtlety, quiet, and light-weight efficiency of animal motion in nature.

In future, as more advanced robotic actuators are developed (e.g. robust artificial muscle tissues), we predict that the impact of *emotive motion* and its use as a design tool in social HRI will grow even more important.

9 Conclusion

In this thesis we have presented our exploration of the concept of *emotive motion* in the context of social Human-Robot Interaction. We feel that the expressive qualities of a robot's motions are a powerful design tool for social HRI researchers and should be given a similar degree of consideration as the robot's visual form or functional context. We built upon established concepts in the research area and presented our conceptual taxonomy by which to frame our discussions. Through the development of a series of robot prototypes and a set of user studies, we explored different facets of *emotive motion* and presented evidence of how robot's motion characteristics can affect how humans interpret their social interactions with these social robots.

In the following sections we review our major thesis contributions, reflect on how they address our original research questions, and go on to discuss future directions for our work.

9.1 Thesis Contributions

1) ***Qualitative and quantitative evidence of the expressive capabilities of emotive motion in social HRI:*** Through a series of experiments (both the design critiques in Chapter 5 and in-depth user studies in Chapters 0and 7), we have demonstrated how the characteristics and style of a robot's motion can affect human observers' emotional interpretations of those robots as social entities. Without any changes to its visual form, we have shown that altering the style of a robot's motions can cause it to be viewed as more or less intelligent, friendly, calm, mechanical, reactive, and so on.
2) ***A theoretical framework and taxonomy for exploring emotive motion in Social HRI:*** In Chapter 4, we proposed that *emotive motion* could be viewed as a separate design axis from a robot's visual form.

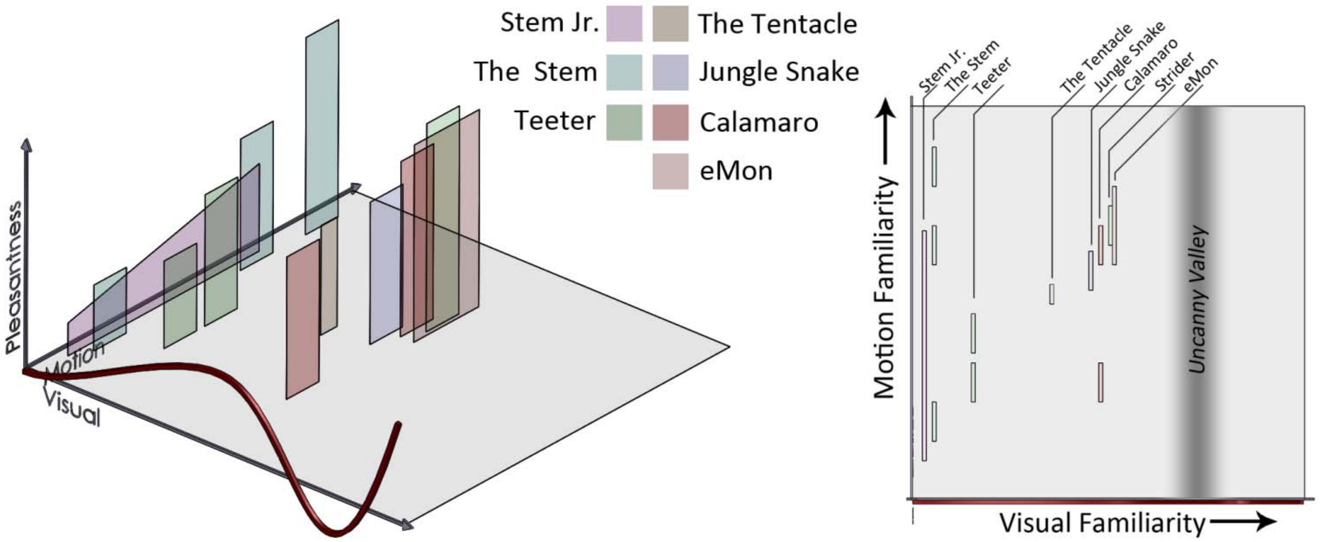


Figure 45 - Our conceptual taxonomy incorporating all of our prototype designs and displaying our full area of exploration. 3D view (left) Top-down 2D view (right)

As we discussed the development of our various robot prototypes and subsequent user studies, we used our taxonomy to map our various efforts onto a coherent design space. The prototypes' various degrees of "visual familiarity" and "motion familiarity" resulted in "exploration spaces" that were positioned throughout the 3D design space. Each prototype was also assigned an overall "pleasantness" score based on their respective evaluations (whether preliminary design critiques or formal user studies). Collectively, this resulted in the composite conceptual "terrain" seen in Figure 45.

While the resultant graphic is based heavily on our subjective judgments, we feel this taxonomy helped us to present a clear relationship between our prototypes and clarify our overall path of exploration.

It is important to remember that our three-dimensional taxonomy is presented only as a means of focusing and directing discussion. Our choice of "pleasantness" for our vertical axis and the resultant "score" assigned to our robot prototypes is highly subjective and primarily useful only for our work as it focuses on social interaction between humans and domestic robots.

3) ***Design and implementation of a set of six unique robot prototypes, which we employed as emotive motion test bed platforms****:* In Chapters 5, 0, and 7 we presented

the design and implementation of several unique robot platforms that we used as vehicles for exploring *emotive motion*. We discussed their design goals, their perceived advantages and disadvantages as exploration platforms, as well as their technical/mechanical limitations.

4) ***Conceptualizing the use of emotive motion in a social robot agent to affect behaviour change, and the subsequent design of an interactive test bed platform ("eMon")**:* While the concept of interactive systems (Froehlich, et al., 2009) (Gustafsson & Gyllensward, 2005) and even "robots" (Intuitive Automata Inc.) that support long-term behaviour change have been discussed previously, our *eMon* explorations (Section 5.3) highlight the unique potential of social robots and their subtle use of *emotive motion* in this specific application domain.

5) ***A hyper-abstract study technique for exploring emotive motion**:* In Chapter 0 we presented our "Zen-like" study approach which allowed almost completely uninhibited freedom of interaction between our participants and *The Stem.* The resultant spoken comments and interactive displays (with participants laughing, fighting, petting, being frightened and playing) demonstrate a level of deep reflection and emotional openness that would be difficult to achieve with other methods (e.g. surveys, interviews).

6) ***A technique for studying emotive motion in a public setting**:* Field studies, where robots are brought "into the wild", are still relatively rare in the realm of social HRI research. In Chapter 7 we presented our *Calamaro* study that struck a compromise between the completely hands-off nature of traditional ethnographic studies such as (Shiomi, Sakamoto, Kanda, Ishi, Ishiguro, & Hagita, 2008) and more direct interview/survey techniques common of laboratory experiments such as (Saerbeck & Bartneck, 2010).

