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ABSTRACT
Interactive maps are now ubiquitous in our daily lives. Whether in the car or at the mall, maps help us find our destinations and discover more about our surroundings. Yet, interacting with maps is not straightforward and depends on the device the map is used on. As drones become more widespread, how will we interact with drone-based maps and navigation devices? In this paper, we propose FlyMap as a novel user experience for interactive maps projected from a drone. We iteratively designed three interaction techniques for FlyMap's usage scenarios. In a comprehensive indoor study (N = 16), we show the strengths and weaknesses of the techniques on users' cognition, task load and satisfaction. We then pilot tested FlyMap outdoors in real world conditions with four groups of participants. We show that its interactivity is exciting to users, opening the space for more direct interactions with drones.

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.

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; sUAV.

INTRODUCTION
Robots are increasingly available and propose new services to users. For example, some socially assistive robots are designed to help elderly users with physical exercise [14], while in public spaces, receptionists [16] and tour guide robots [38, 30] propose to accompany visitors. In the case of a tour guide robot, expected interactions include: greeting visitors, communicating in a language they understand, displaying information about the place or artifact, answering questions, and guiding the person. Typical guidance would include showing a map to the person and possibly walking them through the artifacts they are interested in. We find that much research has been done in the past decades to improve human-robot interaction. Yet, these interaction principles cannot simply be translated into flying robots (a.k.a drones).

In this paper, we present FlyMap, an example of a novel user experience for interactive maps projected from a drone. As drones propose additional use cases, such as being used as navigation guide [11] or for added safety [22], 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. Then, we iteratively designed three suitable interaction techniques.

In an indoor study with 16 participants, we show the strengths and weaknesses of the first two techniques (phone as a spatial controller and phone as a tactile controller). Both techniques were equally preferred by the participants. The Spatial technique was significantly more physically demanding but improved recall of geographic elements. The Tactile technique was more often described as intuitive, however it increased visual separation effects. The results of the the indoor study and the taxonomy guided us for 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 its interactivity is exciting to users and favors collaboration, opening the space for more direct interactions with drones.

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SCENARIOS

We envision several use cases for drone-based map interactions presented in two scenarios:

Scenario 1: Tour Guide Vicky and Dan are visiting a campus with their daughter Jennifer, who has just been admitted. They are given access to a drone tour guide, which projects a large map for them to share. Vicky is an alumnus of the university and is interested in buildings constructed since she graduated, Dan is interested in the housing options, and Jennifer wants to see the science buildings. They can all see the map together, get additional information on points of interest, 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 who will guide them along campus, being shown information about the environment, and asking questions to FlyMap along the way.

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

Scenario 2: Autonomous Drone for Search and Rescue After the storm, Matt and Kate are stuck on the rooftop of their building waiting for someone to come and help them. A drone is sent to evaluate the situation and help the rescue team find people and understand who is in greatest need of help. The drone gets close to Matt who can now gesture to it and input the number of people stuck at his location and report any injury. Kate is worried about her family and thanks to Flymap, gets to navigate a map of the area where she can see 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 smartphones 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 everyday life examples of the use of mobile technologies while the second scenario shows how FlyMap can address specific 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 ground and flying robots are becoming more prevalent, we see them becoming more common in such scenarios, and find the need to design for these emergent technologies. We decided to focus on drones because 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], or projecting arrows on the floor [24], or even using its noise or a leash to guide visually impaired users [2].

This paper proposes a first investigation into suitable interaction techniques for map exploration from a drone. As a first step towards enabling the above scenarios, we investigate several interaction techniques and describe the advantages and drawbacks of each technique.

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] describe that "an important aspect of the tour-guide robot is its interactive component." Indeed, any user encountering a robot should be able to interact with it in an intuitive manner without the need for training. Their robot RHINO interacts through the press of a button on its body and audio feedback. 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] propose a robot tour guide with projection-based interaction. The robot projects an interface that the user can step onto to input their destination, and then guides the user by projecting information along the way.

Human-Drone Interaction

Interacting with flying robots (aka drones) presents specific differences to interacting with ground robots. In particular, touch can be dangerous (although not impossible [1, 17]), and audio feedback is compromised because of the noise [10]. We find several proposed interaction strategies in the literature. In terms of direct input: gesture [8, 13, 26, 27] and voice commands [13] 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 [9, 22].

