Midair Displays: Concept and First Experiences with Free-Floating Pervasive Displays

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ABSTRACT

Due to advances in technology, displays could replace literally any surface in the future, including walls, windows, and ceilings. At the same time, midair remains a relatively unexplored domain for the use of displays as of today, particularly in public space. Nevertheless, we see large potential in the ability to make displays appear at any possible point in space, both indoors and outdoors. Such displays, that we call *midair displays*, could control large crowds in emergency situations, they could be used during sports for navigation and feedback on performance, or as group displays. We see midair displays as a complementary technology to wearable displays. In contrast to statically deployed displays they allow information to be brought to the user anytime and anywhere. We explore the concept of midair displays and show that with current technology, e.g., copter drones, such displays can be easily built. A study on the readability of such displays showcases the potential and feasibility of the concept and provides early insights.

Keywords

Midair Displays, Pervasive Display, Drones, Free-Floating Displays, Interaction Techniques

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: Evaluation/methodology; H.5.m [**Information interfaces and presentation**]: Misc

1. INTRODUCTION

Displays can be found in many public spaces in the form of advertising and information displays or as artistic installations. Through novel display technologies (e.g., eInk, OLED), we envision that in the future, literally every surface could be transformed into a display, ranging from floors and walls to ceilings and windows. Such displays can reach passersby in different situations and places. Yet, they are usually installed in a fixed place and rely upon location, orientation, and viewer distance to be optimally perceived.

In contrast to such static displays, we see large potential in autonomous, free-floating displays that can change their position to appear at any given point in space and approach the user – we refer to such displays as *midair displays*. In an emergency situation such as a fire or earthquake, statically deployed displays may become unusable due to power outage or may even be destroyed. In such cases, midair displays could be used to show emergency instructions and guidance to people. Further scenarios include navigation as well as (personalized) group displays delivering information to people doing outdoor sports or tourists exploring a city. With our work we aim to lay the foundation for future research on midair displays, particularly interaction with the display and means to adapt the display based on the user context.

Figure 1: A sketch of the envisioned midair display with a map attached to a drone.

The contribution of this paper, in which we explore the concept of free-floating midair displays, is threefold. We first describe scenarios that outline the potential of the approach. Second, we present a functional prototype consisting of a copter drone to which we mounted a remotely controllable iPad. Third, we quantitatively and qualitatively explore the concept by demonstrating our prototype, running a brief reading test, and conducting a series of interviews.

2. RELATED WORK

Over the last years the notion of using public displays as a communication medium has been proposed [3]. There is a good understanding of different forms, application areas, and usage aspects of pervasive displays. Alt et al. provide an overview of success factor for public displays and discuss their deployment [1]. It is striking that the vast majority of these displays are installed in fixed locations, such as shop windows, public places, or facades.

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Figure 2: Midair displays can be used in different situations, including scenarios where they are used as personal companions (e.g., sports – left), or where they actively approach the user (emergency situations – center; tourist information – right).

Early approaches that try to overcome the static nature of wall-mounted displays include the *Everywhere Displays Projector* [10]. In this project, a movable mirror allows content to be projected on arbitrary surfaces in the surrounding space. The concept was explored further by Hardy et al. who created the *UbiDisplay* [5], a ubiquitous interactive surface using projection and a depth camera.

A challenge of these approaches is the need for a static installation of the projector. This can be overcome by the use of mobile projectors. An extensive overview of the design space of personal projection and interaction techniques can be found in Rukzio et al. [12]. Scheible et al. presented the *DisplayDrone* [13], a projector-augmented copter that shows user-generated short messages on arbitrary surfaces. Still, the above-mentioned approaches rely upon a projection surface. Particularly in wide spaces, suitable surfaces may not be available and plain sunlight may make projection unsuitable. One solution to this is the use of blimps, which have been used as performance media [16]. Tobita et al. explored blimps as a projection surface [15] to show an image of a communication partner. However, blimps are difficult to fly outdoor, particularly in windy conditions, and they are not able to maneuver rapidly.