9.2 Revisiting our Research Questions

Our work was motivated by our belief that motion is a fundamental component of what differentiates a robot from a traditional computer. We argued that robots, in physically affecting the world around them by gesturing, lifting, pushing, pulling, destroying, assembling, and moving in fundamentally physical and dynamic ways, have an inherent social and emotional impact on the human users around them.

In Chapter 1 we introduced a set of research questions that guided our subsequent discussions. We reiterated them here and reflection on how our thesis contributions address them:

1) ***Do robots' motion characteristics (e.g. speed, smoothness, complexity, timing, interactivity) affect how humans perceive and interact with them?***
   When our study participants first encountered *The Stem,* most were taken aback by its appearance and felt confused that they had volunteered to participant in what was advertised as a "Human-Robot Interaction" study but, apparently, did not involve an actual robot. As soon as *The Stem* began to move however, their interaction with the robot changed and they began to interpret it as an emotionally expressive entity. We observed this phenomenon again with *Calamaro*, *eMon,* and many of our other prototype platforms. Through the use of *emotive motion,* our "mere machines" had become something altogether more "lively".
2) ***Can these motion characteristics be used as deliberate design tools to promote specific emotional interpretations from the humans with which the robot interacts?***
   Between the different *Stem* and *Calamaro* experiment conditions (e.g. their various motion styles) we say distinct differences in our participants' emotional interpretations of the robots. Through deliberate choices of motions styles, the robots were able to elicit a wide range of emotional interpretations; including positive and negative, exaggerated and subtle. With *eMon* we saw that it may also be possible to apply these emotional responses to promote directed behavioural change.

3) ***How are a robot's expressive motion characteristics affected by its other qualities such as visual form or working context?***

Despite our attempts to promote truly open reflection and remove external distractions from our studies, our participant's emotional interpretations of our various robot platforms were always closely tied to concerns regarding their visual form and assumed "purpose". That *The Stem* being, in essence, a wooden stick resulted in many participants assuming it was a weapon or tool meant to be wielded. *The Stem's* wooden texture and *Calamaro's* plastic limbs consistently led participants to infer more about these robots' purposes than was intended. That both *Calmaro* and *eMon* had complex smart-phone "heads" led participants to assume they had greater cognitive and sensing capabilities than they did. And so on.

Although we focus on *emotive motion* as a distinct design axis that can (and should) be deliberately explored, there will likely always be strong coupling between how people interpret a robot's motions and numerous other factors such as that robot's appearance, its stated purpose or goal, its relationship to the viewer, etc.

We argue that our work shows *emotive motion* to be a powerful, multi-faceted design to for social HRI research. Many current social HRI projects focus on specific applications, algorithm design problems, or engineering challenges; resulting in social research concerned with the *what, when,* and *why* of robot motion but often neglecting consideration for *how* these robots move. While addressing these specific challenges is important for the advancement of the research field, we argue (and have endeavoured to demonstrate) that the low-level style and characteristic of robots can affect how people interpret and react to these robots; regardless of their visual appearance or working context.

9.3 Final Words

In this thesis we have emphasized the importance of *emotive motion* in Social Human-Robot Interaction and endeavoured to explored its complexities and demonstrate some of its affects. We feel that the qualities of the motion inherent to all robots are a powerful channel of expression that is largely neglected in current social robot design; with functional context and visual form typically taking priority.

Although we recognize that the limitations of current robotic actuators and controllers is largely responsible for the stereotypical rigid, jerkiness of modern robots, we still stress that researchers should be aware of how these motion characteristics can affect their studies and implementations; even if they lack the resources to address or account for them.

Through movement, humans and robots can express both powerful and subtle emotions. As robots continue to advance in complexity and capability, it is predicted that they will play increasingly larger roles in our daily lives and it will becoming increasingly important that they are able to communicate and interact naturally with their human counterparts. Based on the work presented in this thesis then, we do not find it surprising to find the word *motion* at the heart of “emotion”. We hope that future robot designers will be able to build upon our work and are better able to “breath life” into their creations using *emotive motion.*

10 References

Arroyo, E., Bonanni, L., & Selker, T. (2005). Waterbot: exploring feedback and persuasive techniques at the sink. *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 631-639). New York, USA: ACM New York.

Bartneck, C., Kulic, D., Croft, E., & Zoghbi, S. (2009). Measurement Instruments for the Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots. *1* (71-81).

Bartneck, C., Mubin, O., & Al Mahumud, A. (2007). To kill a mockingbird robot. *Proceedings of the 2nd ACM/IEEE International Conference on Human-Robot Interaction*, (pp. 81-87). Washington, D.C., USA.

BeatBots LLC. (n.d.). *Research*. Retrieved August 2, 2011, from BeatBots LLC: http://beatbots.net/research/

Blevis, E. (2007). Sustainable interaction design: investion & diposal, renewal & reuse. *Proceedings of SIGCHI Conference on Human Factors in Computer Systems* (pp. 503-512). San Jose, California: ACM Press.

Blevis, E. (2008). Two Digital Divides and Four Perspectives. *ACM Interactions January/February* .

Brannen, K. (2010, December 16). *U.S. Army: 'Insatiable Demand' for UAVs in War Zone*. Retrieved August 1, 2011, from Defense News: http://www.defensenews.com/story.php?i=5254787

Dick, P. K. (1968). *Do Androids Dream of Electric Sheep?* Doubleday.

Dourish, P. (n.d.). *Book Review of "The Media Equation"*. Retrieved August 3, 2011, from Dourish.com: http://www.dourish.com/publications/media-review.html

Draganfly. (2011). *Draganfly Photography and Video Applications*. Retrieved August 1, 2011, from Draganfly Innovations Inc.: http://www.draganfly.com/uav-helicopter/draganflyer-x6/applications/

Economist. (2010). *Barack Obama's rant against technology: Don't shoot the messenger.* Retrieved August 1, 2011, from The Economist: http://www.economist.com/node/16109292

EUREKA Prometheus Project. (n.d.). Retrieved August 1, 2011, from Wikipedia: http://en.wikipedia.org/wiki/EUREKA_Prometheus_Project

Forlizzi, J., & DiSalvo, C. (2006). Serivce robots in the domestic environment: a study of the roomba vacuum in the home. *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction* (pp. 258-265). ACM New York, USA.

