Flying Frustum:
A Spatial Interface for Enhancing Human-UAV Awareness

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Figure 1: *Flying Frustum*; (left) the operator draws a path using a pen on the augmented 3D printout of the terrain; (middle) the UAV, a quadrotor in the current prototype, flies along the path in the field; (right) live video footage streaming from the UAV is displayed as a view frustum situated at the correct location on the 3D printout, using augmented reality.

ABSTRACT

We present *Flying Frustum*, a 3D spatial interface that enables control of semi-autonomous UAVs (Unmanned Aerial Vehicles) using pen interaction on a physical model of the terrain, and that spatially situates the information streaming from the UAVs onto the physical model. Our interface is based on a 3D printout of the terrain, which allows the operator to enter goals and paths to the UAV by drawing them directly on the physical model. In turn, the UAV's streaming reconnaissance information is superimposed on the 3D printout as a view frustum, which is situated according to the UAV's position and orientation on the actual terrain. We argue that *Flying Frustum*'s 3D spatially situated interaction can potentially help improve human-UAV awareness and enhance the overall situational awareness. We motivate our design approach for *Flying Frustum*, discuss previous related work in CSCW and HRI, present our preliminary prototype using both handheld and headset augmented reality interfaces, reflect on *Flying Frustum*'s strengths and weaknesses, and discuss our plans for future evaluation and prototype improvements.

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Author Keywords

Unmanned aerial vehicle (UAV); augmented reality; human-robot interaction (HRI); situational awareness; computer-supported cooperative work (CSCW)

ACM Classification Keywords

H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.3 Group and Organization Interfaces: Computer-supported cooperative work; I.2.9 Robotics: Operator interface

INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are increasingly ubiquitous and have many well established uses, including various reconnaissance applications in search-and-rescue and military settings [1][2]. There are also many other applications emerging, from cinematography [3] to shipping and delivery [4].

Challenges of controlling these UAVs remain however. Many aspects of UAV control could benefit from further development, from more efficient interaction with low-level flying mechanisms, to higher-level issues of teleoperation and control [1][2]. *Flying Frustum* focuses on the high-level issues of teleoperation when interacting with UAVs which are performing a reconnaissance task over a terrain. *Flying Frustum* provides the UAV operator with a 3D printout of the terrain, which can be used to plan and draw flight paths for the UAVs. A visualization of the UAV's position on the 3D terrain is superimposed on the 3D printed model and a correctly situated frustum can display real-time information about the UAV. In the case of this prototype the information displayed is a video feed from the

UAV's camera. *Flying Frustum* is designed to provide a remote operator an enhanced level of human-UAV awareness [5][6] and improved situational awareness [7] when controlling one or more semi-autonomous UAVs. Our approach closely follows the footsteps of Drury, et al. [8] which argues that situated streaming information from a UAV would increase the operator's situational awareness. However, *Flying Frustum* extends this paradigm by using a 3D terrain printout with augmented reality visualizations as the interactive medium.

In this paper we present a prototype realizing the *Flying Frustum* concept, based on visualization superimposed on a 3D printout using either a handheld or headset augmented reality interface, and a Parrot Bebop drone as the UAV. While our current prototype is still preliminary, it does allow us to reflect on the strength and weaknesses of the *Flying Frustum* approach, argue the benefits of providing streaming information from the UAVs correctly situated and superimposed on their current 3D location, and to outline our future plans regarding this interface.

RELATED WORK

Maintaining situational awareness has a crucial impact on the design of remote teleoperation interfaces [7][9]. While situational awareness theory originated from aircraft control, air traffic control and other critical interaction settings, it soon emerged as a more general CSCW concept, which could be applied to various workplace scenarios [10]. The field of Human-Robot Interaction (HRI) adapted situational awareness onto its own unique collaborative settings and tasks, using the term HRI Awareness, and recognizing the inherently different and asymmetrical roles humans and robots play within the HRI collaborative settings [11][12]. Work was also done on applying HRI awareness to UAVs in related settings and tasks, for example by studying Desert Hawk UAVs and their operators [5]. These efforts resulted in a discussion of a subset of HRI-awareness called Human-UAV awareness [6], which is specifically concerned with the interaction between UAVs and their remote operators.

Our work follows closely on this path, and can be seen as a direct extension of the aforementioned previous work [8] where a UAV video stream was superimposed onto a geo-referenced 2D map of the terrain and was shown to improve the operators' situational awareness. *Flying Frustum* builds on these works by extending the interface into 3D using a physical printout of the terrain, a pen-based interface that is used to draw the commands on the terrain, and 3D situated streaming video from the UAV. Our work makes use of existing augmented reality interfaces (handheld and headset-based) in keeping with the extensive use of augmented reality in CSCW as seen in works such as [13][14][15][16][17][18].

