Displaydrone: A Flying Robot Based Interactive Display

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ABSTRACT
This paper introduces the Displaydrone, a novel system that combines a multicopter (flying robot) with a video projector and a mobile phone into a flying interactive display for projecting onto walls and arbitrary objects in physical space. Being quickly and flexibly deployed in open space, the Displaydrone allows the angle and direction of the projection to be adjusted on the fly. We realized the Displaydrone system with a custom-built octocopter, an off-the-shelf pico projector, an Android phone and went on flying. By carrying out an experimental evaluation we obtained first impressions on how the Displaydrone is perceived by a viewing audience. The paper highlights the findings and discusses the Displaydrone's potential for enabling new kinds of social group interactions in physical space.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation]:** User Interfaces – *evaluation and methodology, input devices and strategies, interaction styles.*

General Terms
Design, Experimentation, Human Factors, Theory.

Keywords
Drone, multicopter, experimental evaluation, interactive content, public display, mobile projection

1. INTRODUCTION
This work introduces the Displaydrone, a system that combines an octocopter with a pico projector and a smartphone into a flying interactive display for projecting onto walls and arbitrary objects in physical space. The novelty of this system lies in its possibilities to quickly and flexibly deploy it in the urban environment, the ability to project on surfaces high above the ground and in allowing to overcome some of the limitations of static and hand-held projections such as keystoning.

In recent years the deployment of flying robots has moved from military orientated deployments to more general public uses such as carrying a camera for shooting film materials from unique positions and viewing angles. While drones are found in research doing a variety of things such as ball juggling, this has focused mainly on indoor deployments that use a real time tracking system (motion capture) to determine the location of the drones via markers. As prices have come down significantly, flying robots have reached the consumer market, shipping with many features such as capturing photos and videos, while footage is streamed in real-time directly to your smartphone on the ground. This allows experiencing first-person view (FPV) flights or augmented reality games.

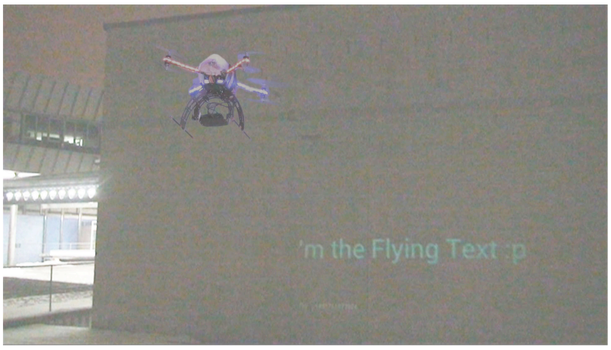

Figure 1. Displaydrone in action.

Public displays, have at the same time, become an almost ubiquitous presence in our everyday lives. Increasingly, these displays are becoming intelligent and interactive, allowing passersby to interact with the information that is displayed. Pervasive technologies such as mobile phones and tablets are becoming key enablers for new kinds of interactions with these displays. However, complex ownership relationships and legal ramifications make urban settings a challenging place for deployment and operation of such displays, as they typically require permissions from many stakeholders. Thus it is no surprise that the inherent freedom of playful arenas, combined with intimate ubiquitous technologies such as video projection, has led to a new breed of guerrilla performances [15].

The idea of projecting interactive digital content onto the world around us has a rich history [10], [16]. In recent years a larger body of research has emerged in the field of mobile and ubiquitous projection which is motivated by the mobility of pico-projectors that can be easily carried, hand-held, and used to project onto fixed surfaces such as walls [19]. The proposed Displaydrone, a flying robot-based projection system carries such a pico-projector, enhancing the mobility of projections to a greater degree than hand-held or static projections, being freely movable

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in all directions. It allows projection on previously difficult to reach or hard to access locations.

The topic of interactivity around the use of public displays has become prominent in recent years for enabling new forms of engagement with digital content [8]. Huber et al. [5] think of interaction as a third stage of pervasive display-centered interaction, the first stage being ubiquitous availability of interactive displays (Smartphones and touch screens everywhere), the second stage being ordinary flat surfaces combined with pico-projectors and direct manipulation input (touch, pen, etc.) and the third stage considering arbitrary objects to become display surfaces such as coffee mugs etc. This leads to the situation that the content that is being displayed and the interaction concepts itself become object specific. With regards to the Displaydrone, we believe that arbitrary objects of larger scale from the physical space can be turned into object specific display and interaction surfaces, enabling new forms of interaction and engaging activities in public space.