Projected Geographic Maps

Projection can be used as means to provide people with geographic information, even in a mobile context [18, 19]. It can be used instead of a screen when it is not inconvenient to look at the device or hold it, as has been demonstrated for instance in a projected bike navigation system [12]. We believe that the potential to support map exploration and navigation through projection has not yet been fully explored. FlyMap contributes to the design space of mobile projected geographic maps.

CHOICE OF INTERACTION TECHNIQUES

Projection is the only of the above mentioned drone outputs capable of displaying an interactive map to one or several people. Our design is closest to [30] with a ground robot and similar to prior work envisioning interacting with a drone projected UI [39]. We propose to create a fully interactive projection system using ground projection, since it is available at all times (and there might be no walls nearby).

For input, we defined that the interaction takes place in a mobile context and no additional hardware should be added. Based on these constraints and a taxonomy on map interaction techniques [6], we identified three most feasible and realistic interaction techniques: using a phone as touch or as spatial controller, and id-air gestures. We decided to first investigate the identified preferred techniques using a phone controller, so we could easily compare the techniques. Since most people in scenario 1 carry a smart phone with them, these techniques are not considered as requiring additional hardware.

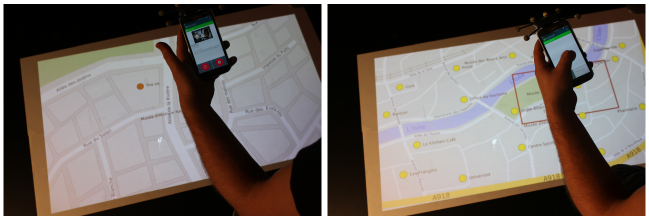

Figure 2. FlyMap Indoor Prototype (Left) the phone is used as controller, with additional details about Points of Interest displayed on the screen. (Right) the phone's touch screen is used to control the map.

Figure 3. Map M2 (European-style map) used in the Indoor Study for Task 3, counter-balanced with M1

FLYMAP DESIGN & EVALUATION (INDOOR)

This section discusses the first two interaction techniques. While prior work investigated the use of phones or mid-hand gestures with maps, there is little work in the combination with floor-projected maps, and no prior work in the context of drone projection [6]. We address this gap in the literature.

Interaction Techniques

We implemented two interaction techniques with a phone used as controller for comparative evaluation.

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 that was too difficult to use. 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: M0 (Tasks 1 and 2), M1 and M2 (Figure 3, Task 3). M1 and M2 were counterbalanced for interaction techniques (Tactile and Spatial). They were used in Task 3 only as to limit the map memorization time. The fictitious maps layout was inspired by [28]. As the studies took place in two countries (France and USA), two sets of maps were designed based on cultural specificities, such as following a grid-like structure in the USA and having a less regular layout in France. M1 and M2 were designed for equivalent difficulty, with 20 POIs on each map from four categories: restaurants, transportation, tourist attractions, and services. We used corresponding names on both maps (e.g., Museum of Fine Arts on M1 and Contemporary Art Museum on M2) and popular names of restaurants and street names.

We implemented typical map functions [33]: zooming, panning, and selecting a point of interest (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(b)). 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. **Point of Interests** can be selected in "zoom in" level.

Indoor Study (Method)

The study compared the usability of the Tactile and Spatial techniques when interacting with a floor-projected map. As such we measured: success rate as effectiveness, task completion time for efficiency, and questionnaires for satisfaction. As maps serve the purpose of acquiring spatial knowledge, we studied the techniques' impact on memorization.

The prototype was set up in a controlled indoor environment without the constraints of the drone (e.g., limited battery life, drone movement, or weather patterns). This system was composed of a projector (LG PF80G) aimed at the ground, an Optitrack tracking system, and a phone (Samsung Galaxy Zoom K).

16 volunteers (8m, 22-40y.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 [21]. 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

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 [23], we designed three 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 participants felt comfortable. After each set of tasks, participants filled out a NASA-TLX [20] and SUS questionnaires [4] about the interaction technique they just tried. At the end of the experiment, participants were asked qualitative questions about the techniques and general drone-based navigation.

The first task "zoom and selection" focused on selection of POIs, i.e., navigating to a geographical marker and clicking on it [23]. The task started in the "zoom out" level. The name of the POI was displayed on top of the projected 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, the user could select the POI. The task then restarted in "zoom out" level with a new target POI for 10 iterations.

The goal of the second task "pan" was to follow 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. The task was repeated 10 times.