DESIGNING FLYING FRUSTUM

The original motivation for our design came from control difficulties and interface limitations discovered in real-world scenarios during geo-science and petroleum field explorations. Such an excursion may require one or possibly multiple UAVs to efficiently cover geological features that are difficult or even impossible to reach, such as cliffs and canyons. In other cases UAVs may provide a more cost effective and less labor intensive alternative to manned aircraft when collecting data over a piece of terrain such as done by SkyHunter[1]. In both scenarios users have basic knowledge of the terrain that is to be explored, however the challenge is to rapidly deploy and effectively teleoperate the UAV while maintaining a high degree of overall situational awareness and human-UAV awareness simultaneously.

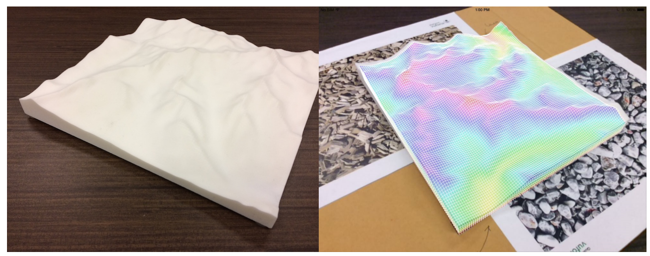

Figure 2: (left) using a 3D printout model as a physical representation to the topographical terrain; (right) augmented reality visualization is superimposed onto the model

Our design goal when creating *Flying Frustum* was to develop a situated 3D interaction with a UAV. The foundation for our spatial interface design is the 3D interactive medium, which is based on a scaled down model of the terrain that the UAVs are exploring. We create this medium using 3D printing, generating a physical representation of the terrain. The 3D printout provides users with a tangible entity that accurately and intuitively communicates detailed topographic information through both visual and tangible sensation. Augmented reality is used to superimpose spatial information onto the physical printout (Figure 2).

We designed the augmented reality layer of *Flying Frustum* considering both see-through AR headset (using Epson Moverio) and handheld AR screen (using iPad Air) (Figure 3). The 3D terrain printout is used as the interactive medium for sending user commands to the UAV by sketching on the terrain model, and for communicating information back to the user via 3D situated visualizations superimposed on the terrain. In order to correctly situate the various 3D information components, *Flying Frustum* needs to track the position and orientation of the handheld or the headset interface relatively to the 3D printout, and the position and orientation of the 3D sketching stylus.

[1] http://www.skyhunter.ca

Figure 3: *Flying Frustum's* augmented reality devices including (left) handheld screen and (right) see-through headset

We designed a set of pen-based interactions performed directly on the physical model of the terrain that allow the operator to control the movement of the UAV. We used physical pen-based interactions to address the "fat finger" problem and to enhance the precision of the operator commands to the UAV, while still allowing direct, tangible interaction and intuitive understanding of the topography of the 3D printout and therefore the terrain (Figure 4).

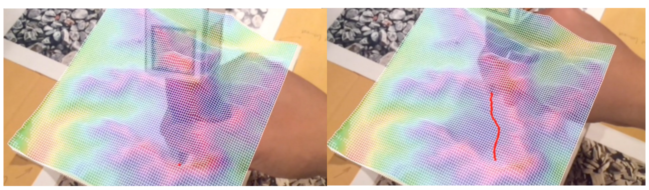

Figure 4: using a pen-based interaction to sketch the flight path of the drone

Similar to drawing a path on a traditional map, the operator may define a path for the UAV by sketching a line upon the surface of the physical model.

After the operator has created a path, the drone will fly to the location that is marked the start point of the path on the model, and then move along the path until it reaches the end point. The visualization of the UAV flight on the model corresponds spatially and temporally to the actual flight path of the drone in the real world.

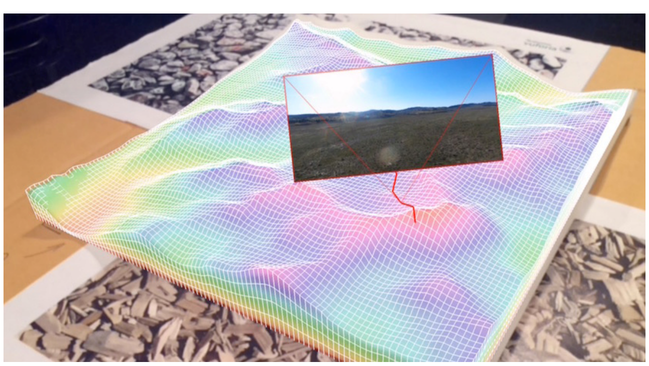

Figure 5: live video footage captured by the drone is displayed on the view frustum in the augmented reality visualization

Once the UAV starts following the path the operator traced on the 3D model, it streams live video footage from its camera and displays it on the far plane of a view frustum which is situated on the physical model according to the location and orientation of UAV on the actual terrain. The view frustum constantly adjusts its position and orientation to mirror the real-time activities of the actual UAV in the field (Figure 5). This design is based on the paradigm that situated streaming information would enhance the human-UAV awareness and situational awareness by helping the operator understand exactly where the drone is and what it is doing at the same time, with the streaming video correctly situated on top of the 3D physical terrain. This builds upon work demonstrating similar ideas in 2D non-AR settings [8].