In order to gain first insights of the potentials of the Displaydrone as an interactive display, we built an SMS moving text application for testing the drone in a real outdoor flight scenario with an audience. The application allows people to send an SMS text message to the drone, which projects the message text onto a wall moving right to left. While everyone in the audience group can see the messages on the 'shared public screen', people had a private input channel to place content to the Displaydrone projection. This mixture of private input channel to a shared public display, allowing anonymous, wireless and mobile participation in a joint social public group interaction, is referred to by Scheible et al. as Mobile group interaction [13]. As a highly networked flexibly deployable flying display, we see the Diplaydrone as a future tool to enable new forms of social interaction in the outdoor space with mobile group interaction at its center.

This paper is organized as follows. Section 2 explores the related works. Section 3 describes the Displaydrone system. Section 4 presents the initial experimental evaluation of the system in an outdoor setup and highlights the most important findings. Section 5 discusses the Displaydrone's potential for enabling new kinds of interesting social group interactions. Section 6 concludes the paper by taking a view into the future, to see what flying displays could provide in the mid and long-term.

2. RELATED WORK

Using mobile technologies such as smartphones or tablets for interacting with public displays have become more and more common. Baldauf et al. state, that "as everyday companions, smartphones are well-suited tools for controlling interactive applications on large public displays." [2] Besides their increasing ubiquity in our contemporary societies, they also feature several advantages over other forms of interaction with a public display [4]. According to Ananny et al. participants prefer using their phones rather than a single terminal in a single space as they are already familiar with their personal devices. This also helps increase anonymity and thereby decreases fear of interaction [1].

Interaction from a distance without great physical effort is another advantage [6]. Mobile phones offer a more unobtrusive way of interacting and are very versatile in their possibilities to interact with a public display [3]. Scheible et al. also point out, that mobile devices enable more people to interact with the display simultaneously, by overcoming the spacial limits of a public display [13].

Various examples of research outcomes have shown how mobile devices can be used for group interaction with a public display. In the "CityWall" project [9], mobile phones were used to enable passersby to share photos on a large urban centered display. Photos could be arranged by people standing in front of a display using multitouch gestures. Lucero et al. created an interactive application called "MobiComics". Mobile phones are used by participants to capture photos in a public social situation (as in a Café) and let other guests augment these photos with graphical speech bubbles and text messages [7]. Another example is the "TexTales" application by Ananny et al. [1]. To support public discourse, they created a "large-scale photographic installation to which people can send SMS text message captions". Over the course of a few weeks, residents of a large apartment building were encouraged to collect photos of their neighborhood, which were then publicly displayed and could be commented on via SMS. These examples show how rich group interaction can be leveraged by using mobile phones as input devices.

With regards to mobile projection, MotionBeam by Willis et al. [17] uses a fixed surface as a projection target while allowing users to steer a projected virtual character through virtual worlds. Willis et al. [18] have also investigated ad-hoc multi-user interaction with handheld projectors on fixed surfaces. Projects like Map torchlight [14], iLamps [12], RFIG Lamps [11] augment static surfaces with digital information.

3. THE DISPLAYDRONE SYSTEM

The Displaydrone system is realized with three components: 1. A professionally built octocopter (figure 2) equipped with a carbon fiber frame with approximately 75cm diameter. The payload of the copter is up to 3.5 kg. 2. A DLP pico-projector with a weight of 200 grams and 100 ANSI lumen light power. 3. A smartphone acting as a computing platform and screen renderer for the projection as well as being a networking device (3G). The mobile phone and the pico-projector are fixed to the octocopter gimbal (figure 3) and both are connected to each other via an HDMI cable.

Figure 2. Octocopter-Displaydrone take-off.

1. The octocopter (multicopter) is equipped with DC-motors and an on-board computer. It has a total weight of approximately 4.0 kg including the pico projector and smartphone. With 5800mAh 3 cells lipo battery, the flight duration is 15 minutes minimum. The multicopter is configured with 8 motors in coaxial distribution (X-shape), which is more compact and agile for projection. The DC-motor servo is standard PWM motor (Pulse Width Modulation) and ESC (Electronic Speed Controller). The flight control computer (FCC) is a custom-built FPGA-based (Field-Programmable Gate Array) on-board computer called ROCS (Research Onboard Computing System), which provides configuration flexibility and enables concurrent processing. The FPGA part serves as hardware interface and low-level controller, on the other hand, a SoC (System On a Chip) embedded Linux system also works as complete guidance-navigation-control system of the multicopter. The flight control software is custom-made by iFR, Institute of Flight Mechanics and Control of University of Stuttgart, who is a partner in this project.