We suggest the use of an autonomous display attached to a copter. The flight mechanics of copter drones have been studied and enhanced for many tasks. Way-finding tasks such as following users while doing sports [4] have been explored. He et al. introduced *Flying Buddy* [6], a personal drone capable of following the user and providing personal services such as taking pictures. Furthermore, drones are capable of more sophisticated flight movements such as ball juggling [9] as well as throwing and catching [11]. We aim to exploit free-floating midair displays for use by both individuals and groups. In the following we present use cases, the design and development of our prototype, and an initial study with 12 participants.

3. SCENARIOS

Midair displays can support users in a lot of different application areas. To showcase the potential of such displays we present the following scenarios (cf., Figure 2): midair displays for use during sports, for crowd control, and as information displays.

3.1 Sports Displays

Midair displays can provide useful information on the users' performance or surroundings, thus enhancing user experience (UX) and safety during outdoor sports. For example, while climbing, route information for different skill levels can be shown to climbers. Or during skiing, midair displays could be used as navigation systems, to point our dangerous areas, or indicate information on the waiting times at lifts or in nearby huts. We see also potential for situations in which wearable displays are inappropriate, such as on the water, where displays can announce the next big wave to surfers.

3.2 Crowd Control / Emergency

A core tasks in emergency situations (e.g., fire, earthquake, terrorist attack) is to keep crowds calm and lead them efficiently out of the endangered area. In many cases, it is risky or cumbersome for rescue teams to enter such areas. Recent examples show that due to power outages, also existing infrastructure may be unusable or even be destroyed. Furthermore, acoustic information presentation is sometimes not applicable due to a high noise levels. Midair displays with camera could help to locate casualties, approach them, and safely guide them through precise information on the display as they move.

3.3 Personal / Group Information Display

Today it is common that people can be reached anytime and anywhere on their mobile phone. At the same time, the small screen makes it difficult to provide information to others. A midair display can provide information to a whole group simultaneously, creating a more immersive experience (e.g., during sightseeing) while interaction between people within the group remains easily possible.

3.4 Flying Museum / National Park Guide

Audio and video guides are nowadays common in museums. However, in large outdoor museums or national parks, these devices suffer from drawbacks such as that they need to be carried around. Copter Displays can be used to guide visitors throughout the area and present information about specific regions at the same time. Visitors simply need to follow the display that are guiding them along specific routes that can be adopted to their interests.

4. A FREE-FLOATING MIDAIR DISPLAY

Current copters can fly at a maximum speed of 40 km/h and can carry up to 3.5 kg of payload. This allows for carrying 60 inch state-of-the-art e-ink displays. As such displays do not depend on backlighting they are readable even during exposure to direct sunlight. We envision that with further developments in copter technology and lightweight displays, the size of carried displays as well as the flight time can be increased and their price reduced.

Depending on the use case we envision different form factors, shapes, and display technologies for mid-air displays. As a basic display for individuals and small groups we imagine a small scale (e.g., 20 cm x 30 cm) free floating e-paper display – much like a floating sheet of paper in front of the user. For larger groups we can believe larger planar display (e.g., 1 m x 1 m) or different form factors (e.g., curved or cylindrically shaped displays) are suitable. Besides using displays, this concept can also be extended to projection technologies mounted on the copter, where the technical feasibility has been shown in [13].

Figure 3: The prototype we used for the user study. A participant is reading the Snellen chart in the baseline condition (left) and in the flying from left to right condition (right).

By adding sensors such as a camera or distance sensor, midair displays could position themselves in a way that puts users into an optimal perspective. Furthermore, sensors can be used to control midair displays with gestures or speech commands, hence, making them a useful companion in everyday life.

To better understand the potential of the concept we created two midair displays – first, a physical mockup of a lightweight display that showcases the envisioned form factor and second, a proof-of-concept prototype based on an octocopter carrying a tablet.

