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, allow a better operators-to-UAV ratio, and enhance the overall situational awareness. We motivate our design approach for *Flying Frustum*, discuss previous related work in CSCW and HRI, present our current 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.

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 (UAV) are becoming widely spread, with a well-established set of applications in various reconnaissance tasks, in search-and-rescue and military settings [1][2], as well as completely new and rapidly emerging set of applications, from leisure cinematography [3], to shipping and delivery [4].

As UAV technology is emerging, many of the challenges of controlling these robots remain acute, from more efficient interaction with their low-level flying mechanisms, to higher-level issues of teleoperation and control [1][2]. *Flying Frustum* is focusing on the high-level issues of teleoperating and interacting with UAVs, which are performing a task over a remote terrain. *Flying Frustum* is providing the remote UAV's operator with a 3D printout of the terrain, which can be used to plan and draw flight paths for the UAVs. The 3D printout provides the operator with a superimposed visualization of the UAV's position on the 3D terrain and with a correctly situated frustum presenting the information (e.g. video) streaming from the UAV. *Flying Frustum* is designed in order 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] in arguing that situated streaming information from a UAV would benefit the operator situational awareness, but is pushing this paradigm into further immersion using the 3D terrain printout with augmented reality visualization as the interactive medium.

In this paper we present the first steps in 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 prototype's 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 for the benefits of providing streaming information from the UAVs correctly situated and superimposed on their current 3D location, and to outline our plans for future evaluation of our interface.

RELATED WORK

Maintaining situational awareness has a crucial impact on the design of remote teleoperation interfaces [7][9]. While the original situational awareness theory evolved around pilots, air traffic controllers and other critical interaction settings, it soon emerged as a more general CSCW theory, which can be applied to various workplace scenarios (for example [10]). The domain 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 related settings and tasks, for example by studying Desert Hawk UAVs and their operators [13]. These efforts resulted in a discussion of a subset of HRI-awareness called Human-UAV awareness [6], which addresses the specified interaction space of UAV and their remote operators.

Our work follows closely on this path, and can be seen as a direct extension of [8] where UAV video stream was superimposed onto a geo-reference 2D map of the terrain, and was shown to improve the operators' situational awareness. *Flying Frustum* is building on this past effort by extending the interface into 3D using a physical printout of the terrain, a situated pen-based interface that is used to draw the UAV's 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) and can be seen as a follow-up on the extensive use of augmented reality in CSCW (for example [14][15][16][17][18][19]).

DESIGNING FLYING FRUSTUM

Our design goal was to enable *Flying Frustum* to facilitate 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 on top of which the UAVs are flying. We realize 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).

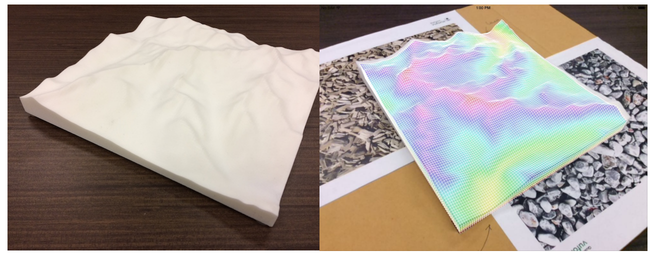

Figure 2: (left) using 3D printout model as a physical representation to the topographical terrain; (right) augmented reality visualization is superimposed onto model

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 both the user commands to the UAV, based on direct sketching on the terrain mode, and for communicating information back to the user, based on 3D situated visualization 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.

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

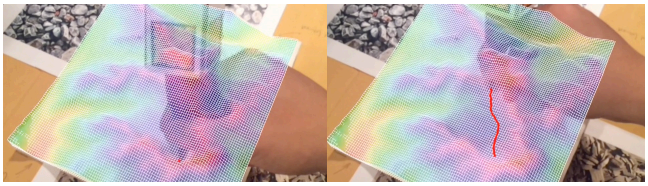

Figure 4: using a pen-based interaction to sketch the flight path of the drone

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 referred by start 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.