For building a similar copter platform the following parts are needed: A mechanical frame of the copter, motors, motor controllers and propellers, a flight control system including sensors and flight control computer with software, a radio remote controller, a video projector, a smartphone with accessories (cable etc.) and a set of batteries.

Our multicopter can be operated in three different modes: a. manual control (rate control and attitude control), b. semi-autonomous control (autonomous height control with manual velocity control), c. full-autonomous control (autonomous position control, including trajectory control and position holding control). As the platform of the projector, the multicopter is mostly operated in hovering mode, hence a stable and robust attitude control is developed and verified, which provides enough precision for projection. During maneuver, a controller controls the servos of the gimbal system on which the projector is mounted, compensating the disturbance introduced by maneuver and wind, hence maximizing the projection stabilization.

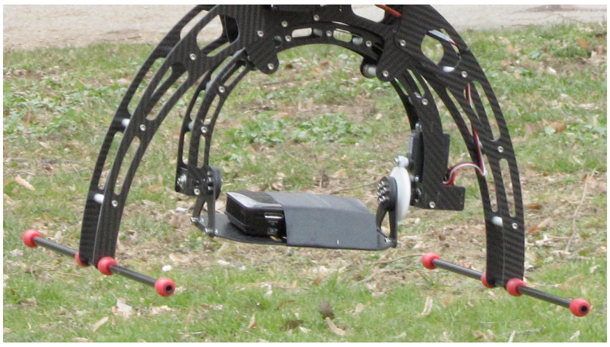

Figure 3. Pico-projector attached to the gimble system.

2. The pico-projector in use is an Optoma PK320 with a device size of 120 x 70 x 30 mm (W x D x H) and a weight of 200 grams. It has a maximum screen resolution of 1280x800 pixels offering 100 ANSI lumen light power. Its battery lasts 1.5 hours according to specification, however we experienced in an outdoor use with a temperature near 0 degree Celsius the battery lasted approximately only 20 minutes. The achievable projection display size is approximately 4 x 3m in ambient light conditions. In complete darkness a projection display size of approximately up to 7 m width can be achieved with full color well viewable. This was a surprise to us.

3. The smartphone comes with an Android OS on which multiple applications can be installed for running on the Displaydrone system. We programmed and installed a custom-made application for testing the potentials of the Displaydrone as an interactive display system. It is an SMS moving text application to facilitate mobile group interaction. While everyone in the audience group can see the shared public screen projected by the Displaydrone, individuals of the group can send an individual SMS text message from their mobile phone to the drone, using a private input channel to post content onto the shared public screen. The Displaydrone then projects the received SMS content in form of a moving text via the video projection onto a designated backdrop, for example a facade of a building or a rock face or any suitable object in nature. The text color was chosen to be white on black background for better contrast (figure 1). The SMS message is shown until a new message comes in. If multiple SMS messages arrive at the same time the messages are queued in the system and processed in the order they come in. Our application could also allow returning an automated SMS text message to participants holding a link to a winning coupon of a lottery or a link to a product or shopping website. This would provide a reliable return channel for delivering confidential user specific information back to the user as proposed by Scheible et al. [13]. However we chose not to implement this feature at this stage. This bi-directional interaction makes the Displaydrone an interesting system for example for interactive advertising or guerilla marketing.

When developing the Displaydrone system with our SMS application we went through several iterative design cycles. We started with static text projections to get a feel about suitable sizes of letters and to see if projecting text would work with the flying projection in terms of sharpness and overall readability. After successful projection tests in outdoor flight situations on several building facades made of concrete, we went on to create an animated text, finding out the suitable speed of text movement and the narrowness of letters so a viewer can still read the text easily. The next step was to implement the interactive text feature for our final version of the system.

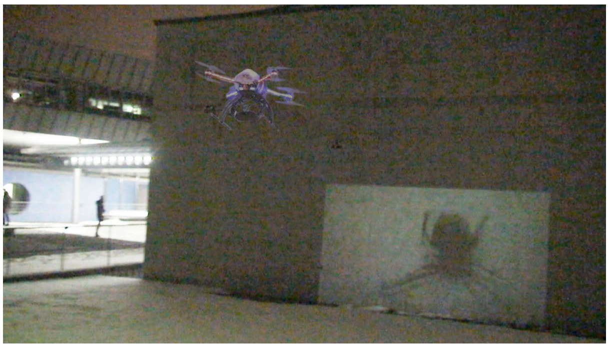

Figure 4. Projecting a video via the Displaydrone.

