Quadcopter-Projected In-Situ Navigation Cues for Improved Location Awareness

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ABSTRACT
Every day people rely on navigation systems when exploring unknown urban areas. Many navigation systems use multi-modal feedback like visual, auditory or tactile cues. Although other systems exist, users mostly rely on a visual navigation using their smartphone. However, a problem with visual navigation systems is that the users have to shift their attention to the navigation system and then map the instructions to the real world. We suggest using in-situ navigation instructions that are presented directly in the environment by augmenting the reality using a projector-quadcopter. Through a user study with 16 participants, we show that using in-situ instructions for navigation leads to a significantly higher ability to observe real-world points of interest. Further, the participants enjoyed following the projected navigation cues.

Author Keywords
Augmented Reality; In-situ Projection; Navigation; Human-Drone Interaction; Quadcopter

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION AND BACKGROUND
Before the era of smartphones, pedestrians needed a distinct navigation device or paper maps to get directions. With the proliferation of smartphones, everyone who has a phone can receive GPS-based turn-by-turn directions. Some years ago navigation was mostly used to get the directions to an unknown place. Nowadays, navigation systems are also used out of convenience, to get live traffic updates or an estimated time of arrival, regardless of whether the destination area is known.

Further, navigation systems are often used while walking or doing a sightseeing tour in a foreign city. However, walking around with a smartphone in one's hand might limit the sightseeing experience for the user, as the user needs to look at the screen to not get lost. For that reason, pedestrians could fail to see a monument or other points of interest (POIs). To improve the sightseeing experience, it has been suggested to use visual landmarks or POIs as a navigation aid [11]. This has been evaluated, and has been found to improve the navigation experience [7]. Recently, Wakamiya et al. [22] suggested using this fact for generating memorable routes based on useful visual landmarks. However, using a smartphone while walking not only limits the sightseeing experience; it can also be dangerous. According to a study [14], the number of pedestrian accidents in the United States which involved a pedestrian talking or texting on a mobile phone while walking has increased over the last years. This is because even more pedestrians are immersed in using their phone and do not pay attention to their surroundings anymore.

(a) (b)

Figure 1. We conducted a user study comparing (a) projected in-situ navigation instructions to (b) traditional navigation instructions presented on a smartphone.

Although the traditional smartphone-based navigation is one of the most used, different navigation systems have been suggested. These navigation systems are not limited to visual navigation cues; in fact, over the last decades, a number of

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navigation systems have begun or have proposed using haptic, auditory, or visual navigation cues. Considering haptic navigation systems, Heuten et al. [6] use a belt that provides tactile navigation cues. Similarly, Pfeiffer et al. [17] use electronic muscle stimulation to remote control a pedestrian's route. In the area of auditory navigation, Baus et al. [2] are investigating auditory landmarks as navigation aids. Further, Lokki and Grohn [9] found that using auditory navigation in addition to visual cues is beneficial for navigation in virtual environments. Finally, regarding visual navigation cues, the state-of-the-art is traditional turn-by-turn navigation instructions, which are presented on the screen of a smartphone. These can be found on the pre-installed Maps applications in Android or iOS. Research also suggested using in-situ projection [18]. E.g. Winkler et al. [24] are presenting a body-worn system which can present in-situ navigation instructions. Their system is further capable of presenting public and private projected content. Moreover, for receiving projected navigation instructions while riding a bike, Dancu et al. [4] proposed mounting a projector and a smartphone on a bike. All presented systems require a shift of attention from the environment to the display. Augmented Reality (AR) solutions overcome this limitation by presenting the information directly in the environment. Narzt et al. [13] describes a visualization paradigm for in-car AR navigation systems. Rehrl et al. [19] conducted a study comparing navigation performance using voice, digital map and AR cues and report that AR presented on a smartphone causes significantly worse navigation performance. AR solutions still lack comfort and require the user to carry a separate, often bulky device [19, 24].

