FlyMap: Interacting with Maps Projected from a Drone

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ABSTRACT

Interactive maps have become ubiquitous in our daily lives, helping us reach destinations and discovering our surroundings. Yet, designing map interactions is not straightforward and depends on the device being used. As mobile devices evolve and become independent from users, such as with robots and drones, how will we interact with the maps they provide? We propose FlyMap as a novel user experience for drone-based interactive maps. We designed and developed three interaction techniques for FlyMap's usage scenarios. In a comprehensive indoor study (N = 16), we show the strengths and weaknesses of two techniques on users' cognition, task load, and satisfaction. FlyMap was then pilot tested with the third technique outdoors in real world conditions with four groups of participants (N = 13). We show that FlyMap's interactivity is exciting to users and opens the space for more direct interactions with drones.

ACM Classification Keywords

H.5.2. User Interfaces: Input devices and strategies; I.3.6. Methodology and Techniques: Interaction techniques

Author Keywords

Interactive Maps; Human-Drone Interaction; Tour Guide; Projection; Mobile Interaction; UAV.

INTRODUCTION

Interactive maps are widely used for people to navigate to a location and discover their surroundings. Prior work shows that the interaction technique affects several factors such as the spatial understanding and memorization of the map. Moreover, we find that the choice of the technique depends on the device of use [33], so that interacting with a map on a phone will be different from interacting with a map on a robot.

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Figure 1. FlyMap in use in a tour guide context at Stanford University by a visitor defining what route to take using mid-air gestures.

Robots are increasingly available and can provide new services to users. For example, some socially assistive robots are designed to help elderly users with physical exercise [13], while in public spaces, receptionists [15] and tour guide robots [30, 38] can accompany visitors. In the case of a tour guide robot, expected interactions include greeting visitors, displaying information about the place or an artifact, answering questions, and guiding. Typical guidance would include showing a map to the person and possibly walking them through the artifacts they are interested in. Much research has been done in the past to improve human-robot interaction. Yet, these interaction principles cannot simply be translated into flying robots.

In this paper, we present FlyMap, a novel user experience for interactive maps projected from a drone. As drones allow additional use cases, such as being used as navigation guides [10] or for added safety [21], it is crucial to provide suitable interaction techniques. Through drones, we explore new forms of interaction where users can visualize and interact with geographic content displayed on the ground in front of them. We propose several scenarios for FlyMap and we designed and developed two suitable interaction techniques.

In an indoor study with 16 participants, we show the strengths and weaknesses of the two techniques, phone as Tactile and Spatial controller. We found that the techniques were equally preferred by the participants. Tactile was more often described as intuitive, however, it increased visual separation effects.

The Spatial technique improved recall of geographic elements, however it was more physically demanding. The results of the the indoor study guided the design of a third interaction technique: Mid-air gestures. FlyMap was then tested outdoors using this third technique in real world conditions with four groups of participants. We show that FlyMap is exciting to users and favors collaboration. This work contribute to opening the space for direct collocated human-drone interaction.

SCENARIOS

We envision several use cases for drone-based map interactions. Here we present two possible scenarios:

Scenario 1: Tour Guide Dan and Vicky are visiting a campus with their daughter Jenn, who has just been admitted. They are given a drone tour guide, which projects a large map for them to share. Vicky is interested in the housing options, Dan in the sports facilities, and Jenn wants to see the science buildings. They can all see the map together, get additional information on Points Of Interest (POI), and one by one select the places they want to visit. Once they agree on the places, FlyMap presents a tour to best fit their choices. They can now follow the drone that will guide them, being shown information about the campus, and asking questions to FlyMap along the way.

This scenario focuses on personalized experience for multiple users. The users do not have a precise destination in mind, and the experience matters more than the time required.

Scenario 2: Search and Rescue (SAR) After the storm, Matt and Kate are stuck on the rooftop of their building waiting for help. A drone is sent by a SAR team to find people and understand who is in greatest need of help. The drone gets close to Kate who can now gesture to it and input the number of people stuck at her location and report any injuries. Matt is worried about his family and uses the projected map to get real-time information about the status of the rescue efforts.

This scenario focuses on ad-hoc interaction with a drone acting as information provider in a context where smartphone usage is limited because of the lack of access to a power supply and the amount of time people may have been stranded.

