Midair Displays: Exploring the Concept of Free-Floating Public 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 spaces. 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 they could be used as group displays which enable information to be brought to the user anytime and anywhere. We explore the concept of midair displays and show that with current technology, for example copter drones, such displays can be easily built.

Keywords
Drones; Public Displays; Midair Displays

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Introduction

Displays can be found in many public spaces in the form of advertising and information displays or as artistic installations. By means of 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 many 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.

The contribution of this paper, in which we explore the concept of free-floating midair displays, is threefold. We first describe several 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 qualitatively explore the concept by demonstrating our prototype and conducting a series of interviews.

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.

Early approaches that try to overcome the static nature of wall-mounted displays include the *Everywhere Displays Projector* [8]. In this project, a projector and a movable mirror make it possible for content to appear 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 need 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. [10]. Scheible et al. presented the *DisplayDrone* [11], 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 [13]. Tobita et al. explored blimps as a projection surface [12] 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.

Figure 1: 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).

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 [7] as well as throwing and catching [9]. We aim to exploit free-floating midair displays for use by both individuals and groups. In the following we present three different use cases, the design and development of our prototype, and a qualitative interview study with 12 participants.

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 1): midair displays for use during sports, for crowd control, and as information displays.

Sports Displays

Midair displays can provide useful information on the users' performance or surroundings, thus enhancing the user experience and safety during outdoor sports. For example, while climbing, route information for different skill levels can be shown to a group of climbers. We see particular potential for situations in which wearable displays are inappropriate, e.g., on the water, where displays can announce the next big wave to surfers.

Crowd Control / Emergency

A core tasks in emergency situations (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.

Figure 2: A sketch of the envisioned copter display (left) and the actual prototype (right).

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.

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., 20cm x 30cm) 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., 1m x 1m) 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 [11].

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.

Prototype
We developed a proof-of-concept prototype. The prototype consists of an octocopter with an attached iPad (cf., Figure 2 – right). It uses DC motors and is powered by two 5800mAh 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 a display we use an off-the-shelf iPad. In this way we can show content using different web-based applications, for example, navigation information.

Interviews
To gain more insights into the users' likes and dislikes, we showed our prototype to twelve potential users of such system. They were aged between 20 and 35 years ($M = 24.83$ years, $SD = 4.78$ years). The outdoor demonstration included showing them the prototype in action for several minutes, so that people could experience the midair display under real conditions. After the demonstration we conducted semi-structured interviews with them. Furthermore, we handed out questionnaires.

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 / emails* (P7)) or provide warning (e.g., *during festivals* (P4)).

In the questionnaire, we used 5-point Likert scales (1=totally agree, 5=totally disagree) to gather 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 ($Mdn = 5$).

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.

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 the public displays. Future work could investigate means to identify the user, providing suitable interaction techniques such as remote interaction [2], and investigate social acceptance.

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