4.1 Interactive MidAir Displays

x We see particular potential in making midair displays interactive. This does not only include the control of the display itself (i.e., where the display is flying to), but also interaction with the content (e.g., browsing through information about a particular place). The following section discusses different means and challenges for interaction with midair displays. Today, an increasing number of interactive displays can be found in public space. Prior work identified a number of challenges when it comes to enticing passersby to interact, including means to raise the attention, communicate interactivity, and provide easy-to-understand interaction techniques [7].

We believe that midair displays are particularly suited to raise the attention of passersby since they can be made to appear in the visual field of the viewer. At the same time, this is also a challenge, since people currently not interested in the information provided by such displays may feel annoyed. Hence, future research should investigate the users' view on such displays, the development of means to determine the current interest, and an understanding about in which cases it could be most valuable to approach people.

Communicating interactivity may be a major challenge for midair displays. Unlike for static displays where analog signage or the honeypot effect could make users aware of their interactive capabilities [8], we believe that midair displays need to employ means for communicating their interactivity mainly through their content. This can be done, for example, through calls-to-action or through attract sequences.

Touch, mobile phones, and gestures have been identified to be the most suitable interaction techniques for static displays. We believe the latter two techniques to be particularly promising for midair displays. From a technology perspective, mobile phone based interaction could be realized via an Internet connection or a local network (e.g., the midair displays employing a WiFi hotspot). For gestures, the display could employ a (depth) camera. Particular challenges include the movement of the display as well as exposure to sunlight in which it may be difficult to correctly recognize the user's input.

For controlling the movement of the midair display, we imagine both explicit and implicit means to do so. Today, drones are mostly steered through specialized remote controls. Some drones, however, can already be controlled using mobile phone apps, for example, through tilting the phone in the direction to fly. At the same time, gesture-based control may be suitable, where the user is simply pointing to a direction the display should move to. We believe the optimal interaction technique to strongly depend on the task and the distance to the user. For many of the presented scenarios, implicitly controlling the midair displays seems most natural. For example in the sports and crowd control scenario, the midair display should approach and follow the user. At the same time it may need to efficiently guide the user towards a particular direction. From a technology perspective, this infers also some challenges. For instance, as soon as the user squints into the sun, the drone would need to move to increase the readability of the attached display.

4.2 Technical Limitations

Current copter drones have some technical limitations that need to be addressed to be usable in the wild. First, current copter drones only have a flight time of about 10-20 minutes. By carrying heavy objects, the flight time further decreases. As possible solutions, we see a combination of blimps and copters as promising. The blimps creates uplift so that the flight time increases and the rotors are mainly used for steering. As another possible solution on-the-fly charging could be possible – either through solar charging or on-the-fly battery pack replacement. A large flying base-station could provide docking stations with fully charged battery packs.

Additionally, current copter drones are quite noisy. Talking directly next to a flying copter drone is hardly possible. Particularly for the group information and flying guide scenario, this limitation needs to be overcome, for mid-air displays to become ubiquitous.

5. USER STUDY

We conducted a controlled user study exploring the readability of midair displays. We built a free-floating midair display by means of a professional octocopter and an iPad (cf., Figure 4). The octocopter uses DC motors and is powered by two 5800 mAh 3 cells lipo batteries, allowing for 7 minutes of flight time. To maintain a stable flying position the copter is configured with 8 motors in coaxial (X-shape) distribution. The device can be controlled manually or fly full-autonomously (position, including-trajectory, and position holding). As we see the benefit of such displays in presenting different types of information in public space, we were particularly interested in how motion of both the display and the user would affect reading performance. Thus, we investigated the following situ-

Figure 4: Midair display prototype with Snellen chart.

ations: (1) display standing on a table (baseline – Figure 3, left), (2) display hovering in front of the user, (3) display flying past the user (cf., Figure 3, right), and (4) user walking behind the moving display at a constant distance. As stimuli we used Snellen charts [14] containing 60 letters each. The task in each situation for the participants was to correctly read as many characters of decreasing size as possible (top row: 3.4 cm, bottom row: 0.3 cm, Figure 4).