We are observing a trend of quadcopters becoming more widely used in navigation-related applications. In a sports context, Müller & Muirhead [12] have proposed using a quadcopter as a jogging companion. They were using a fully autonomous flying quadcopter which can follow a previously defined route. For providing a clean environment, Obaid et al. [16] are using drones to locate, then encourage people to clean up trash. Schneegass et al. [21] are suggesting to use free-floating displays mounted on a quadcopter to create temporary navigation signs to control crowd movements in emergency situations. Scheible, Funk, and Nozaki [20, 15] present two similar concepts using a projector and a canvas attached to a single quadcopter to provide information to people. Matrosov et al. [10] additionally added a depth camera to the down-facing projector to facilitate a tangible interaction projection surface. Moreover, Avila et al. [1] suggested using small nano quadcopters to navigate blind and visually impaired travelers using the sound which a quadcopter naturally emits. Recently, Kim et al. [8] proposed to use a quadcopter as a navigation aid to get home safely when walking alone in the dark and Colley et al. [3] explored the potential to communicate navigation cues just with the drone's movements. In conclusion, quadcopters are currently used to control crowds in emergency situations [21], display information during sports [12, 21], and display tourist information [21]. However, we want to explore how to extend these scenarios by combining quadcopters with additional technology.

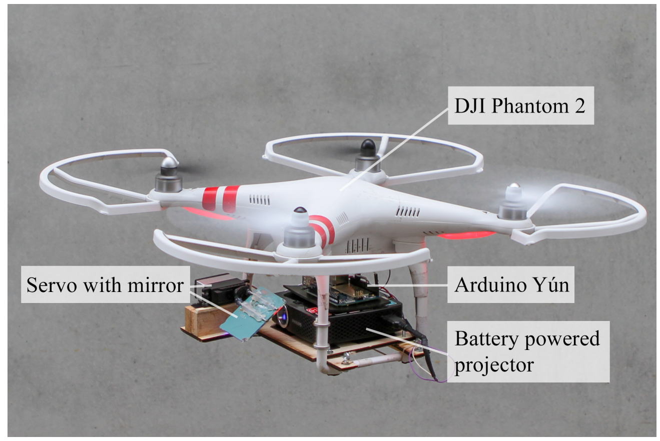


Figure 2. The prototype of the steerable levitating projector.

Displaying context-aware navigation instructions directly in the real world opens a new design space for pedestrian navigation. In this paper, we explore this space by combining the benefits of in-situ projection and quadcopters. We present our prototype of a quadcopter-mounted projector that is capable of projecting navigation instructions in-situ. Further, we show in a preliminary user study that in-situ navigation cues using a quadcopter lead to a higher memorability of POIs along a route.

QUADCOPTER-MOUNTED PROJECTOR

Our prototype is a quadcopter-mounted projector. The levitating projector can project wirelessly streamed content onto surfaces underneath or in front of the projector. Inspired by Wilson et al. [23], we use a steerable mirror to change the angle of projection and therefore the surface which is projected on. All components of the prototype are depicted in Figure 2.

The starting point of our levitating projector is a DJI Phantom 2 quadcopter. This quadcopter was chosen because of the additional take-off weight of 1300 g with a flight time of up to 25 minutes. Additionally, it offers advanced GPS-supported flight assistance systems. We use a Phillips PicoPix PPX3610/EU projector. It weighs only 284 g and is battery powered with a runtime of 90 minutes at 60 lumen. Further, the projector has built-in WiFi and is running Android 2.3.1. A small mirror was glued to a light servo and placed next to the projector to deflect the projectors light cone. The servo is connected to an Arduino Yún which includes a separate WiFi module. The Arduino Yún is USB powered by the projector and is running a server application receiving commands to adjust the angle of the mirror. Depending on this angle the projected image is in front of the quadcopter, directly underneath it or slightly behind it.

We developed two applications which we connected via WiFi. One runs on the projector and controls the projected navigation instructions. Based on the mirror position the projected image is mirrored horizontally to compensate for the effect of the mirror. The second application runs on a mobile device and sends the navigation instructions to the projector as well as the required angle to the Arduino Yún. During our study, this application was operated by a Wizard of Oz.