Froehlich, J., Dillahunt, T., Klasnja, P., Mankoff, J., Consolvo, S., Harrison, B., et al. (2009). UbiGreen: investigating a mobile tool for tracking and supporting green transportation habits. *Proceedings of the 27th international conference on human factors in computing systems.* Boston, USA: ACM New York.

Garage, W. (n.d.). *PR2 Robot Overview*. Retrieved August 1, 2011, from Willow Garge Inc.: http://www.willowgarage.com/pages/pr2/overview

Gaudin, S. (2011, February 11). *Social networks credited with role in toppling Egypt's Mubarak*. Retrieved August 1, 2011, from Computer World: http://www.computerworld.com/s/article/9209159/Social_networks_credited_with_role_in_toppling_Egypt_s_Mubarak

Gibson, J. (1979). *The Ecological Approach to Visual Perception.* Psychology Press.

Goldman, B. (2010, October 1). *Health Care Should Embrace Social Media*. Retrieved August 1, 2011, from Canadian Broadcasting Corporation News: http://www.cbc.ca/whitecoat/2010/10/01/health-care-should-embrace-social-media/

Google driverless car. (n.d.). Retrieved August 2, 2011, from Wikipedia: http://en.wikipedia.org/wiki/Google_driverless_car

Green light given to Google as changes to the law make driverless car legal. (n.d.). Retrieved August 2, 2011, from Daily Mail UK: http://www.dailymail.co.uk/sciencetech/article-2007725/Google-gets-green-light-changes-law-make-driver-cars-legal.html

Guizzo, E. (2011, July 12). *Do Robots Take People's Jobs?* Retrieved August 1, 2011, from IEEE Automaton: http://spectrum.ieee.org/automaton/robotics/industrial-robots/john-dulchinos-adept-do-robots-take-peoples-jobs

Guizzo, E. (n.d.). *Telenoid R1: Hiroshi Ishiguro's Newest and Strangest Android*. Retrieved August 2, 2011, from IEEE Spectrum - Automaton: http://spectrum.ieee.org/automaton/robotics/humanoids/telenoid-r1-hiroshi-ishiguro-newest-and-strangest-android

Guizzo, E. (2010, April 02). *Who's Afraid of the Uncanny Valley*. Retrieved August 2, 2011, from IEEE Spectrum - Automaton: http://spectrum.ieee.org/automaton/robotics/humanoids/040210-who-is-afraid-of-the-uncanny-valley

Gustafsson, A., & Gyllensward, M. (2005). The power-aware chord: energy awareness through ambient information display. *CHI'05 extended abstracts on human factors in computing systems* (pp. 1423-1426). New York, USA: ACM New York.

Gutierrez, J. (n.d.). *7 films that got stuck in the uncanny valley*. Retrieved August 2, 2011, from ToplessRobot.com: http://www.toplessrobot.com/2011/03/7_films_that_got_stuck_in_the_uncanny_valley.php

Harper, D. (n.d.). *"Anima"*. Retrieved August 2, 2011, from Online Etymology Dictionary: http://www.etymonline.com/

Harris, J., & Sharlin, E. (2010). My Robot Is a Tree Hugger: Leveraging Emotive Actuation in Sustainable Interaction Design. *HRI Pioneers Workshop, Adjunct Proceedings of the 5th ACM/IEEE international conference on Human-robot interaction.* Osaka, Japan.

He, H. A., Greenberg, S., & Huang, E. M. (2010). One size does not fit all: applying the transtheoretical model to energy feedback technology design. *Proceedings of the 28th international conference on Human factors in computing systems* (pp. 927-936). ACM New York.

Heider, F., & Simmel, M. (1944). An Experimental Study of Apparent Behavior. *The American Journal of Psychology , 57* (2), 243-259.

Heider, F., & Simmel, M. (n.d.). *Video - An experimental study of apparent behavior*. Retrieved August 2, 2011, from Youtube.com: http://youtu.be/sZBKer6PMtM

History of DARPATech Proceedings. (n.d.). Retrieved August 1, 2011, from Defense Advanced Research Projects Agency: http://www.darpa.mil/About/History/Archives.aspx

Hoffman, G., & Breazeal, C. (2008). Anticipatory Perceptual Simulation for Human-Robot Joint Practice: Theory and Application Study. *Proceedings of the Twenty-Third AAAI Conference on Artificial Intelligence.*

Honda Motor Company Limited. (n.d.). *U3-X Product Web Page*. Retrieved July 20, 2011, from Honda Worldwide Site: http://world.honda.com/U3-X/

Human Population: Urbanization. (n.d.). Retrieved August 1, 2011, from Population Reference Bureau: http://www.prb.org/Educators/TeachersGuides/HumanPopulation/Urbanization.aspx

Intuitive Automata Inc. (n.d.). *"Autom" Product Website*. (Intuitive Automata Inc.) Retrieved July 19, 2011, from Intuitive Automata Company Website: http://intuitiveautomata.com/autom_intro.html

iRobot Corporation. (n.d.). *iRobot Product Page*. Retrieved August 2, 2011, from http://store.irobot.com/home/index.jsp iRobot. (n.d.). *iRobot CEO Discusses Q4 2010 Results - Earnings Call Transcript*. Retrieved August 2, 2011, from Seeking Alpha.com: http://seekingalpha.com/article/252090-irobot-ceo-discusses-q4-2010-results-earnings-call-transcript?source=yahoo

Ishiguro, H. (2005). Android Science: Towards a New Cross-Interdisciplinary Framework. *Proceedings of the 12th International Symposium of Robotics Research.* San Fransisco, U.S.A.

Johnston, O., & Thomas, F. (1995). *The Illusions of Life: Disney Animation.* Disney Editions.

Kamiyama, K. (Director). (2002). *Ghost in the Shell: Stand Alone Complex* [Motion Picture].

Kidd, C. D., & Breazeal, C. (2004). Effect of a robot on user perceptions. *Proceedings of the 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems.*

Kidd, C. (2008). *Designing for Long-Term Human-Robot Interaction and Application to Weight Loss.* Boston, USA: Massachusetts Institute of Technology.

Kiesler, S., & Hinds, P. (2004). Introduction to this special issue on human-robot interaction. *Human-Computer Interaction* , Volume 19, Issue 1.

Kosuge, K., Hayashi, T., Hirata, Y., & Tobiyama, R. (2003). Dance partner robot - Ms DanceR. *Proceedings of 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2003. (IROS 2003).*

Kotkin, J. (2000). *The new geography: how the digital revolution is reshaping the American.* Random House.

Kozima, H., Michalowski, M. P., & Nakagawa, C. (2009). Keepon: A Playful Robot for Research, Therapy, and Entertainment. *International Journal of Social Robotics , 1* (1), pp. 3-18.