5.1 Study Design and Setting

As we see large potential for outdoor applications, we decided to perform the study outdoors in plain sunlight. To achieve controlled conditions, we maintained a 45 degree angle between sun and participant for all tasks, hence reducing the dazzling and reflection on the display. Tests are to be performed at a distance of 5 arc minutes between participant and display [14] – in our case 6 meters. Hence, we made sure that in all conditions, participants constantly maintained this distance and that the display was continuously at eye level. Due to the limited flight time, 3 participants conducted the task simultaneously. We believe this to be a strength, since in the real world users are likely to encounter such displays together. To avoid cheating, we separated subjects through whiteboards. We designed the study as a repeated measures experiment where participants had to complete all tasks in counterbalanced order to avoid learning effects. We counted the number of correctly read letters.

5.2 Procedure

As the participants arrived at the lab, we introduced them to the purpose of the study and showed them the prototype of our midair display. After that we asked them to fill in a demographic questionnaire, assessing age, gender, and whether they needed any glasses or contact lenses. Then, participants performed the reading task in situations (1) – (4) described above and in counterbalanced order. In the reading task they were ask to read out the 60 characters shown on the screen using the Snellen chart. The chart was chosen in a way that large characters were easily readable whereas the smallest characters could not be read. For each user and each condition the number of correctly read characters was recorded. To minimize errors due to attention switches we asked the participants to read out the characters aloud. Answers were recorded by three experimenters accompanying one participant each while performing the task. Participants were told that accuracy was more important than finishing the test quickly. For each test we used a different Snellen chart. These were switched remotely by one of the experimenters betweens the tasks. Each reading test lasted for approximately 90 seconds. After the test, participants were provided with final questionnaires and we conducted semi-structured interviews.

5.3 Results

The study was completed by 12 participants we had recruited from University mailing lists and bulletins in the surrounding area (1 female, 11 male). Participants were aged between 20 and 35 years ($M = 24.83$ years, $SD = 4.78$ years). All participants had normal or corrected to normal eyesight.

5.3.1 Reading Test

Participants can read most letters in the hovering condition ($M = 31.42$ characters, $SD = 7.55$), followed by flying ($M = 31.08$ characters, $SD = 9.28$) and the baseline ($M = 30.83$ characters, $SD = 7.80$). Performance in the walking condition ($M = 27.75$ characters, $SD = 8.58$) was worst. We performed a repeated measures analysis of variance (ANOVA). The ANOVA shows a statistically significant difference, $F(3, 33) = 3.616$, $p = .023$ between the conditions. To investigate this further a pairwise comparison between the tasks, using the Least Significant Difference post-hoc test, was conducted. It shows that the walking task performs statistically significant worse than the three other tasks (Walking–Stationary $p = .03$, Walking–Hovering $p = .01$, Walking–Flying $p = .02$). However, the results of the other three tasks are not statistically significant different from each other (Hovering–Flying $p = .83$, Hovering–Stationary $p = .47$, Flying–Stationary $p = .87$).

On one hand, this suggests that in situations were display and user are in motion, the font size, or content size in general, needs to be increased. On the other hand, potential effects in conditions where the user is standing are small. Although we cannot claim a non-significant difference in these conditions, there is a strong indication that free-floating midair displays do not have a major influence on reading performance and can thus be used for a large variety of application areas, as presented in the scenario.

5.3.2 Qualitative Feedback

In addition to the Snellen tests, participants filled out a questionnaire and took part in a semi-structured interview. In the questionnaire (5-Point Likert scale; 1=totally agree, 5=totally disagree) we gathered information about application areas or preferred content.

