Ningyo of the CAVE:
Robots as Social Puppets of Static Infrastructure

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ABSTRACT
In this paper, we present a view of robots as physical agents submitting to a static infrastructure, allowing a computerized static system to use the robot as a dynamic puppet, which is a social agent that can communicate on physical and social terms with its human users and visitors. We demonstrate our approach with *Ningyō of the CAVE*, a prototype designed to allow a virtual reality CAVE facility to introduce its capabilities to human users and visitors. Through the robot, the CAVE is able to highlight capabilities and uses of the facility through performance, showmanship and physical actions to create an engaging interaction that conveys an overview of the facility and demonstrates its key functionalities. We examine the quality of the resulting engagement with preliminary reflection by several human visitors to our CAVE system. We believe that viewing robots as components of a greater and more capable computerized ecosystem is a less explored research path in social human-robot interaction, and hope that our *Ningyō of the CAVE* prototype could set the stage and inform some of the future research on this topic.

Author Keywords
Social Physical Agents; Robot Theater Play; Human-Robot Interaction; Human Factors; CAVE Automatic Virtual Environment

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INTRODUCTION
Many static infrastructures have sufficient computational power to allow them to mimic logical thinking and employ synthetic emotions in order to act as intelligent agents. However, due to the lack of mechanical physicality, it can be difficult or impossible for such static facilities to interact with their human users and visitors in a dynamic and social way. For example, a modern high-performance computer has tremendous computational capability and potential to leverage this capability to interact with the world in interesting ways, but this potential may be hindered without some physical medium to facilitate it.

With this in mind, the challenge is to find a way to give a static infrastructure the opportunity to interact and communicate with people, not only scientifically and logically but also socially and artistically. Inspired by the Japanese Bunraku play, in this paper we explore the use of humanoid robots as a physical representation of a computerized static infrastructure to provide a socially engaging means of interaction with people. Ningyō (人形) is the Japanese term for the puppet that commonly used in Bunraku or Ningyō Jōruri, which is a form of a traditional Japanese puppet play (Figure 1). During the performance, puppeteers control mechanically sophisticated human-like figures, providing the illusion that the puppets perform under their own agency and will. In our *Ningyō of the CAVE* prototype, the humanoid, like a Ningyō puppet, is indeed teleoperated by the static CAVE infrastructure, which plays the role as a puppeteer.

Figure 1: Bunraku puppeteers manipulate Ningyō [20]

The CAVE [1] system is a highly capable computerized static infrastructure, used to puppeteer *Ningyō of the CAVE* in order to demonstrate its capabilities to visitors, and to physically engage its users. We believe that our approach can scale to other highly computerized static infrastructures, and explores a variation on the common social human-robot interaction design approach, which usually views robots as egocentric autonomous intelligent agents rather than as agents of a larger computerized entity, which fully controls them.

RELATED WORK

Use of robots has been explored in a wide range of public interactive settings, including lobby interaction [2], museum guidance and navigation assistance [3][4], as well as museum interaction [5]. Interaction patterns and strategies among robots and humans in public spaces have also been explored and discussed [3][6][7]. Human-like motions, such as head movements, eye contact, hand gestures, etc. were shown to significantly improve the experience of visitors during their interactions [8][9]. These works show not only the possibility to use human-like robots as a means of meaningful and dynamic social interaction, but also the potential to enhance and enliven static infrastructures.

There have been several novel attempts at robotic theatrical performances. These efforts evolve from the early study of Bunraku puppet [10], science shows [11], to recent professional theater plays such as *I, work*, *In the heart of the forest*, and *Sayonara*, where robots perform physical feats along with real actors [12][13][14]. In the play *Sayonara*, the android actor, Geminoid F, has been said to be almost indistinguishable from a human actresses. The Bunraku master Kanjūrō III was also involved in the play, demonstrating the existence of commonality between the traditional puppet show and modern robot theater [12]. In other recent approaches, both humanoid robots and androids with a less human appearance are being used in performances where the robot is acting as itself, playing the role of a robot interacting with the human players [15][16].

Virtual agents have also been explored as cost effective solution for education and training purposes, requiring advanced graphical technologies and a large amount of technical work to provide a believable experience [17][18][19]. However, virtual agents inherently cannot support the physicality that interaction with a robotic agent provides.

The design of *Ningyō of the CAVE* was informed by both artistic intent and research objectives. The core focus of the design may be summarized with two primary goals: building on the important role robots can play when guiding or introducing people to static infrastructure, and on their inherent ability to act as perfect puppets in a carefully orchestrated play.

A unique design angle of *Ningyō of the CAVE* is that the static infrastructure itself, in our case a highly computerized one, is the director which fully controls the robot as its interactive puppet, serving its need to communicate and engage visitors and users in a physical and socially meaningful manner.