Kozima, H., Nakagawa, C., & Yasuda, Y. (2007). Children-robot interaction: a pilot study in autism therapy. *Progress in Brain Research , 164*, pp. 385-400.

Kravets, D. (2011, June 3). *U.N. Report Declares Internet Access a Human Right*. Retrieved August 1, 2011, from Wired Magazine: http://www.wired.com/threatlevel/2011/06/internet-a-human-right/

Kurzweil, R. (2005). *The Singularity Is Near: When Humans Transcend Biology.* The Viking Press.

Macdorman, K. F., & Ishiguro, H. (2006). The uncanny advantage of using androids in cognitive and social science research. *Interaction Studies , 7* (3).

Mancuso, G. (Director). (2008). *30 Rock - Season 2, Episode 13: "Succession"* [Motion Picture].

Mankoff, J., Matthews, D., Fussell, S. R., & Johnson, M. (2007). Leveraging Social Networks to Motivate Individuals to Reduce their Ecological Footprints. *40th Annual Hawaii International Conference on Systems Sciences*, (p. 87a).

Microsoft Corporation. (n.d.). *Kinect Product Page*. Retrieved August 2, 2011, from http://www.xbox.com/en-ca/kinect

Mint Robot Vacuum Cleaner. (n.d.). (Evolution Robotics Inc.) Retrieved August 2, 2011, from http://mintcleaner.com/

Moore, G. E. (1965). Cramming more components onto integrated circuits. *Electronics , 38* (8).

Moravec, H. (2000). *Robot: Mere Machine to Transcendent Mind.* Oxford University Press.

Mori, M., MacDorman, K. F., & Minato, T. (1970). The Uncanny Valley. *7* (4), 33-35.

Mutlu, B., Forlizzi, J., Nourbakhsh, I., & Hodgins, J. (2006). The Use of Abstraction and Motion in the Design of Social Interfaces. *DIS 2006.* University Park, Pennsylvania, USA.

Neato Robotics Inc. (n.d.). *Neato Robotics homepage*. Retrieved August 2, 2011, from www.neatorobotics.com

Parkinson, B. (1996). Emotions are social. *British Journal of Psychology* (87), 663-683.

Paro Robots U.S., Inc. (n.d.). *Paro Robots Homepage*. Retrieved August 2, 2001, from http://www.parorobots.com/

Philips Electronics. (n.d.). *Philips Research - Robotics*. Retrieved August 2, 2011, from http://www.research.philips.com/technologies/robotics.html

Potel, M. (2008). Overcoming the Uncanny Valley. *IEEE Computer Graphics and Applications* .

Power, Politics, and Protest: The Growth of Political Rights in Britain in the 19th Century - Luddites. (n.d.). Retrieved August 1, 2011, from The National Archives (United Kingdom): http://www.nationalarchives.gov.uk/education/politics/g3/

Reeves, B., & Nass, C. (1996). *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places.* Cambridge University Press.

Robotis Inc. (n.d.). *Dynamixel Product Page*. Retrieved July 20, 2011, from Robotis Company Website: http://www.robotis.com/xe/dynamixel_en

Rosie the Robot - Jetsons Cartoon Characters. (n.d.). Retrieved August 2, 2011, from Wikipedia: http://en.wikipedia.org/wiki/Rosie_the_Robot_Maid#Rosie

Sabanovic, S., Michalowski, M. P., & Simmons, R. (2009). Robots in the Wild: Observing Human-Robot Social Interaction Outside the Lab. *The 18th IEEE International Symposium on Robot and Human Interactive Communication*, (pp. 816-821). Standbul, Turkey.

Saerbeck, M., & Bartneck, C. (2010). Perception of affect elicited by robot motion. *Proceedings of the 5th ACM/IEEE international conference on Human-robot interaction* (pp. 53-60). Osaka, Japan: ACM New York.

Saito, T., Shibata, T., Wada, K., & Tanie, K. (2002). Examination of Change of Stress Reaction by Urinary Tests of Elderly before and after Introduction of Mental Commit Robot to an Elderly Institution. *Proceedings of the 7th International Symposium on Artificial Life and Robotics*, *1*, pp. 316-319.

Sakamoto, D., Kanda, T., Ono, T., Ishiguro, H., & Hagita, N. (2007). Android as a telecommunication medium with a human-like presence. *Proceedings of the ACM/IEEE international conference on Human-robot interaction.* ACM New York.

Saygin, A. P., Chaminade, T., & Ishiguro, H. (2010). The perception of humans and robots: Uncanny hills in the parietal cortex. *Annual Meeting of the Cognitive Science Society* .

Segway Inc. (n.d.). *Segway i2 Product Web Page*. Retrieved July 18, 2011, from Segway Corporate Website: http://www.segway.com/individual/models/i2.php

Shiomi, M., Sakamoto, D., Kanda, T., Ishi, C. T., Ishiguro, H., & Hagita, N. (2008). A semi-autonomous communication robot: a field trial at a train station. *Proceedings of the 3rd ACM/IEEE international conference on human robot interaction.* Amsterdam, Netherlands: ACM New York.

Staff, R. T. (2010, February 16). *iRobot Delivers 3,000th PackBot*. Retrieved August 1, 2011, from Robotics Trends: http://www.roboticstrends.com/security_defense_robotics/article/irobot_delivers_3000th_packbot/

Stanton, A. (Director). (2008). *Wall-E* [Motion Picture].

Sung, J.-Y., Grinter, R. E., Christensen, H. I., & Guo, L. (2008). Housewives or Technophiles?: Understanding Domestic Robot Owners. *HRI'08.* Amsterdam, Netherlands.

Tapscott, D. (2011). *Growing Up Digital: The Rise of the Next Generation*. Retrieved August 1, 2011, from http://www.ncsu.edu/meridian/jan98/feat_6/digital.html

Thompson, C. (2011). How Khan Academy Is Changing the Rules of Education. *Wired Magazine , July*.

Turkle, S. (2011). *Alone Together: Why we expect more form technology and less from each other.* Basic Books.

Twitter - About. (n.d.). Retrieved August 1, 2011, from Twitter: http://twitter.com/about

Wada, K., Shibata, T., Saito, T., & Kazuo, T. (2002). Analysis of factors the Bring Mental Effects to Elderly People in Robot Assisted Activity. *Proceedings of the 2002 IEEE/RSJ International Conference on Intelligent Robots and Systems.* Lausanne, Switzerland.