The task "exploration and memorization" focused on map exploration and was inspired by previous studies [19, 29]. The goal was to identify POIs with certain characteristics. We informed participants that they would be asked questions about the map without specifying the type of information to memorize. The experimenter then asked a series of 10 questions such as "Which museum closes the latest?". To answer the questions, participants needed to zoom, pan, and select POIs to read the descriptions. At the end, the projected map was removed and the participant was given a printed version of the map, containing only the main geographic elements (highway, river, park). Users then had to draw a sketch map containing all the POIs that they remembered, taking as much time as needed.

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 7.8/10 (SD=1) in Tactile and 7.7/10 (SD=0.7) in Spatial condition.

Spatial Cognition

We counted the number of correctly named POIs on each map and only accepted identical choice of names (e.g., "sports hall" was not accepted for "gymnasium"). Users remembered more landmarks correctly with Spatial (μ=5.7, SD=2.6) than with Tactile (μ=4.5, SD=2.3). A Wilcoxon rank sum tests revealed a significant difference ($Z = -2.14$, $p < .05$). Also, more users stated that they lost the overview of the map in the Tactile (4 users, 25%) than in the Spatial condition (1 user, 6%). This is in line with previous studies that reported an advantage of spatial interfaces for map exploration and memorization [37]. The Gardony map drawing analysis (GMDA) [15] of the sketch map did not reveal significant difference across interaction techniques or maps.

Time

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

Workload

In the analysis of the NASA-TLX results, only Physical Demand revealed a significant difference ($Z = -3.23$, $p < .001$) across interaction techniques, with Spatial (μ=3.6, SD=1.5) being more physically demanding than Tactile (μ=1.6, SD=0.8). This result differs from prior work [34] where more people reported fatigue in the Tactile vs. Spatial condition.

Satisfaction

In Tactile condition, the SUS values ranked from 52.5 to 95 (μ=77.66, SD=13.43), compared to 37.5 to 95 (μ=75.31, SD=17.20) in Spatial. According to Bangor et al. [3] the mean values are in the range of good usability.

We found that exactly half of the participants preferred one technique over the other. When asked about the advantages and drawbacks of each technique, 6 participants described the Tactile technique as precise, and 7 as quick. Furthermore, 10 participants found the Tactile technique intuitive and 4 found it easy to use and familiar. Several users criticized the visual separation between the map projection and the list of POIs on the screen, which is in line with prior work [19, 7].

Four participants found the Spatial technique playful, 2 found it fun to use, and 2 immersive. Three users found the Spatial technique more intuitive since the interaction was focused on the projection and not the screen, and 2 users stated preferring this visualization. Four participants enjoyed moving to interact with the map, 4 participants mentioned the shadows caused by the user's body, arm and the phone.

Acceptability of drone-based maps and navigation systems

We asked participants how they felt about a drone-based system. Eleven participants (68.74%) felt secure using a drone-based navigation system, and only one stated being worried about this perspective. Participants came up with ideas for improvement, such as dynamically displaying excerpts of movies or telling stories about places, voice interaction or 3D visualization. Three participants suggested direct interaction instead of using the phone as a controller. Finally, participants suggested a broad range of usage scenarios, such as autonomously 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 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 efficiency (time) or effectiveness (success rate). 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. However, the Spatial technique requires significantly more physical effort. In the Tactile condition separation of the visual display was disturbing. In an iterative design process, we designed our next prototype based on these findings.

FLYMAP DESIGN & EVALUATION (OUTDOOR)

In this section, we describe FlyMap on a drone and its evaluation in situ.

Implementation

Some adaptations were needed to increase the portability of the system, ensuring full mobility on a drone. We updated the hardware with lightweight and mobile alternatives that can be flown on a drone and adapted the interaction techniques.

Hardware

A 3DR Solo drone was fitted with a laser projector (Celluon PicoPro). A depth sensor (Structure Sensor) was connected to an iPod Touch for input tracking. The map interface was rendered on the projector using an Android phone (Google

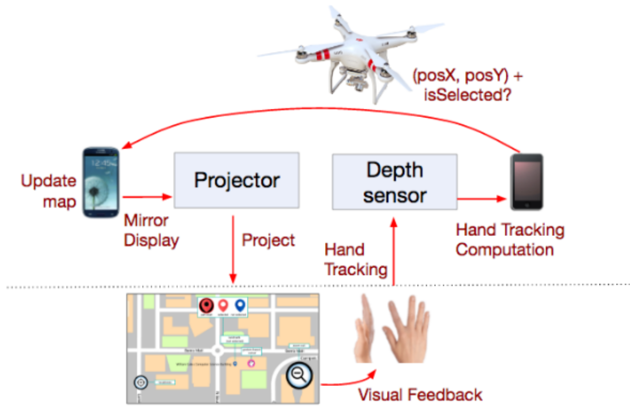

Figure 4. FlyMap Outdoor Architecture with the two hand gestures used for input.