The design of *Flying Frustum* is based on 3D situated streaming information from the UAV. Following, once the UAV starts following the path the operator determined for it on the 3D model, it streams live video footage 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 the conditions the drone is in, correctly situated on top of the 3D physical terrain (following previous work demonstrating similar effect in 2D non-AR settings [8]).

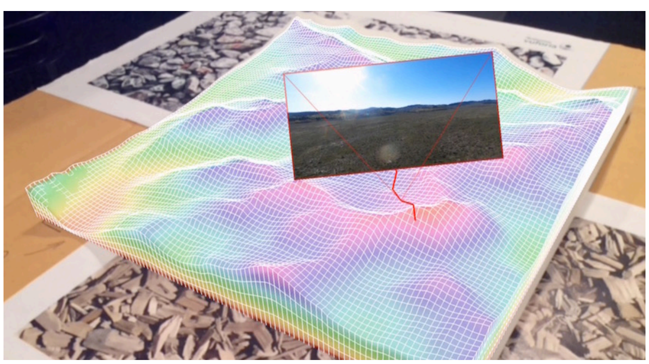

Figure 5: live video footage captured by the drone is displayed on the view frustum in the augmented reality visualization

With a certain level of automation [20], 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 UAV. 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 a setting can help the operator maintain 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 current prototype of *Flying Frustum* presented in this short paper is a preliminary proof-of-concept. While the core 3D printout interactive medium, its augmented reality layer, the pen input and the 3D video frustum were fully realized and are completely functional, the control and communication with the UAV are currently more of a mockup than a deployable system, with us using Wizard-of-Oz prototyping methods when flying the UAV and when playing the video back to the user via the situated frustum.

Our prototype uses both Epson Moverio[1] headset and an iPad as the augmented reality hardware, and the Qualcomm Vuforia[2] engine was used for tracking and in order to illustrate the visualization. The 3D printout is made from strong flexible plastic[3] and was acquired from a commercial 3D printing company (Shapeways Inc.). We use iPad as our primary augmented reality device to realize our proof-of-concept.

A Parrot Bebop Drone[4] is used as our UAV. It is a lightweight drone with the capability of performing 3-axes movements, and recording full HD video footage.

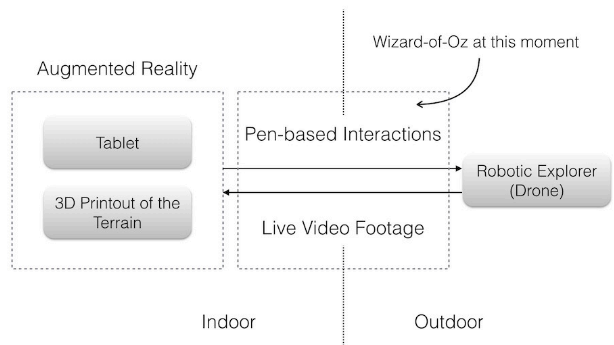

Figure 6: *Flying Frustum's* block diagram

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.

1 http://www.epson.com/cgi-bin/Store/jsp/Landing/moverio-bt-200-smart-glasses.do

2 https://www.qualcomm.com/products/vuforia

3 http://www.shapeways.com/materials/strong-and-flexible-plastic

4 http://www.parrot.com/ca/products/bebop-drone

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 primetime in an actual user study.

A major drawback of our design approach is the current state-of-the-art augmented reality technology, and specifically the questionable usability of see-through headsets. 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 gestures 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 immediate application and benefits 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 number of 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 flying drones. *Flying Frustum* is using a 3D printout of the terrain as an interactive medium. The UAV operator can use pen-based interaction to input flight paths and commands to the UAVs by sketching directly on the physical topographical model of the terrain. The UAVs can in turn present information, e.g. streaming video, back to the operator with the information being situated as 3D view frustum on top of 3D 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 still cannot report findings from a formal evaluation, we believe that *Flying Frustum* provides a unique human-UAV interface, and that the 3D online situated interaction it affords can enhance human-UAV awareness.

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