Wang, L., Rau, P.-L. P., Evers, V., Robinson, B. K., & Hinds, P. (2010). When in Rome: the role of culture and context in adherence to robot recommendations. *Proceedings fo the 5th ACM/IEEE international conference on Human-Robot interaction* (pp. 359-366). Osaka, Japan: ACM New York.

Wise, J. (2009, October 1). *Civilian UAVs: No Pilot, No Problem*. Retrieved August 1, 2011, from Popular Mechanics: http://www.popularmechanics.com/science/space/4213464

Young, J. E., Igarashi, T., & Sharlin, E. (2008). Puppet Master: designing reactive character behavior by demonstration. *Proceedings of the 2008 ACM SIGGRAPH/Eurographics Symposium on Computer Animation.* Aire-la-Ville, Switzerland.

Young, J. E., Ishii, K., Igarashi, T., & Sharlin, E. (2010). Showing robots how to follow people using a broomstick interface. *Proceedings of the 5th ACM/IEEE international conference on human-robot interaction.* Osaka, Japan.

Appendix A – Materials, Fabrication and Control

All of our robot prototypes were constructed using commercially available components. Although the individual configuration of each robot and its component parts varied according to each robot's unique purpose, we generally utilized a common library of materials (e.g. actuators, sensors, and controllers) throughout our investigations. Rather than repeatedly detail their use for each robot, we briefly discuss the more noteworthy components in this section for the sake of compactness. We will subsequently only discuss a robot's mechanical components if an important conceptual or theoretical point calls for further description.

Actuators

Most industrial robots employ heavy-duty motors which, while immensely powerful, cost many tens of thousands of dollars and require tremendous power to operate. Much more common in academic and social HRI research scenarios is the use of "hobby servo motors".

A "servo motor" differs from a conventional "dumb motor" in that, rather than simply spinning in proportion to the applied voltage, a servo motor can be commanded to assume a desired angular position and will subsequently hold that position until commanded otherwise. This is achieved through the use of embedded sensors and control circuitry which continuously measure the motor shaft's angular position with respect to the desired command position and spinning the shaft appropriately to compensate for any discrepancy. In essence, servo motors allow for "position control" rather than "speed control".

"Hobby" servo motors refers to the hobbyist remote control aircraft/car/boat/toy industry that specializes in the mass-production of the low-power, low-cost, and low-weight servo motors used extensively in these small-scale machines. Due to the long history and wide-spread popularity of these toys, hobby servos are inexpensive and plentiful; typical prices range from $5 for micro-sized models (e.g. 0.05kg-cm torque) to $50 for more powerful models (e.g. 10kg-cm torque). There is a distinct gap in both price and capability between these "hobby" servo motors and those motors used in industrial applications however; with industrial motors capable of generating hundreds of kilograms of torque (such as those used in Honda's famous ASIMO robot) costing many tens of thousands of dollars each.

Recently, as robotics development has gained in popularity in academic and hobbyist circles, intermediate classes of servo motors have begun to emerge. Popular among these have been Robotis Inc.'s "Dynamixel" series of servo motors (Robotis Inc.) and their "Bioloid" robot construction kits (http://www.robotis.com/xe/); both of which were used extensively during our robot prototyping explorations.

The majority of our robot prototypes employed "Dynamixel AX-12+" servo motor which were capable of outputting approximately 15 kgf.cm of torque as well as reporting a number of real-time internal statistics such as operating temperature, current position/speed, and emergency overload workings.

Power Source

One of the primary factors limiting the widespread adoption of mobile robotics (and electric cars) in general is shortcomings in battery technology. Robot designers must consider trade-offs between size, weight, capacity, and cost. E.g. The added weight and bulk of a high capacity battery (e.g. nickel-metal hydride) will weigh down a robot significantly and could actually result in a shorter running time than a more light-weight battery. At the same time, more energy-dense batteries, while light weight, are exceedingly expensive and often rely on volatile chemistries that require special protection circuitry and care, lest they violently explode (e.g. lithium-ion).

Our robots employed "lithium-iron nano-phosphate" batteries which strike a middle ground between low-cost, low-capacity batteries and high-cost, high-performance batteries. Most importantly, they exhibited good energy-density while also being immune to damage from under-volting or poor recharging habits. With these batteries, even our most complex and power-hungry robot prototypes could operate for upwards of 45 minutes before requiring a recharge.

In the instances where our robot platforms were tethered, they would receive external power from an attached cable. This obviates power concerns but renders the robot relatively immobile. (E.g. Limited to the range of its tether.) In addition, we would try to avoid tethering our robots due to the “external control” connotations of a wire leading into them from some unseen, external source.

Controllers

Even robots that are being completely controlled via “Wizard of Oz” techniques typically require some form of on-board computational power. Generally this is so that the robot can translate incoming high-level control commands into low-level commands to its individual motors, sensors, etc.

The majority of our robots were tethered to external controllers (generally a laptop computer) and fed control commands via an attached set of wiring. Besides *Teeter,* which employed a very simple “Arduino” microcontroller (http://www.arduino.cc/) to process its balancing requirements *Calamaro* was our only fully “mobile” robot prototype. It achieved this by incorporating a single-board computer into its frame; specifically a FitPC2i (http://www.fit-pc.com/web/). Although *Calamaro’s* processing requirements were relatively limited, its on-board processor was equivalent to a complete Windows 7 personal computer; capable of performing advanced networking functions and even on-board computer vision processing with an attached USB webcam.