Nexus 6P), connected using Miracast. All devices but the Android phone were attached to the base of the drone with cable ties and Velcro for a total weight of 360g (12.7oz).

Interaction Technique

In a pilot study, users tried FlyMap with the Spatial interaction technique. We found that the visual separation effects were intensified when the projection moved (the drone never being completely stable), making even the Spatial interaction difficult and tiresome. We also found that the presence of the phone affected the "wow" factor for users who solely wanted to focus on the projection and have the impression that they were directly interacting with the drone. To increase interface appeal and mitigate discomfort, we designed a gesture-controlled interface to replace the phone. We designed the interface to maintain the benefits of providing spatial cues.

The interaction requires a calibration phase where the user stands on projected foot marks. Once detected, users are instructed to first extend and then retract their hand. 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. To navigate around the map, the user moves a cursor with their palm down (Figure 4) to a desired map area. They can then tilt their hand 90 degrees to the side to zoom in or select on the interface.

Outdoor Implementation

The architecture is described in Figure 4.

Input The Optitrack system used in the indoor study was replaced by a lightweight depth 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 hand size. The computation is done on an iPod touch that broadcasts these values to an Android client (Google Nexus 6P).

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

Outdoor Study

We ran a small qualitative user study to validate FlyMap's usability and suitability in real world conditions. 13 participants (4f/9m, 19-37 y.o., μ=24.9, SD=5.5) were recruited from our institution. They were divided into a group of four and three 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 a drone, apart from a participant who owned a drone. The study took about 45 minutes per group, and participants were compensated $15.

Participants were asked to role-play a variation of Scenario 1 (as described in the introduction of this paper, 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 participants. Two experimenters observed and recorded these decisions. The study was run outdoors on 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 an interview where participants were asked to comment on the positive and negative points of the interface, to discuss group interaction, safety, position of the drone, and to list five features they wished to see in the future.

Observations

The enthusiasm among participants was high. Participants were very collaborative, helping each other figure out parts of the interface and even cheering when other participants 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. This was 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 are 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 supports 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. They 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 (5-point Likert scale, 5 being the safest). The 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. No participant expressed major concern. Most participants desired a positioning of the drone slightly in front of themselves, instead of overhead. The height at which the drone was flown at was acceptable to all participants.

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 all three techniques implemented for FlyMap present some advantages and drawbacks, without a clear winner. Nonetheless, 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 input. 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 demands.

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. The projection served as a shared display for group interaction and we observed people helping each other to figure out the interface. Participants generally struggled with keeping track of the cursor position, and we need to improve this in the future.

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 the space to move around and the user to bend their arms, and this might not be accessible for users with motor impairment.

Human-Drone Interaction

In the outdoor study, we found that participants were excited about interacting with a drone, and especially not having to use 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 possible 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 [10]. In our study some users also mentioned a discomfort from the wind and noise generated by the propellers.

In our current studies, we have investigated map interaction as a first and necessary step of a drone-based navigation aid. Other researchers have investigated how a drone could be used to guide people along a path [2, 22] or by following arrows [24]. In our future work we intend to continue in the field of designing navigational aids such as studying which navigational cues (e.g., arrows, distances, or information about obstacles) should be projected to the user, how, and when.

LIMITATIONS

The current version of the system has some limitations that make it hard to build a real-life FlyMap system today. The use of projection 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 output techniques can be explored for daylight interaction.

FUTURE WORK AND CONCLUSIONS

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 environment to compare two interaction techniques (Tactile and Spatial) using a phone as controller. Results showed that the techniques were equally preferred by the participants. The Spatial technique was significantly more physically demanding but improved recall of geographic elements. The Tactile technique 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 piloted this technique in a multi-user context in the real world environment and noticed that participants enjoyed it. We also observed collaborative behavior. The results of our studies show that all three techniques have potential for interaction with projected geographic maps, using drones or other mobile agents.

Our work can be continued in several directions. The interaction techniques can be improved to work better in the outdoor context (with the drone moving and daylight), or in different scenarios, for example with a larger number of users. We also intend to study how navigational cues should be provided to a user following the system along a path. Finally, some findings from our study are not limited to drones, but could be extended to other devices, such as ground robots.

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