As a control condition, participants had to use simple graphical navigation instructions presented on a smartphone. In this condition, we showed the same visualization that was presented using the in-situ projection quadcopter. In fact, the smartphone was running the same application as the projector, displaying the navigation instructions controlled by the Wizard of Oz with the subtle difference that the content never got mirrored. To facilitate future replications of this work a detailed description of the assembled hardware and developed software is available online[1].

EVALUATION

For evaluating our in-situ navigation instructions using the previously introduced quadcopter-mounted projector, we conducted a user study for comparing it against the traditional smartphone-based navigation system.

Method

We designed the study following a repeated measures design with the used instruction method (in-situ instructions by levitating projector and smartphone navigation) as the only independent variable. As dependent variables, we measured the Task Completion Time (TCT), the Raw NASA Taskload Index (RTLX) score [5], and the error distance between the actual location of the POIs and where the participants remembered them ($\text{DISTANCE}_{\text{POI}}$). We treat the ORDER of the routes that were used in the study as a between-subjects variable.

The apparatus used in the study was the two prototypes that were presented previously; i.e. we were using the *in-situ* projection quadcopter and the *smartphone* navigation as a control condition. We defined two different routes starting and ending at distinct points (e.g. at a crossing or a landmark). The routes had approximately the same length (510 m and 530 m). Both routes are depicted in Figure 3. The walking time at a slow paced walking speed is approximately 6 minutes for each of the routes. Each participant walked both routes once – one route with the quadcopter navigation system and one route with the smartphone navigation system. We counterbalanced the order of the navigation systems and the order of the routes in a way that each route and each navigation system was used equally during the study. To ensure a good visibility of the projected navigation information, the study was conducted at dusk (between 7 pm and 9 pm). We only conducted the study on days with good weather and clear sky.

As we are interested in analyzing the memorability of the surroundings, we introduced points of interest (POIs) located at buildings or crossings along the route. During each route we presented 3 POIs, which were visualized using a geometric shape (blue circle, red rectangle, and orange triangle). The geometric shapes were presented on the smartphone or by the levitating projector when the participant reached the position of the POI with an accuracy of 1 m (also depicted in Figure 3). The POIs in the first route were a distinctive set of stairs, a small alley, and a big sign. For the second route the POIs were another distinctive set of stairs, a noticeable balcony, and a container. All POIs were not directly on the path of the route; rather on the sides. When choosing the POIs for the study, we made sure that they were distinctive points along the way which could be used for memorizing the way afterwards.

[1]`https://github.com/hcilab-org/QuadcopterProjectedNavigationCues`

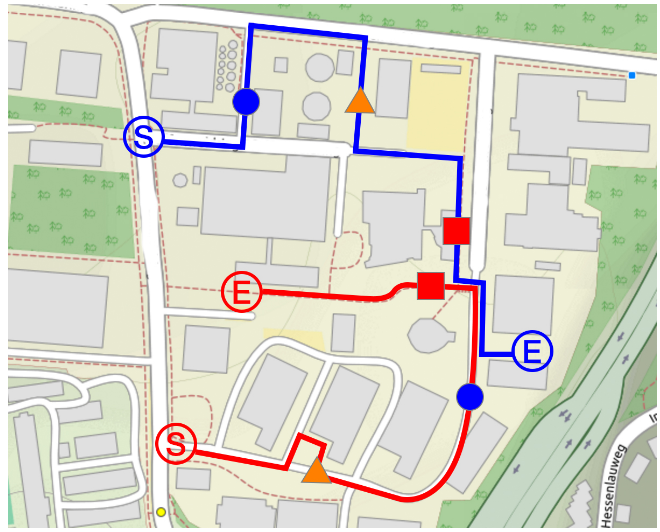
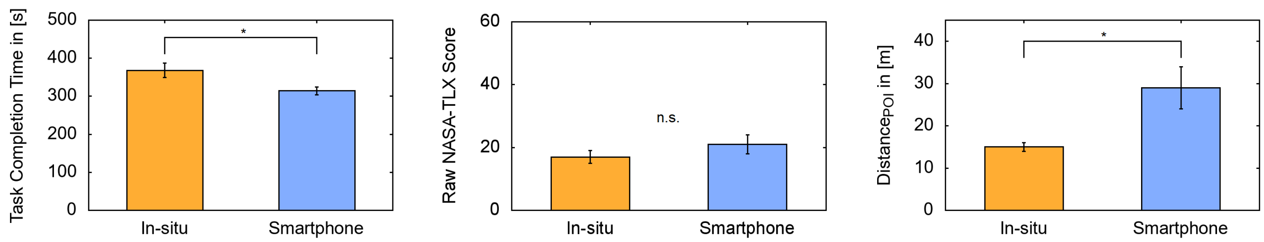