Fabrication

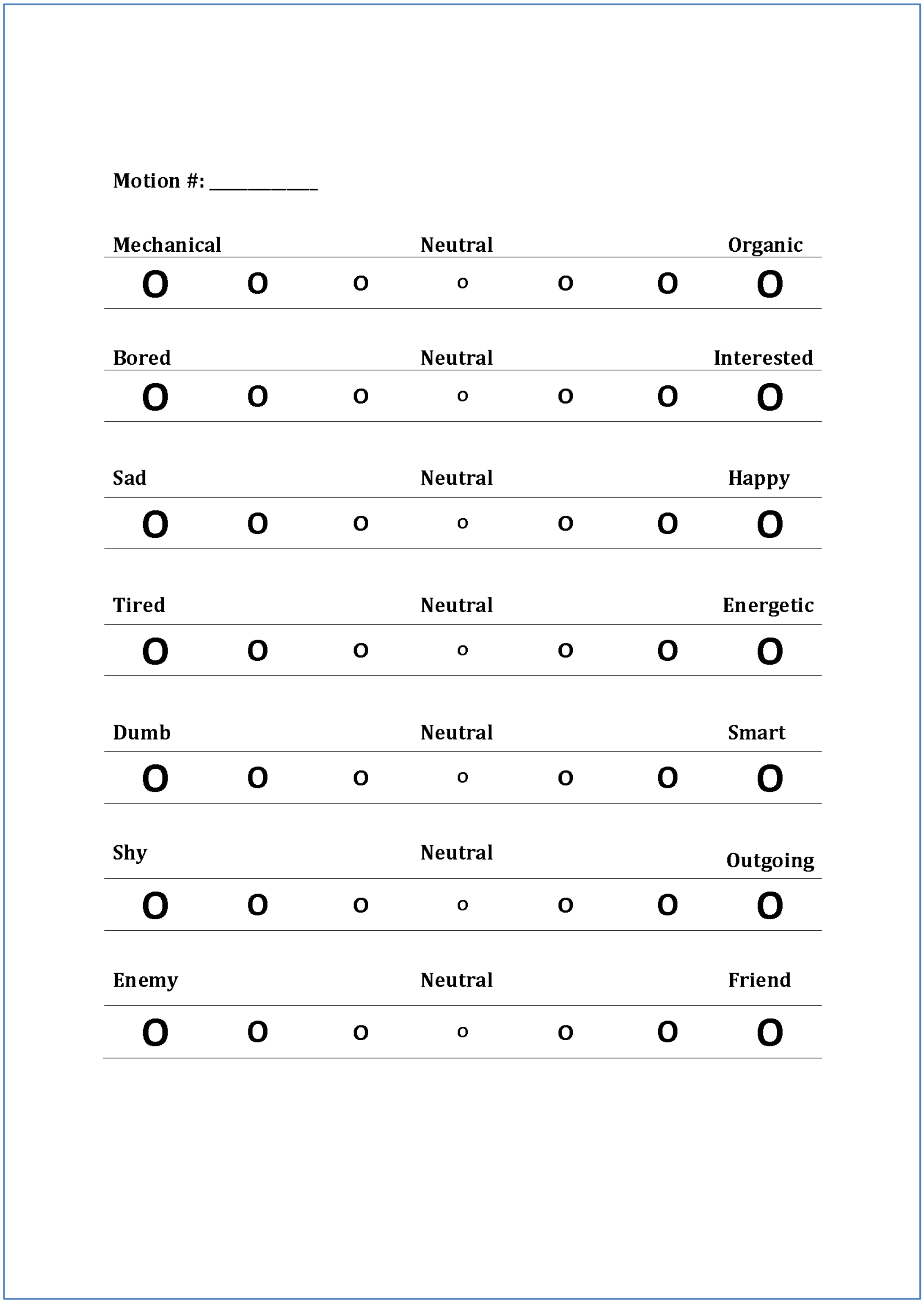
One of the other primary advantages of using the Robotis Bioloid kits to develop our prototype robot platforms was the ease and speed with which the included “assembly frame” pieces our be used to create a functional robot prototype of almost any configuration. In essence, these Bioloid frame pieces acted as “snap-together” Lego-style robot parts; allowing use to rearrange our robot’s morphology in minutes rather than having to redesign and re-machine it from scratch repeatedly.

As convenient as these pre-made frame pieces were however, our specific design requirements often required that we break away from the Bioloid kit's largely right-angled assembly limitations. When it was necessary to creating custom frame components, we would often use a commercial laser-cutting machine (http://en.wikipedia.org/wiki/Laser_cutting) to create our made-to-order robot frame pieces. Our material of choice was basic, clear Acrylic plastic sheets due to its easy availability, relatively low cost, good strength, flexibility, and that it allowed us to more easily see through to our underlying components and uncover mechanical design problems more easily.

This reliance on acrylic plastic is most evident in *Calamaro's* many "arms", *Strider's* "torso", and both robots' "head" case which hold their smart-phone faces.

Appendix B - User Study Material

1. Sample Participant Questionnaire Used During *"The Stem"* Study



Motion #: __________

Mechanical			**Neutral**			**Organic**
○	○	○	○	○	○	○

Bored			**Neutral**			**Interested**
○	○	○	○	○	○	○

Sad			**Neutral**			**Happy**
○	○	○	○	○	○	○

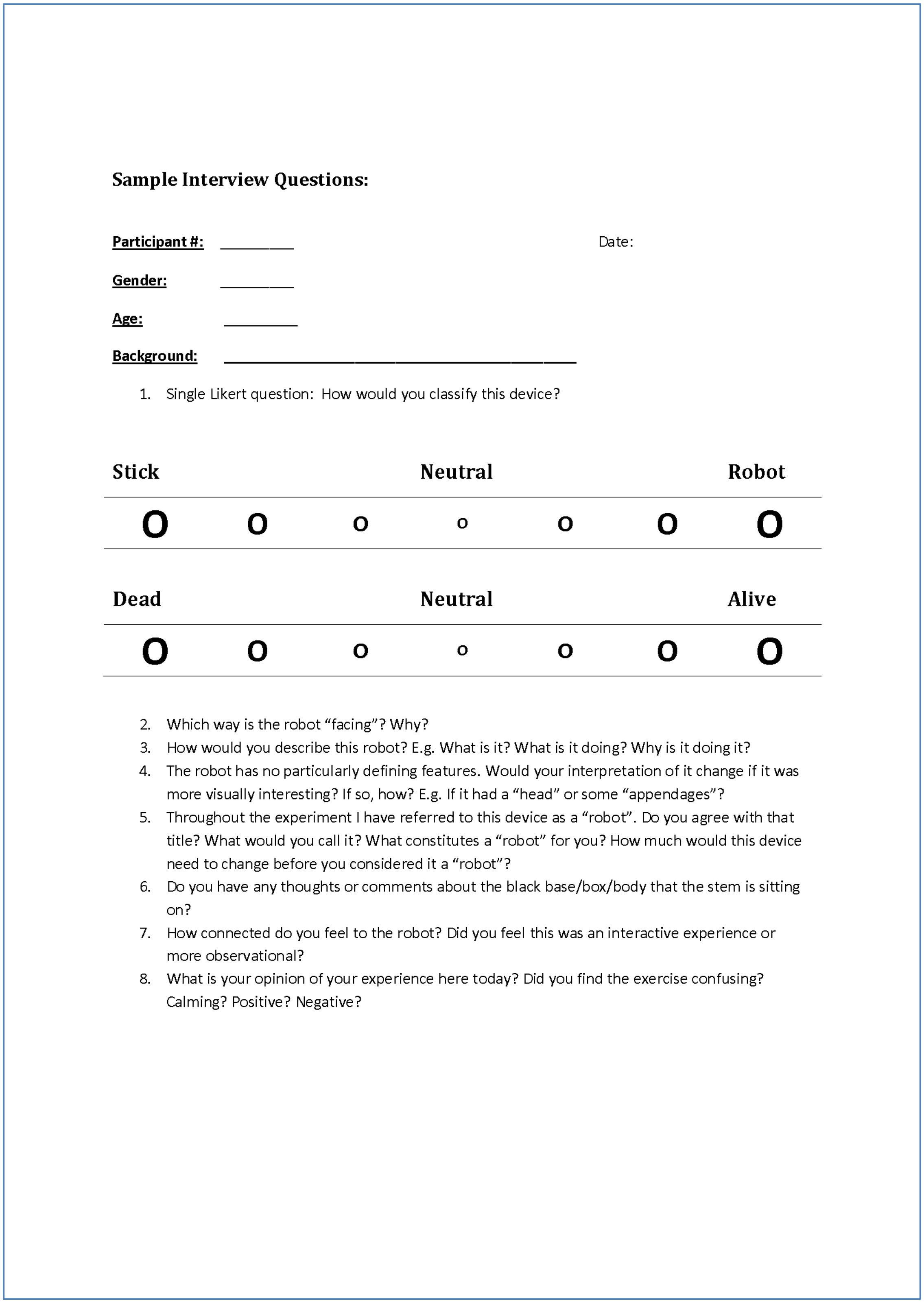
Tired			**Neutral**			**Energetic**
○	○	○	○	○	○	○