DESIGN

In this project we are using the CAVE system, located in the Foundation CMG / Frank and Sarah Meyer Collaboration Centre at University of Calgary, as the static infrastructure, which puppeteers our *Ningyō of the CAVE* prototype. Our CAVE has four projected surfaces: three walls and floor, and a high quality Vicon tracking system with 8 high-resolution infrared motion capture cameras mounted above (Figure 2).

Figure 2: CAVE area, surrounded by display screens

Both the CAVE and Vicon systems are connected to and driven by a powerful server. The visual appeal of a visualization facility such as a CAVE, along with the high-performance computational capability attached, represent an excellent computerized static infrastructure. This CAVE system is used extensively to showcase and explore oil-and-gas processes and data, particularly for reservoir engineering applications. This often necessitates the introduction of the facilities technological capabilities, tools and applications to oil-and-gas domain experts with little knowledge of technology and facilities such as a CAVE. The use of an environment such as a CAVE by users, which often lack the skills and knowledge to effectively interact with it, creates an interesting interaction space for a robotic agent that will physically represent the CAVE facility. Motivated by the overall vision of robots as puppets of static computerized environments, and by the instance of our CAVE, we designed the *Ningyō of the CAVE* to help demonstrate the validity of our concept.

The goal of our prototype is to give an interactive introduction of the CAVE infrastructure to visitors. These visitors range from students and researchers on campus, to members of other institutions and industrial partner organizations, to members of the public. The introduction, or the self-introduction from the perspective of the CAVE, is delivered in the form of an interactive theater play. This is accomplished by using multiple autonomous agents on the server synchronized to control the humanoid robot and provide the illusion that the robot controls the CAVE, while in practice it is being controlled by it. This impression is

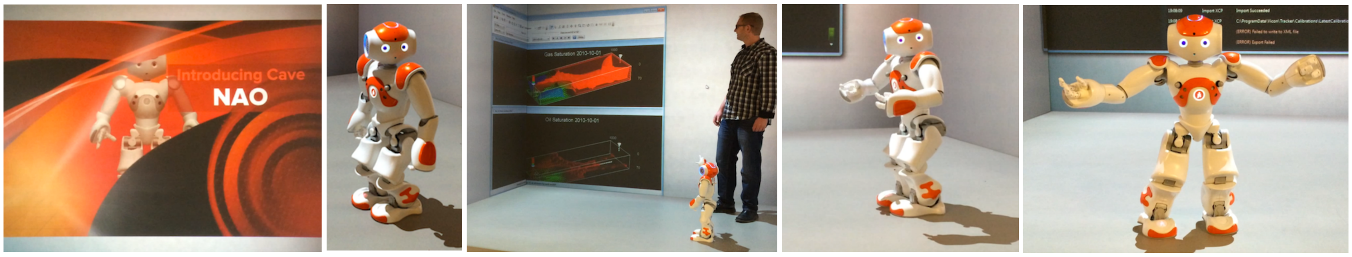

Figure 4: snapshots during the performance

From left to right: the virtual robot; the physical robot "steps out" of the screen; robot manipulates an application window; robot shows its Vicon makers; robot has personality traits and makes jokes

accomplished through manipulation of content and demonstrations on the CAVE screens while interacting with an audience in a human-like fashion. We endeavored to further enrich the performance by assigning the humanoid a certain personality, and then examined the consequent social impact.

IMPLEMENTATION

In our system, an Aldebaran Robotics NAO robot is used as the physical humanoid agent that is puppeteered by the CAVE. The NAO is a humanoid with 25 degrees of freedom that allows it to perform basic human-like gestures and legged locomotion (Figure 3). Our *Ningyō of the CAVE* prototype is designed as an interactive theatre play, which is controlled by the CAVE and delivered to the human audience by the humanoid within the CAVE area, on the floor projection screen.

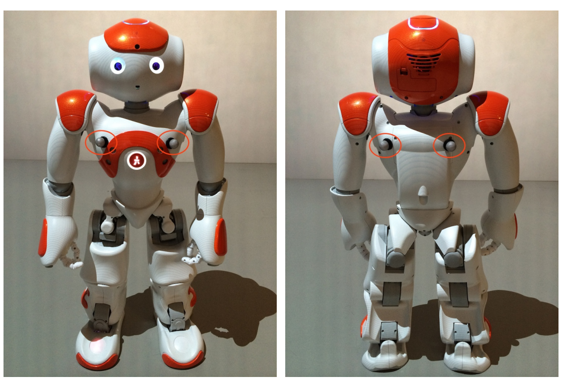

Figure 3: NAO with Vicon markers attached on it

The Vicon cameras are used to track the motion of the robot. Reflective markers, arranged in an asymmetrical pattern, are attached to the torso of the robot (Figure 3), in order to allow the system to monitor the precise location and orientation of the robot in real time. By tracking the robot in this manner, the necessary orientation and positioning is maintained so that the impression that the robot is interacting with the audience is preserved. For instance, the robot's head orientation is adjusted in real time based on the robot's body position; hence the robot is always looking in the direction where the audience is located. This seems to greatly enhance the experience by creating a sense of direct communication between the robot and the CAVE visitors and users.