With a certain level of automation [19], we expect *Flying Frustum* to further release the operator from constant observation of the drone's activities, which is common in traditional linear controlling of UAVs. Our design assumes that the UAV is semi-autonomous, meaning that it is able to hover and follow a predetermined path without human supervision until receiving any further instructions.

We believe that such an interface can help the operator maintain a high level of situational awareness without dramatically increasing the workload or cognitive load, which in turn could enable the operator to control multiple drones simultaneously.

IMPLEMENTATION

The prototype of *Flying Frustum* presented in this short paper is a preliminary proof-of-concept. The 3D printed interactive medium including the augmented reality functionality, the pen input and the 3D video frustum are fully realized and are completely functional. However, direct control and communication with the UAV has not been implemented and we use the Wizard-of-Oz prototyping method when flying the UAV and when playing the video back to the user via the situated frustum.

Our prototype was tested with both an Epson Moverio[2] headset and an iPad as the augmented reality devices, and the Qualcomm Vuforia[3] engine was used to illustrate the visualization. The 3D printout is made from strong flexible plastic[4] and was acquired from a commercial 3D printing company (Shapeways Inc.). We use the iPad as our primary augmented reality device to realize our proof-of-concept.

A Parrot Bebop Drone[5] is used as our UAV. It is a lightweight drone capable of performing 3-axes movements, and recording full HD video footage.

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[2] http://www.epson.jp/products/moverio

[3] https://developer.vuforia.com

[4] http://www.shapeways.com/materials/strong-and-flexible-plastic

[5] http://www.parrot.com/ca/products/bebop-drone

Due to the lack of reliable network coverage by commercial cellular networks and ISPs at certain locations the drone was operated, the communications between the operator and the UAV is implemented by means of the Wizard-of-Oz technique, including sending the instruction and receiving the video footage (Figure 6). We believe that this comprise still allows us to reflect on the overall validity of the *Flying Frustum* concept.

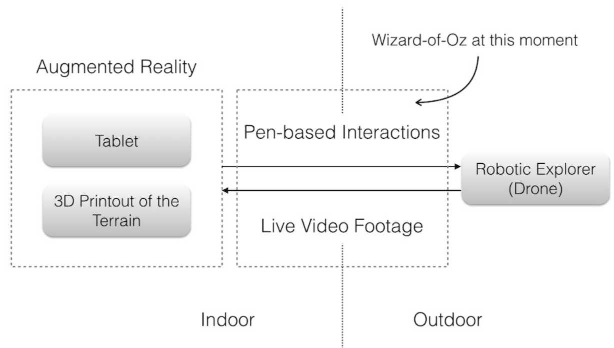

Figure 6: *Flying Frustum's* block diagram

LIMITATIONS AND FUTURE WORK

Although we see *Flying Frustum* as a direct extension of past work that demonstrated that situated streaming information improves human-UAV awareness [8], our augmented reality approach still requires formal evaluation and validation, and the preliminary prototype we presented here still needs to be solidified to make sure it is ready for use in an actual user study.

One limitation is the current state of augmented reality technology, and specifically the questionable usability of see-through headsets primarily due to the limited field of view. However, we believe that with the rapid development of this technology future augmented reality headsets will have much larger field-of-view and higher fidelity. We are looking forward to integrating future headsets (e.g. Microsoft HoloLens) in *Flying Frustum* as well as to exploring other visual augmentation approaches such as projection mapping on top of the 3D model.

We would like *Flying Frustum* to support a much richer gesture vocabulary. For example, allowing the operator to sketch a loop to indicate an area on the 3D printout, or to use a pre-defined search pattern (e.g. spiral or grid), which will direct the UAV to continuously monitor a path above the terrain, to search a specific area, or to follow a specific flight pattern. Such an extended gesture vocabulary could have applications and benefits to various tasks such as search and rescue operations.

In addition, we plan to study how *Flying Frustum* can improve the operator-UAV ratio, and allow control of a several UAVs simultaneously. We are interested in learning the overall workload and performance impact of *Flying Frustum* on operators of multiple UAVs, especially in comparison to other UAVs control mechanisms (e.g. [2]).

CONCLUSION

We presented a new human-UAV interface we call *Flying Frustum*, which facilitates spatial situated remote interaction with drones. *Flying Frustum* uses a 3D printout of the terrain as an interactive medium. The UAV operator can use pen-based interactions to input flight paths and send commands to the UAVs by sketching directly on the physical topographical model of the terrain. The UAVs can in turn present information such as streaming video back to the operator via the augmented reality overlay on the terrain model. The information is situated in a 3D view frustum on the model in the correct location corresponding to the UAV's current position. We outlined our design approach using handheld and headset augmented reality techniques, and our current preliminary prototype based on a Parrot Bebop drone.

Though our work on *Flying Frustum* is still ongoing and while we have not performed a formal evaluation, we believe that *Flying Frustum* provides a unique human-UAV interface, and that the 3D real-time situated interaction it affords is intuitive and increases human-UAV awareness over previous works.

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