Dumb			**Neutral**			**Smart**
○	○	○	○	○	○	○

Shy			**Neutral**			**Outgoing**
○	○	○	○	○	○	○

Enemy			**Neutral**			**Friend**
○	○	○	○	○	○	○

2. Sample Experimenter Interview Sheet Used During *"The Stem"* Study



Sample Interview Questions:

Participant #: _________ Date:

Gender: _________

Age: _________

Background: ____

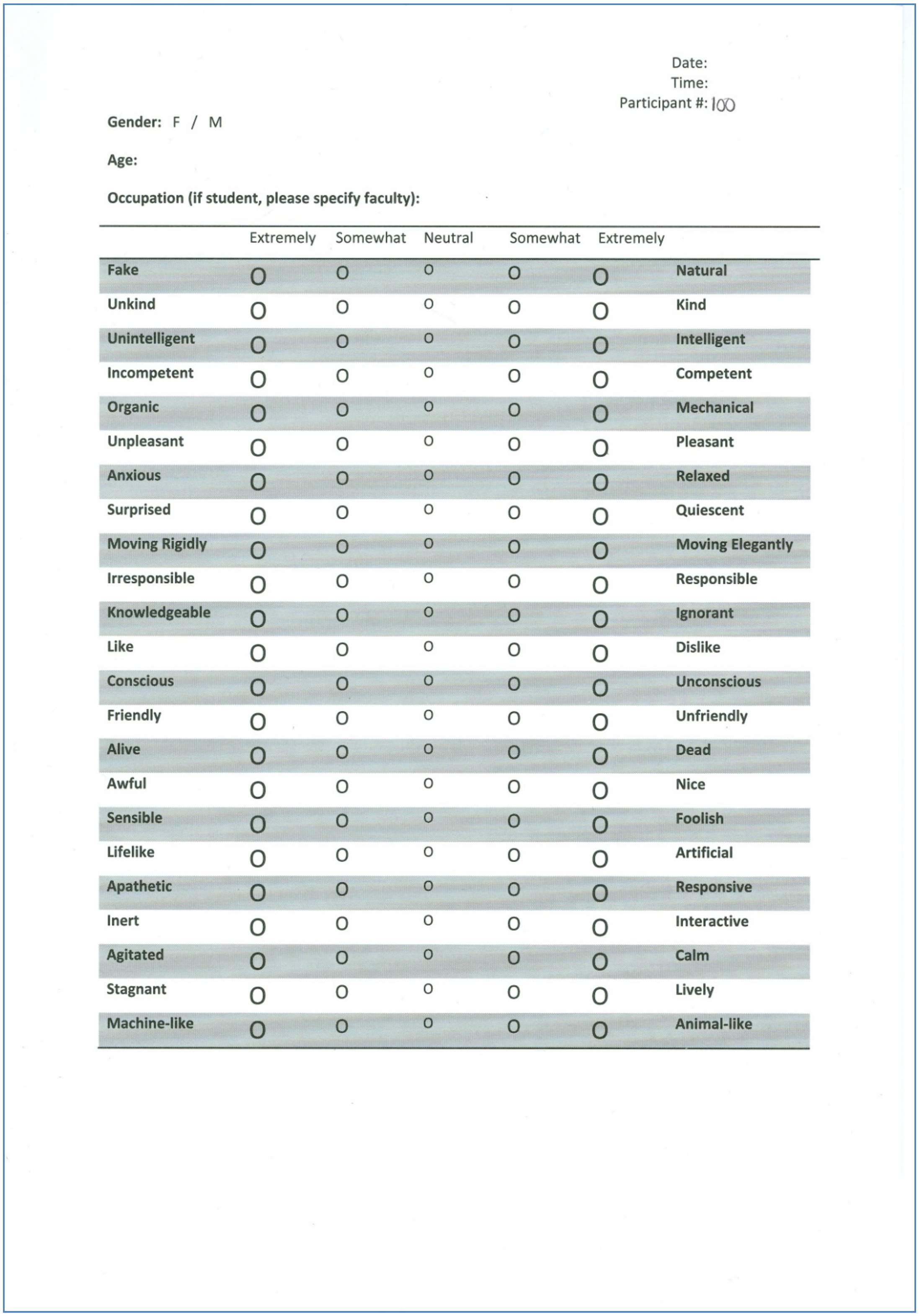
1. Single Likert question: How would you classify this device?

Stick			**Neutral**			**Robot**
○	○	○	○	○	○	○

Dead			**Neutral**			**Alive**
○	○	○	○	○	○	○

2. Which way is the robot "facing"? Why?
3. How would you describe this robot? E.g. What is it? What is it doing? Why is it doing it?
4. The robot has no particularly defining features. Would your interpretation of it change if it was more visually interesting? If so, how? E.g. If it had a "head" or some "appendages"?
5. Throughout the experiment I have referred to this device as a "robot". Do you agree with that title? What would you call it? What constitutes a "robot" for you? How much would this device need to change before you considered it a "robot"?
6. Do you have any thoughts or comments about the black base/box/body that the stem is sitting on?
7. How connected do you feel to the robot? Did you feel this was an interactive experience or more observational?
8. What is your opinion of your experience here today? Did you find the exercise confusing? Calming? Positive? Negative?