Figure 3. The routes that were walked by the participants in our user study. Both routes are approximately 500m long and consist of 8 turns. The S indicates the start of the route and the E indicates the end of the route. The location of the POIs are marked with the geometric shapes (circle, rectangle, and triangle) as they were used in the study.

Procedure

After explaining the course of the study, the participants were asked to sign a consent form, which informed the participant about potential risks of participating in the study and explained which data would be collected. We further instructed the participants to always be aware of their surroundings. Further, we instructed the participants to walk at a comfortable pace. As a first priority we defined following the navigation instructions, and as a second priority we instructed the participants to memorize the location of the POIs. After briefing the participants, we made them familiar with the first navigation system. Both the levitating projector and the smartphone navigation system were presented as fully automated systems. In the in-situ condition, two study assistants acted as a Wizard of Oz. The first wizard was operating the quadcopter at a distance of 5 m in front of the participant. The second was controlling the projected navigation instructions using a tablet computer. In the smartphone condition, only one wizard was needed to control the presented navigation instructions. Once the participants were familiar with the task and the navigation system, we started the study. The two wizards were walking behind the participants at a distance of approximately 2 m. After each route, we asked the participants to fill out an Raw NASA Taskload Index (RTLX) questionnaire and to recall the position of the POIs by walking back along the route and telling the experimenter the position of the POIs. The experimenter logged the position of the recalled POI using a smartphone application, which determines the recalled POI using GPS. Afterwards, the real POI GPS location is compared with the perceived POI GPS location to calculate the distance between perceived location and real location using the Haversine formula. Afterwards, we repeated the procedure with the other route for the second condition.



(a) (b) (c)

Figure 4. The results of the user study. (a) The Task Completion Time in seconds needed for each condition. (b) The perceived cognitive workload represented by a Raw NASA Taskload Index score. (c) The error distance the participants made when trying to recall points of interest. All error bars depict the standard error. The * indicates a statistically significant difference.

Participants

We recruited 16 participants (7 female, 9 male) via our university's mailing list and personal contacts of one of the authors. The participants were aged from 18 to 62 years ($M = 33.7$ years, $SD = 13.9$ years). They were mostly students with various majors or persons working in a variety of industry jobs. All participants owned a smartphone. The participants were rewarded with candies for participating in our study. As we conducted the study at a remote part of the campus, none of the participants were familiar with it.

Results

We statistically compared the TCT, the RTLX, and the DISTANCE$_{POI}$ using a one-way repeated measures ANOVA with the order of the routes (ORDER) as a between-subjects variable.

First, we analyzed the average time the participants needed to walk the routes (TCT). The *smartphone* navigation condition ($M = 314.62$ s, $SD = 43.55$ s) was faster than the *in-situ* projection condition ($M = 368.69$ s, $SD = 77.88$ s). A one-way repeated measures ANOVA revealed a significant main effect between the approaches, $F(1, 15) = 7.33$, $p = .017$. The effect size estimate shows a large effect ($\eta^2 = .301$). There was no interaction effect for TCT $\times$ ORDER. The results are depicted graphically in Figure 4a.

Considering the RTLX, representing the perceived subjective workload the participants had while consuming navigation instructions, the *in-situ* projection condition led to a lower perceived workload ($M = 17.14$, $SD = 8.11$) compared to the *smartphone* condition ($M = 21.82$, $SD = 12.35$). A one-way repeated measures ANOVA could not reveal a significant difference between the two conditions ($p > 0.05$). Also there was no significant interaction effect for RTLX $\times$ ORDER. The results are shown in Figure 4b.