At the beginning of the act the CAVE attempts to introduce its capabilities using a virtual robot, which appears on its screens. However, shortly after the introduction starts, it is interrupted by an error message, creating an interesting twist (Figure 4).

Following the error message, the virtual robot on the screen appears to be surprised by the technical issue and tries to comfort audiences by saying: *"…What the… Please don't panic, this happened before"*.

Next, the virtual robot walks toward the edge of screen. When the virtual image reaches the middle of the side screen, the physical robot is brought to life and stands up from a slightly hidden compartment placed at a corner of the stage, and starts marching toward the center of the CAVE area. The transition gives audiences the illusion that the robot breaks the fourth wall, walks out of the screen, and turns into a real one, which is a metaphor often used in cinema, for example in Woody Allen's *the Purple Rose of Cairo*.

The physical robot expresses itself in a slightly grumpy and dramatic manner. For example, because the robot is less than a meter tall, right after coming out, it faces the audience and exclaims, *"Yes, I'm short, stop staring at me"*.

Then robot starts walking around the CAVE area, introducing various functionalities of the facility according to the arrangement of the lab environment, including the screens of the CAVE system and other attached equipment such as the Vicon cameras above the interactive area. The robot also describes applications that are used to visualize and explore different domains in this environment. Since the robot is tracked using the Vicon cameras (Figure 2), the content on the CAVE screens is completely synchronized with the robot motion and actions. The impression is that the robot indeed controls the entire facility through the use of motion, gaze, and hand gestures. For example:

> One simple scenario unfolds when the robot points at a screen and says, *"Let me open a program."*

The application window appears at exactly the location where the robot is pointing. Next, the robot says, *"And let me move the window to a different screen."*

As the robot waves its hand across and eventually pointing at a different CAVE screen, the application window floats across the CAVE to the new corresponding location smoothly, as if controlled directly by the robot gestures.

The robot is able to not only give system level instructions, such as moving or resizing an application window, but is also able to manipulate the application contents, for example rotating the reservoir model inside an oil-and-gas visualization, or a molecule structure inside a biochemistry simulation.

From the software perspective, our prototype implementation includes four software modules: the "tracking agent", the "window control agent", the "robot control agent", and the physical robot (Figure 5).

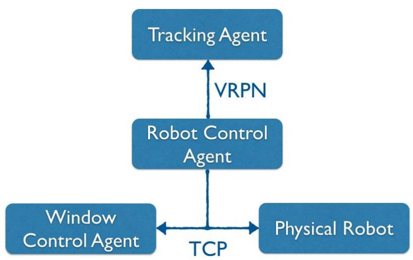

Figure 5: block diagram of the software implementation

The "tracking agent" reads data from the Vicon system via Virtual Reality Peripheral Network (VRPN). VRPN is a standard protocol dedicated to support communication of devices within virtual reality systems. The Vicon system uses the VRPN channel to communicate the spatial location and orientation of objects that are being tracked by it, in *Ningyō of the CAVE* the robot's torso is one such object (Figure 3).

The "window control agent" determines when and where an application window should be displayed in the CAVE screens directly. It is also able to initialize a new program at a given screen coordinate, or move an existing window to a new location in the screen. We calculate the direction at which the robot points, and make the window move corresponding to the motion of the robot arm. The combination of the robot's movements and the window animation provides the illusion that the robot is directly manipulating the selected application window on the corresponding CAVE screen with its hands.

The "robot control agent" module is the core of the system: it fetches the robot's spatial information from the "tracking agent" in real time, and gives synchronized instructions to both the "window control agent" and to the physical robot. In our system we use Aldebaran Robotics Choregraphe to interpret and apply the robot's physical actions. We either use standard postures and movements provided by the graphical programming interface of the software, or program custom ones if the there is nothing in the standard library that is sufficient.

Ningyō of the CAVE is designed with loose coupling as a goal, so any of its components may be changed without impacting other parts of the system. We implemented a several minute interactive sequence that first introduces visitors to our CAVE facility, describing its main components and features, and then walks them through some of our CAVE's interactive visualizations such as those used to explore reservoir engineering and biochemistry simulations. However, since *Ningyō of the CAVE* is an generic entity, which can interactively engage with any content the system displays on its screens, the CAVE can deploy it to serve as needed to execute any interactive task or show any application it needs to engage users with.