The first scenario represents an everyday life example of the use of mobile technologies while the second scenario shows how FlyMap can address exceptional needs. Drones can navigate independently from users, proposing additional abilities, such as taking videos and pictures from a high vantage point or even spotting someone in the dark using thermal cameras.

As drones become more prevalent, we need to design for these emergent technologies. We focused on drones as they represent an under-explored area compared to ground robots and present additional safety challenges that require more thoughtful design. As a first step, this paper focuses on map interaction for selecting POIs for a guided tour (scenario 1), and not on following a drone that is moving along the tour path [25], projecting arrows on the floor [24], or even using the noise it produces or a leash to guide users [2].

This paper proposes the first investigation into interaction techniques for map exploration from a drone.

RELATED WORK

This section presents related work on robot tour guides, human-drone interaction, and projected geographic maps.

Robot Tour Guides

Burgard et al. [5] described that "an important aspect of the tour-guide robot is its interactive component." Their robot RHINO interacted through the press of a button on its body and audio feedback. They found that a user encountering a robot should be able to interact with it intuitively without prior training. Minerva [38], a robot exhibited in a Smithsonian museum, was designed as a "believable social agent" with facial expressions, moods, and voice output. More recently, Sasai et al. [30] proposed a robot tour guide that projected an interface that the user could step onto to input their destination, before being guided by projected information along the way.

Human-Drone Interaction

Interacting with flying robots presents specific differences from interacting with ground robots. In particular, touch can be dangerous (although not impossible [1, 16]), and audio feedback is compromised because of the noise [9]. We find several proposed interaction strategies in the literature. In terms of direct input: gesture [6, 12, 26, 27] and voice commands [12] are most prevalent in collocated settings. Output can be provided through the motion of the drone [27, 35], lights [36], a screen attached to the drone [32], projection [31], and emotion through flying behavior [8, 21].

Projected Geographic Maps

Projection can be used as a means to provide people with geographic information [17, 18]. Projection can be used instead of a screen when it is not convenient to look at the device, as with a bike navigation system [11]. We believe that the potential to support projected map exploration and navigation has not been fully explored. FlyMap contributes to the design space of mobile projected geographic maps.

CHOICE OF INTERACTION TECHNIQUES

Projection is the most suitable drone output for displaying an interactive map to one or more users. Our design is closest to [30] with a ground robot, and similar to prior work envisioning interacting with a drone projected UI [39, 23]. We propose to use ground projection since it is the most available projection space in the proposed scenarios.

Since the interaction happens in an ad-hoc mobile context, no additional hardware should be added. Based on these constraints and prior research, we identified three very suitable interaction techniques: using a phone as Tactile or Spatial controller, and Mid-air gestures.

I/O DRONE METHODOLOGY

Since we are in the early stages of human-drone interaction research, there are no set methodologies for evaluating novel interaction techniques. We propose the Indoor/Outdoor (I/O) drone methodology that consists of first testing the interaction with the drone setup in a fixed setting indoors before moving to the real world setting outdoors. This way the technique is tested in the best possible conditions before introducing the constraints of the drone, such as its movements or the weather.

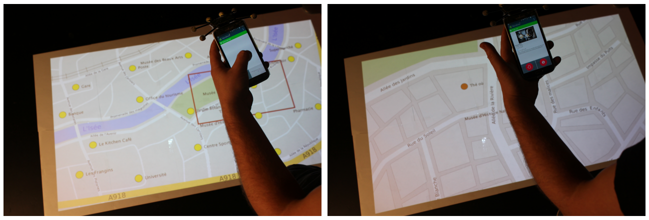

Figure 2. FlyMap Indoor Prototype (Left) Tactile: touch screen used to control the map. (Right) Spatial: phone as controller, with additional details about Points of Interest displayed on the screen.

FLYMAP DESIGN & EVALUATION (INDOOR)

To our knowledge, this work is the first investigation of map interactions in the context of a drone.

Interaction Techniques

We decided to first investigate and implement the interaction techniques with a phone used as controller, so they could be thoroughly compared. Since most people in Scenario 1 carry a smart phone, these techniques do not require additional hardware.