3. Sample Questionnaire Used During *"Calamaro"* Study



Date:
Time:
Participant #: 100

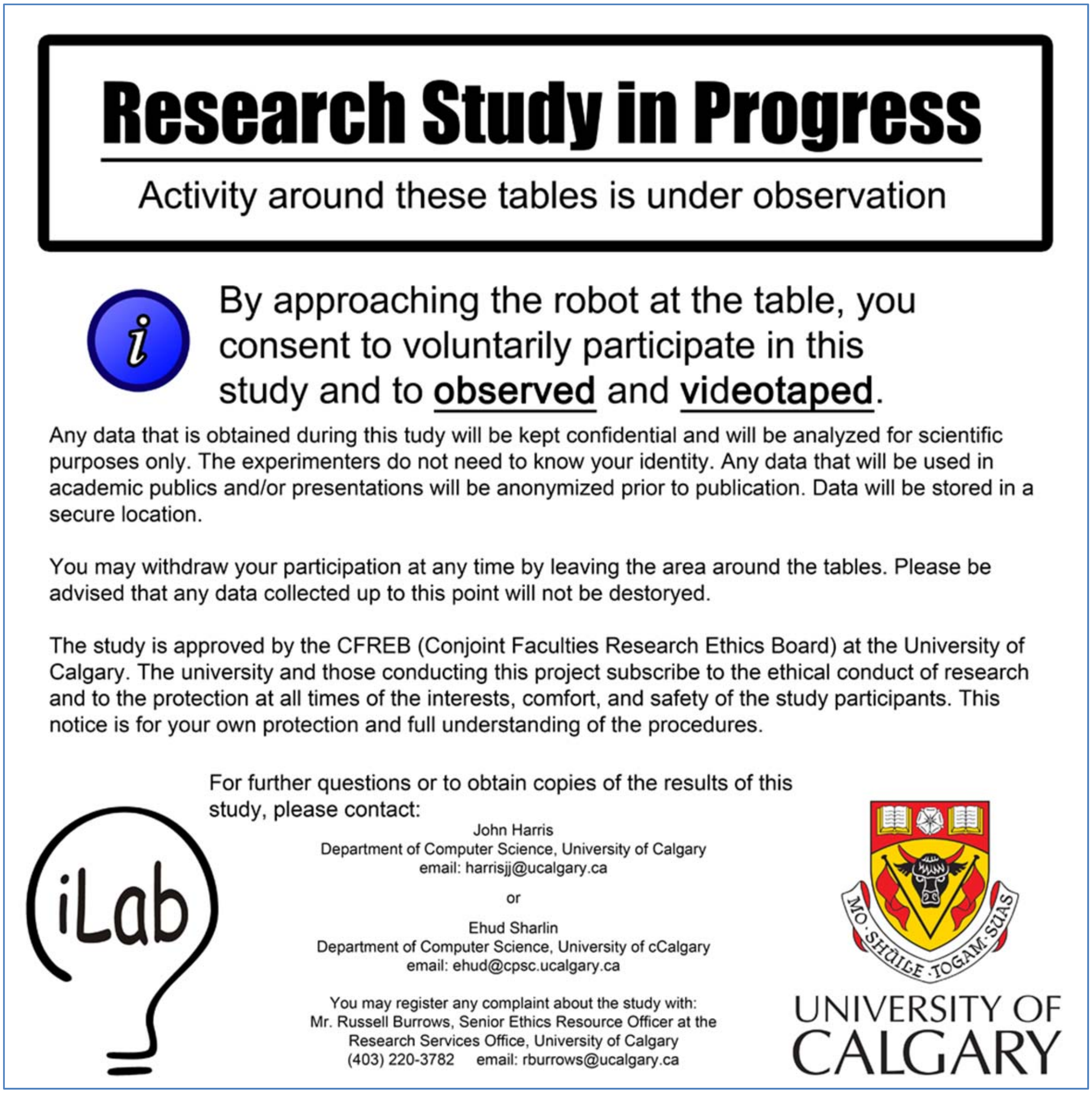
Gender: F / M

Age:

Occupation (if student, please specify faculty):

	Extremely	Somewhat	Neutral	Somewhat	Extremely	
Fake	○	○	○	○	○	**Natural**
Unkind	○	○	○	○	○	**Kind**
Unintelligent	○	○	○	○	○	**Intelligent**
Incompetent	○	○	○	○	○	**Competent**
Organic	○	○	○	○	○	**Mechanical**
Unpleasant	○	○	○	○	○	**Pleasant**
Anxious	○	○	○	○	○	**Relaxed**
Surprised	○	○	○	○	○	**Quiescent**
Moving Rigidly	○	○	○	○	○	**Moving Elegantly**
Irresponsible	○	○	○	○	○	**Responsible**
Knowledgeable	○	○	○	○	○	**Ignorant**
Like	○	○	○	○	○	**Dislike**
Conscious	○	○	○	○	○	**Unconscious**
Friendly	○	○	○	○	○	**Unfriendly**
Alive	○	○	○	○	○	**Dead**
Awful	○	○	○	○	○	**Nice**
Sensible	○	○	○	○	○	**Foolish**
Lifelike	○	○	○	○	○	**Artificial**
Apathetic	○	○	○	○	○	**Responsive**
Inert	○	○	○	○	○	**Interactive**
Agitated	○	○	○	○	○	**Calm**
Stagnant	○	○	○	○	○	**Lively**
Machine-like	○	○	○	○	○	**Animal-like**

4. "Calamaro" Study Information Poster



Research Study in Progress

Activity around these tables is under observation

By approaching the robot at the table, you consent to voluntarily participate in this study and to **observed** and **videotaped**.

Any data that is obtained during this tudy will be kept confidential and will be analyzed for scientific purposes only. The experimenters do not need to know your identity. Any data that will be used in academic publics and/or presentations will be anonymized prior to publication. Data will be stored in a secure location.

You may withdraw your participation at any time by leaving the area around the tables. Please be advised that any data collected up to this point will not be destoryed.

The study is approved by the CFREB (Conjoint Faculties Research Ethics Board) at the University of Calgary. The university and those conducting this project subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of the study participants. This notice is for your own protection and full understanding of the procedures.

For further questions or to obtain copies of the results of this study, please contact:

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You may register any complaint about the study with:
Mr. Russell Burrows, Senior Ethics Resource Officer at the
Research Services Office, University of Calgary
(403) 220-3782 email: rburrows@ucalgary.ca