CRITIQUE

Since the goal of our current *Ningyō of the CAVE* prototype is to introduce the CAVE system to visitors and users we held preliminary critique sessions and collected feedback from five stakeholders and visitors to the CAVE. Our evaluation is very preliminary and based on a limited number of participants who visited the facility and interacted with *Ningyō of the CAVE.*

According to observations from these sessions, all viewers enjoyed watching the introduction given by *Ningyō of the CAVE* to the CAVE facility. Most of the viewers were focused on following the humanoid's movements, gestures, and interaction with the content on the CAVE's screens. One observation brought forward by the CAVE stakeholders was the difficulty of both retaining and ensuring availability of high quality human guides to demonstrate the facility to visitors, which is a common need that occurs sometimes on short notice. Using *Ningyō of the CAVE* as a key tool for introducing the facility and its various applications to visitors on an ongoing basis was proposed as a result of the critique sessions. Based on the reaction of the viewers and feedback received, we believe that *Ningyō of the CAVE* has the potential to become an effective method of introducing environments such as ours to visitors and users.

In addition, all audiences noticed and appreciated the personality of the robot and reported being entertained by its jokes and actions. Several reported that the human-like appearance and behavior caught their attention effectively and in a positive manner as evidenced by smiles and laughter. We observed that people treated the robot as a living creature rather than a machine or equipment, and attached emotive state to it. We believe this treatment to be due to the appearance and behavior of the robot.

Both visitors to the facility and stakeholders were excited by *Ningyō of the CAVE*, and a lot of suggestions were collected to further improve both the structure and content of the humanoid performance.

FUTURE WORK

We consider *Ningyō of CAVE* to be at the proof of concept stage, and believe there are many possible extensions of this work.

In particular, we would like to execute a user study to quantify and qualify the difference between our robot theater play and traditional in-person active or passive touring. Two major questions that we would like to answer are:

1. What changes to user response and feedback does *Ningyō of the CAVE* evoke? We assume our performance of the robot is able to create a strong positive impression of the facility and will motivate users to request more information and participate in future events or projects at the facility. To find supporting evidence for this assumption would show clear benefit to the use of an agent in this manner and for this purpose.

2. Does *Ningyō of the CAVE* help the audience understand the facility in a better way? Using this performance as an engaging learning tool that can be continuously improved over time could provide a consistent and effective means of introduction and information dissemination. Assuming this is the case, how much benefit could this technique provide over traditional tutoring methods and what factors contribute to the effectiveness of the performance as a communication technique?

The humanoid, NAO, which we are using as the physical agent in *Ningyō of the CAVE*, has limitations due to its physicality. For instance, the humanoid's lack of an expressive face may be reducing the effectiveness and users' engagement during interaction. We are hoping to integrate different robotic platforms in our project, allowing us to explore whether different robotic physical capabilities, such as facial expression, could create stronger social engagement with visitors.

In the longer term, we would like to apply the *Ningyō of the CAVE* approach to other computerized static infrastructure. Of particular interest is infrastructure comprised of "smart" technology. Smart buildings and smart homes are currently gaining popularity and there is an ever-increasing selection of sensing and tracking devices as well as a greatly increased capability to communicate both among these devices and other machines. Further to this, many things now have the label "smart" on them, from light bulbs to washing machines to thermostats. Such devices are improving our daily lives in an intelligent way, yet their lack of dynamic physicality limits any possible physical interaction with human users. It is an exciting and potentially very impactful research objective to experiment and examine the possibility to embody and reflect the "smartness", embedded in this new world of static infrastructure to create an engaging and interactive experience that may provide information and entertainment to humans. For example, would it be a more impressive and positive experience to be handed fresh clothing from a personable robot, rather than receiving a text message, "job done", from your washing machine?

CONCLUSION

In this paper we presented a view of robots as physical agents submitting to static infrastructure, where a computerized system uses the robot as a dynamic social agent, which can communicate physical and social needs to human users and visitors. We demonstrate our approach with *Ningyō of the CAVE*, a prototype designed to allow our virtual reality CAVE facility to introduce its technical capabilities and uses to human visitors through interaction with a physical agent. We provided a detailed description of the current *Ningyō of the CAVE* prototype, and presented a preliminary evaluation of our concept and its validity.

We believe that viewing robots as mere physical components of a much larger and more capable computerized ecosystem is a less explored research path in social human-robot interaction, and we hope that our *Ningyō of the CAVE* prototype could set the stage and inform future research on this topic, potentially bringing this design concept to other advanced and highly computerized static infrastructures.

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