Finally, when comparing the DISTANCE$_{POI}$, the *in-situ* condition led to a smaller error in the distance between the POIs and the recalled position of the POIs ($M = 15.16$ m, $SD = 6.33$ m) compared to the *smartphone* condition ($M = 30.25$ m, $SD = 22.46$ m). A one-way repeated measures ANOVA revealed a significant difference between the approaches, $F(1, 13) = 6.384$, $p = .027$. The effect size estimate shows a large effect ($\eta^2 = .347$). There was no interaction effect for DISTANCE$_{POI}$ $\times$ ORDER of the routes. A graphical representation of the results can be seen in Figure 4c. It has to be mentioned that two participants were not able to remember one of the presented POIs. One could not remember a POI in the in-situ condition and another could not remember a POI in the smartphone condition.

After conducting the user study, we asked the participants to provide additional qualitative feedback through a semi-structured interview. Considering the quadcopter condition, three participants (P2, P3, P16) were *"a little scared of the quadcopter"* and therefore told us that *"[they] reduced [their] walking speed not to come too close to the quadcopter"*. Further, some participants felt that our prototype of the projector quadcopter is *"too loud for using it in an everyday setting"* (P6, P7, P12). When we asked them if they followed the quadcopter instead of the in-situ navigation instructions, P4 stated that the quadcopter was *"flying too high to just follow the quadcopter. Therefore, the projected navigation instructions were very useful"*. Similarly, considering the POIs, P1 stated that he *"like[s] that the drone is projecting the points of interest directly into the real world. This helps to not miss any of them."* (P1) In the smartphone condition, P1 had problems noticing the POIs as he was concentrating on his walking and not continuously looking at the screen of the smartphone.

DISCUSSION AND LIMITATIONS

Considering the Task Completion Time (TCT), we found that the smartphone-based navigation led to a significantly faster TCT. Qualitative analysis revealed that this was mainly due to participants being careful about walking too close to the quadcopter. As we did not want to rush the participants, we instructed the two Wizards-of-Oz to always retain a fixed distance between the quadcopter and the participant. Defining a fixed speed for the quadcopter might have yielded different results considering the TCT. We could not find a significant effect between the two navigation systems considering the RTLX score. However, when comparing the DISTANCE$_{POI}$ between the two conditions, we found that the in-situ navigation instructions provided by the levitating quadcopter were leading to a significantly shorter DISTANCE$_{POI}$ compared to the smartphone-based navigation instructions. Additionally, during the smartphone control condition of our user study, we had to verbally intervene once for P7 and P13 as they nearly walked into a wall.

It has to be mentioned that our proposed projector quadcopter system for in-situ navigation instructions comes with a few limitations. While conducting the study, some participants mentioned that the quadcopter we were using was loud. The participants thought that in an everyday scenario this would distract passersby. However, while conducting the study, passersby were very interested in the prototype and the in-situ navigation approach. This opens up interesting possibilities for investigating whether personal companion quadcopters could foster social interaction. Despite the in-situ navigation instructions, our projector quadcopter additionally presents two more navigation aids: the quadcopter itself and the sound that it emits naturally (cf. [1]). We asked the participants whether they followed the quadcopter or the instructions, and all except one stated that they were following the projected instructions. Further, our system was only tested at dusk and night. With the current prototype, projected navigation instructions are barely visible in daylight due to the low luminous intensity of the projector. We believe that using an advanced monochrome laser projector could solve this issue.

CONCLUSION

In this paper, we investigated using a quadcopter-mounted projector for presenting in-situ navigation instructions as an alternative to smartphone navigation instructions. In a user study, we compared the in-situ navigation instructions to a state-of-the-art smartphone navigation. The results show that although participants required considerably more time to complete a route using in-situ navigation instructions using a levitating projector, the participants could memorize points of interest significantly more accurately using in-situ instructions.

We conclude that using in-situ navigation instructions while walking leads to a higher memorability of the surroundings. In future work, we want to investigate the social implications of using a personal quadcopter for receiving in-situ navigation instructions. Further, we want to explore more use-cases, e.g. augmenting sports or outdoor sightseeing and introducing a quadcopter-mounted projector as a smart companion for everyday scenarios.

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