Most participant could imagine to use midair displays ($Mdn = 2$). The questionnaire revealed that displays are more likely to be used in group settings with friends ($Mdn = 2.5$) and unknown persons ($Mdn = 2.5$). Talking about use cases, participants choose that emergency, advertisement, group displays, and entertainment in general ($Mdn = 2$) are most suited, followed by single- and multiplayer games ($Mdn = 2.5$). Participants preferred using midair displays while walking ($Mdn = 2$) rather than on the bike ($Mdn = 4$) or in the car ($Mdn = 5$).

In the interviews, participants came up with several use cases in which this kind of displays may be useful. These include particularly situations in which a mobile phone or wearable glasses are not available (e.g., *swimming in a lake* (P4)) or situations with many people (e.g., *football stadium to present replays* (P8)). Participants talked about the limitations of the prototype. One area in which the system needs to be improved is the flight stabilization, because otherwise *watching movies* (P5 / P6) and *reading books is stressful* (P8). The participants felt that the current prototype, however, could be used to show notifications (e.g., *new Skype messages or emails* (P7)) or provide warning (e.g., *during festivals* (P4)).

5.3.3 Flight Data

We recorded several kinds of data during the flights. Two built-in processors (FPGA, Gumstix) read the copter velocity and Euler angle. The data shows that the angle in which the copter is moved is almost constant (cf., Figure 5, right) and, thus, that the copter

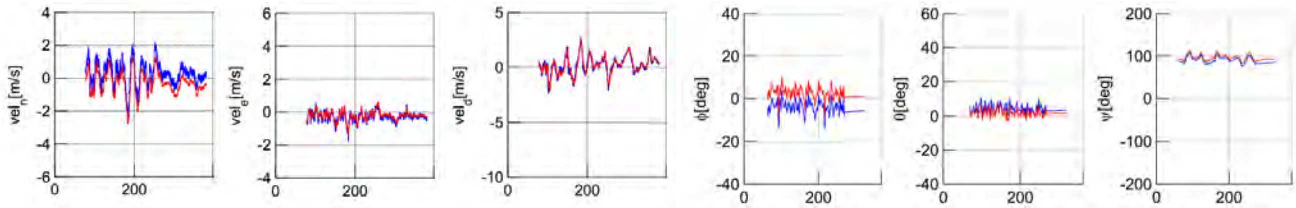

Figure 5: Velocity data and Euler angles of the copter during the first task (i.e., hovering). Since the copter has two build in processors (Gumstix: red – FPGA: blue) reading the velocity sensor, we have two data values for each velocity and Euler angle.

did not rotate much during the study. This shows that the display was always readable by the participants. Looking at the copter‘s velocity, the copter moved with up to 2 m/s from left to right (cf., Figure 5, left). Due to the fact that the copter is controlled manually and the study conducted outside, it also moved slightly from the front to the back as well as up and down.

6. DISCUSSION AND CONCLUSION

In this paper we introduce the concept of midair displays and present a prototype which combines an octocopter with a 10" display. In addition we showcase scenarios in which such displays can be useful. Interviews reveal that participants see the main benefit for situation, in which mobile phones as well as glasses are difficult to be used (e.g., during swimming or skiing) and where content needs to be shared with a group of people (e.g., in emergency situations). We see mid-air displays as a complementary technology to wearable displays (such as Google Glass) rather than a competitive technology.

During the user study, we gained insights into how mid-air displays can be used. Our results indicate that knowing whether the user is standing or walking is a central prerequisite. Particularly in situations in which users need to be able to precisely recognize the display content, this information could be used to adapt the layout and font size accordingly. Furthermore, the adaption to the number of users is important and, thus, sensors for tracking them (e.g., cameras) should be integrated with mid-air displays.

Participants saw large potential for situation in which they are approached by the display. Similar to static displays, value could be added by providing personalized services rather than scattershot ads. Hence, midair displays could likely benefit from knowledge about public displays. Future work could focus on more realistic reading tasks, means to identify the user, provide suitable interaction techniques such as remote interaction [2], and investigate social acceptance.

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