Tactile: All actions are performed through touch on the phone's screen. The information regarding a selected POI is displayed on the phone's screen (Figure 2(a)).

Spatial: The position of the phone in space is used to control the map view, except for the zoom. To select a POI the user hovers over it and taps the screen, which displays relevant information (Figure 2(b)).

Map Design

Three maps were designed: Tasks 1 & 2: M0 and Task 3: M1 & M2 (Figure 3). The maps M1 & M2 were counterbalanced for interaction techniques, designed for equivalent difficulty, and were used in Task 3 only so to limit their memorization time. The fictitious maps layout was inspired by [28]. Their design respected cultural specificities, here France. M1 & M2 present 20 POIs each from 4 categories: restaurants, transportation, tourist attractions, and services. We used similar names (e.g., M1: Museum of Fine Arts, M2: Contemporary Art Museum) and popular names of restaurants and streets.

We implemented typical map functions [33]: zooming, panning, and selecting a POI. There are two levels of **Zoom**: an overview "zoom out" and a detailed view with additional information "zoom in". In "zoom out" view, a red rectangle indicates the portion of the map that will be displayed when zooming in (Figure 2(a)). Zooming out brings the view back to the center of the map. **Panning** is available in "zoom in" view and is limited by the borders of the map. **Points of Interest** can be selected at the "zoom in" level.

Indoor Study

The study compared the usability of the Tactile and Spatial techniques when interacting with a floor-projected map.

Apparatus

We used a projector (LG PF80G), an Optitrack tracking system, and a phone (Samsung Galaxy Zoom K).

Figure 3. European-style Map 2 used in the Indoor Study for Task 3

Participants

16 volunteers (22-40 y.o., μ=27.2, SD=4.3) were recruited evenly across genders and distributed evenly across conditions. Participants completed the Santa Barbara Sense of Direction Scale (SBSOD) for self-evaluation of their spatial abilities [20]. SBSOD scores vary from 1 (low) to 7 (high). Participants' scores varied from 2.7 to 6.3 (μ=4.4, SD=1.1).

Procedure and Measures

The study was composed of three tasks performed with both interaction techniques. The order of techniques and maps was counter-balanced within participants. As in [22], we designed 3 tasks so that the users would both pan and zoom (see below). For each technique, the experimenter described and demonstrated the prototype and allowed the participant to get familiarized. Experimental tasks began once the participant felt comfortable. After each set of tasks, participants filled out NASA-TLX [19] and SUS questionnaires [4] about the technique they just tried. At the end of the experiment, participants were asked qualitative questions about the techniques and drone-based navigation.

Task 1: Zoom and Selection focused on selection of POIs: navigating to a marker and clicking on it [22]. The task started in the "zoom out" level. The POI's name was displayed on top of the map, and in an area highlighted in blue to remove search time from our measurements. The participant had to move the cursor onto the blue area and zoom in. Then, they could select the POI. The task restarted with a new target POI in the "zoom out" level for 10 iterations.

Task 2: Pan aimed at following a path displayed on the "zoom in" map, as accurately and as fast as possible. Once the participant reached the end of the path, another one appeared, and the view was moved to its beginning for 10 iterations.

Task 3: Exploration and Memorization was inspired by previous studies [18, 29] and its aim was to identify POIs with certain characteristics. We informed participants that they would be asked questions about the map later on without specifying the type of information to memorize. The experimenter asked a series of 10 questions such as "Which museum closes the latest?". To answer, participants needed to zoom, pan, and select POIs and read their descriptions. At the end, the projection was stopped and the participant was given a printed version of the map, containing only the main geographic elements (highway, river, and park). The participant then had to sketch a map containing all POIs that they remembered, taking as much time as needed.

We measured: Success Rate for effectiveness, Task Completion Time for efficiency, and NASA-TLX and SUS questionnaires for usability and satisfaction. Since maps serve the purpose of acquiring spatial knowledge, we also studied the techniques' impact on memorization.

Results

We analyzed both interaction techniques regarding their usability and impact on spatial learning.

Success Rate

All participants were able to successfully complete Task 1 and 2 (perfect score). For Task 3, no one succeeded in replying correctly to all questions, with an average score of 7.8 out of 10 (SD=1) in Tactile and 7.7 out of 10 (SD=0.7) in Spatial.

Task Completion Time

The average task completion time for tasks 1 and 2 in Tactile was 5.5 min (SD=2), and in Spatial: 5.8 min (SD=1.8). For task 3, the average duration in Tactile was 5.6 minutes (SD=1.3) and in Spatial: 5.5 minutes (SD=1.3). We did not find any significant difference in completion time.

Workload

In analyzing the NASA-TLX results, only Physical Demand revealed a significant difference ($Z = -3.23$, $p < .001$) across techniques, with Spatial (μ=3.6, SD=1.5) being more physically demanding than Tactile (μ=1.6, SD=0.8). Prior work [34] has investigated fatigue in tactile vs. spatial interactions.

Satisfaction

SUS values ranged in Tactile from 53 to 95 (μ=78, SD=13.4), compared to in Spatial from 38 to 95 (μ=75, SD=17.2). The mean values are in the range of good usability [3].

We found that half of the participants preferred one technique over the other. When asked about the advantages and drawbacks of each technique: **Tactile** was described as intuitive (10 participants), quick (7), and precise (6). Several users criticized the visual separation effects between the map projection and the list of POIs on the screen, which is in line with prior work [7, 18]. **Spatial** was described as playful (4), fun to use (2), and immersive (2). Four participants enjoyed moving to interact with the map. Three found Spatial more intuitive since the interaction was focused on the projection and not the screen, with 2 users preferring this. Four participants mentioned the shadows caused by the body and the phone.

Spatial Cognition

We counted the number of correctly named POIs on each map, only accepting precise choice of names (e.g., "sports hall" not accepted for "gymnasium"). Users correctly remembered more landmarks with Spatial (μ=5.7, SD=2.6) than with Tactile (μ=4.5, SD=2.3). A Wilcoxon rank sum test revealed a significant difference ($Z = -2.14$, $p < .05$). Also, more users stated that they lost the overview of the map with 4 users (25%) in Tactile and only 1 (6%) in Spatial. This is in line with previous studies that reported an advantage of spatial interfaces for memorization of spatial information [37]. The Gardony Map Drawing Analyzer [14] of the sketch map did not reveal any significant difference across interaction techniques or maps.

Acceptability of drone-based maps and navigation

We asked participants how they felt about a drone-based system. Eleven participants (70%) felt secure using a drone-based navigation system, and only one stated being worried about this scenario. Participants provided ideas for improvement, such as dynamically displaying excerpts of movies or telling stories about places, voice interaction, and 3D visualization. Three participants suggested direct gestural interaction instead of using the phone. Finally, participants suggested a broad range of usage scenarios, such as visiting foreign cities without any language barriers, guidance for hiking or in museums, and search and rescue scenarios.

Lessons Learned

We learned that using a phone as a controller works well with both techniques. We could not identify one technique as better than the other, as there was no significant difference in terms of effectiveness (success rate) and efficiency (task completion time). Even if the Spatial technique was less familiar, half of the participants preferred it. We found the Spatial technique to be beneficial for spatial learning, but requiring significantly more physical effort. In the Tactile condition, the visual separation effects of the two displays was disturbing. Using an iterative design process, we designed the next prototype based on these findings.

FLYMAP DESIGN & EVALUATION (OUTDOOR)

In this section, we describe the adaptations made to implement FlyMap on a drone and its evaluation in-situ.

Implementation

Some adaptations were needed to increase the portability of the system and ensure full mobility on a drone. We also designed and developed a third interaction technique (Mid-air gestures) for outdoor interaction with FlyMap.

Interaction Technique

We opted for a one-handed mid-air gesture interface. This technique has the benefits of providing spatial cues (as Spatial did in the indoor study) while removing visual separation effects. It also fits with future Scenario 2. In a pilot study with the drone, we found that removing the phone increased interface appeal and mitigated discomfort.

The interaction requires a short calibration phase (a few seconds) where the user stands on projected foot marks. The system calculates the user's height, hand pixel size, and arm radius. The user can then interact with the system. For simplicity of use, we propose a two-gesture vocabulary based on hand orientation: 1. To navigate, the user moves a cursor with their palm down (Figure 4) to a desired map area, 2. To zoom in or select, they tilt their hand 90 degrees to the side.

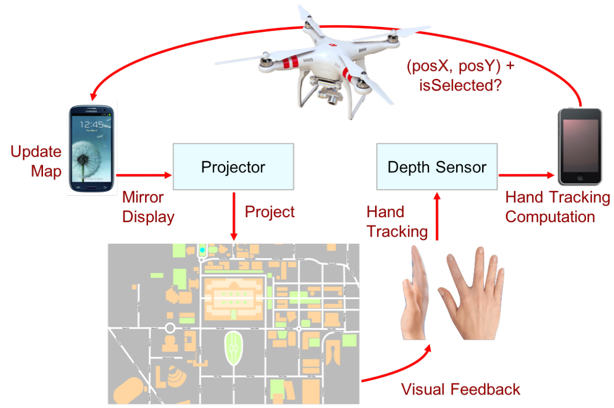

Figure 4. FlyMap Outdoor Architecture with the two hand gestures used for input.

Hardware
We updated the hardware with lightweight and mobile alternatives that can be flown on a drone. A 3DR Solo drone was fitted with a laser projector (Celluon PicoPro), and a depth camera (Structure Sensor) connected to an iPod Touch for input tracking. The map interface was rendered on the projector using an Android phone (Google Nexus 6P), connected using Miracast. All devices but the Android phone were attached to the base of the drone for a total weight of 360g (12.7oz).

Outdoor Implementation
The architecture is shown in Figure 4.

Input The Optitrack used indoor was replaced by a Structure Sensor facing down. It determines the hand position in space and the gesture type based on the pixel size of the hand compared to the calibrated one. The computation is done on an iPod Touch that broadcasts these values to the Android client (Google Nexus 6P).

Output After receiving the input data, the Android phone updates the cursor position and the map is projected by the laser pico-projector via a wireless connection.

The interface is designed to maximize the size of each icon, and in the described setup we obtained a selection accuracy of 98% in real world conditions. This system functions in low lighting conditions.

Outdoor Study
We ran a qualitative user study to validate FlyMap's usability and suitability in real world conditions. Thirteen volunteers (4f/9m, 19-37 y.o., μ=24.9, SD=5.5) were recruited from Stanford University and divided into a group of four and 3 groups of three. Three pairs of participants knew each other beforehand. All but one had seen a drone before, though none had significant experience interacting with one, apart from one participant who owned a drone. The study took about 45 minutes per group, and participants were each compensated $15.

Participants were asked to role-play a variation of Scenario 1 (see Figure 1), where FlyMap is used as a campus tour guide. They were invited to plan a tour as a group by selecting POIs on the map, with individual pre-defined interests. Groups made their own decisions as to who controlled the interface and how control was handed off between them. Two experimenters observed and recorded these decisions. The study was run outdoors in a large secluded area. We found that groups took approximately 10 minutes to complete the task, so battery life did not end up being an issue in interaction time. The drone was flown at an average altitude of 3.7 meters. The group task was followed by a semi-guided interview where participants were asked to comment on the positive and negative points of the interface, discuss group interaction, safety, and to list features they wished to see in the future.

Observations
The enthusiasm among participants was high. They were collaborative, helping each other figure out parts of the interface and even cheering when another participant successfully added a POI to the tour. Each and every participant interacted with the interface. In two of the groups, participants took pictures of FlyMap during the study. None of the participants focused on the drone, instead they focused on the projection and discussed the experience with each other.

The most common challenge participants had was in keeping track of the cursor position due to the jitter of the drone. To regain control, participants would behave in unexpected ways, such as walking over the map to find the cursor, switching orientations around the map, or changing hands to control. These actions were not supported by the interface and led to some frustration among participants.

We observed some multi-user engagement around the interface, where groups would attempt to have multiple participants control the interface simultaneously. Every group, however, eventually realized that the system only supported single user interaction. The recalibration feature of the interface, meant to be used in between participants, was used by only one group.

Interview
Participants commented positively on the novelty and visual nature of the interface. They liked the simplicity of the gestures. They felt engaged, even while watching other participants use the system. Participants, as expected from observation, commented negatively on the difficulty of cursor control. Some also felt a slight discomfort from the wind and noise generated by the propellers.

When asked about multi-user interaction, almost every participant first asked if the use of the interface would involve a leader taking primary control of the interface. If so, participants stated that the size of groups able to use the interface effectively would be significantly higher. Used as is (without a named leader), participants thought the system could support groups from 3 to 20 users at a time (μ=7.7).

The average safety score of the interface was 3.7 out of 5 being the safest. The participants who did not feel as safe had less experience with drones and unrealistic concerns such as it falling from the sky when running out of battery. No participant expressed major concern. Most desired a positioning of the drone slightly in front of themselves, instead of overhead. The flying height was acceptable to all.

When asked about desired features, 12 out of 13 participants asked for the ability to use voice communication, both for input and output. Other common suggestions were to have the interface include recommended routes and for the drone to be able to take pictures along the way.

DISCUSSION

We find that map exploration and navigation is possible from a drone. All three techniques implemented for FlyMap present some advantages and drawbacks, without a clear winner. The indoor and outdoor studies allowed us to gain valuable insights, which we discuss here.

Choice of Interaction Technique

In the indoor study, we used a phone as controller for either Tactile or Spatial interaction. Preference for each technique was split evenly among participants. Users mentioned finding the Tactile technique intuitive more often. We observed that using the Spatial technique, participants were able to remember more POIs correctly, which is an important aspect of map exploration and navigation support. On the other hand, the Spatial technique comes with higher physical demand.

In the outdoor study, we showed that a gesture-based interface was usable in real world conditions on a drone. We found that participants were enthusiastic, even when they were only observing and not controlling the interface. Another important observation concerned collaboration between users. The projection served as a shared display for group interaction and we observed people helping each other during the study. While we did not implement multi-user interaction at this point, in the future, the system should recognize gestures from different users, allowing people to interact together in groups.

As a recommendation for future drone-based maps and navigation systems, we suggest that all the visual information should be integrated into a single display (the projection). We believe that spatial interaction makes a lot of sense in the context of geographic maps, especially since it is known that kinesthetic cues can improve memorization of spatial information [37]. Of course, other factors will impact the choice of interaction techniques. For instance, using spatial interaction requires space to move around, and for the user to bend their arms, which might not be possible for users with motor impairment.

Human-Drone Interaction

Participants were excited about interacting without a controller. They enjoyed interacting with people they had not met before, and were able to collaboratively perform a task. Although, they wished for a more robust interface, they liked the large display area, found the interaction intuitive, and the experience engaging and playful. While there is a certain novelty factor, it is undeniable that this interaction would not have been as fun and collaborative with a phone. We believe that this experience is promising in the adoption of drones.

We found that participants who did not feel as safe had less experience with drones and concerns such as it falling from the sky when running out of battery, which is in line with [9]. In our study some users also mentioned a discomfort from the wind and noise generated by the propellers.

LIMITATIONS

The use of projection and infra-red technology constrains the system to be used only in low lighting conditions. We believe that projection technology will make further progress in terms of brightness (for instance through the use of lasers) and that other techniques can be explored for daylight interaction.

FUTURE WORK AND CONCLUSIONS

We have investigated map interaction as a first and necessary step for a drone-based navigation aid. In our future work, we will study which navigational cues (e.g., arrows, distances, or information about obstacles) should be projected to the user, how, and when. Our work can also also be continued in several other directions. The interaction techniques can be improved to work better in the outdoor context (with the drone moving and in daylight), or with different scenarios, such as with a large number of users.

In this paper, we investigated suitable interaction techniques with geographic maps projected from a drone. We implemented FlyMap as a novel user experience. We conducted a comprehensive study in a controlled indoor environment to compare two interaction techniques (Tactile and Spatial) using a phone as controller. Results showed that the techniques were equally preferred by participants. The Spatial technique was significantly more physically demanding but improved recall of geographic elements. The Tactile one was more often described as intuitive, however it increased visual separation effects. Based on these results, we implemented the final FlyMap version on a drone with mid-air gestures interaction. We evaluated it in a multi-user context in a real world environment outdoors. We observed that participants enjoyed it and collaborated around it. The results of our studies show the potential for interaction with geographic maps projected from drones and potentially other robots.

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