4. EXPERIMENTAL EVALUATION

The first evaluation of the Displaydrone with a real audience was carried out at a University event where a series of innovative works were presented to the general public during the evening (already dark outside). The goal of this experimental evaluation was to obtain first impressions on how the Displaydrone is perceived by a viewing audience. For this we installed the previously described ‘SMS moving text’ application onto the Displaydrone allowing anyone in the audience to interact during the entire test flight of the drone. The phone number for sending the SMS to was shown on the projection.

During the evaluation phase, the Displaydrone was hovering in front of an outside wall of the university building as shown in

Figure 5 with a height of 3-4 meters and a distance of 4-5 meters to the facade while being manually controlled by a pilot.

Figure 5. Evaluation in outdoor setting.

The sharpness (focus) of the projection was manually set before the copter flight was started (figure 6). An audience of approximately 40 people was standing at a distance of 15 meters in front of the facade. The achieved projection width was approximately 4 meters by 3 meters, while having a clearly visible image. The test flight lasted 7 minutes during which 23 SMS messages were send by the audience to the Displaydrone. We collected qualitative data in form of audience feedback from 14 people via audio interviews on the spot during the test flight and right after.

In the following, we present the issues that caught test user's attention. Significant factors are presented in the form of the answers and comments given by audience members in response to a series of questions by the researchers. Comments have been translated to English and are printed in *italics.*

Fun experience. A clear general observation was that people enjoyed the 'Displaydrone experience' while having great fun together seeing each other's SMS message contributions. This was indicated by cheering and clapping when certain messages appeared like *"Felix do you want to marry me?"* being followed by a *"Yes"*.

Interactive storytelling. It seemed like interactive storytelling was happening by itself. The system was used as a stage for showing funny jokes but also to express specific words in front of an audience. The possibility to interact with the Displaydrone was used by 4 of the 14 interviews, while 2 stated they would have interacted if their phone battery had not been empty.

Creating attention. The majority of the people interviewed stated that the system easily catches your attention and causes interest. *"It is an eye catcher, it certainly grabs your attention, it looks exciting"*. The attention seems to be caught first through the noise of the copter and then the projection was noticed. *"First I heard this noise and then I discovered the visuals"*. None of the 14 interviewees had seen a multicopter with an integrated projector before but with a camera attached or a load unit for carrying objects. *"I have seen it as a delivery service tool for burritos"*.

Potential use for advertising purposes. One SMS message contained a link for advertising a film project. It showed the potential that we believe such a system has toward advertising. When asked if the interviewees could imagine this system being used for advertising purposes, answers were mostly positive toward it. *"It certainly reminds me of airplanes towing a text banner"; "Especially for advertising festivals or parties it would work, because it's an eye-catcher."; "I see it less for advertising but rather for social interaction in groups"*. The success of such a system for advertising purposes is seen to be directed by various factors such as the target group and the content of the ad, but also how well the system performs and matures in flying. One person could see the Displaydrone well used for guerrilla campaigns.

Future deployment scenarios. When asked of possible scenarios of the usage of a Displaydrone in urban areas, the reaction was mixed. *"Concerts"; "Valentine's day would be nice, however to have such interaction inside the city is questionable from security point of view."; "Augmented reality, alternative reality or story telling"; "Rather have it integrated inside a show"; "For a few minutes it is certainly interesting"; "Especially for funny things it is interesting"*.

5. DISCUSSION

In the following we discuss various aspects of the Displaydrone system that caught our attention during the design and testing phase.

Stable hovering. Calm and stable hovering of the Displaydrone is important in order to achieve a projection that is bearable for an audience. This means a stable and robust position control to maximize the projection precision and stabilization. With a multicopter and its rather calm flight characteristics we found it is possible to achieve quite satisfying results already.

Battery life. The battery life of the Displaydrone is still rather short lived, providing flight duration of around 15 minutes minimum, depending on the wind condition. A way to overcome this problem is to bring several fully charged spare batteries along. However, in order to change the batteries the drone must land multiple times, which may interrupt the main purpose of the flight.

Viewing distance of the projection. With the current version of the pico-projector of 100 ANSI lumen the Displaydrone can not be too far away from an audience in order to enjoy a full color projection in reasonable size. This narrows the scope of the deployment radius of the current version of the Displaydrone to an approximate maximum of 50-60m distance from an audience.

Darkness. The current Displaydrone works only in darkness due to the limited light emission of the pico projector. With our 100 ANSI lumen projector we were able to achieve a projection display size of approximately 4m x 3m, while still having some ambient light from street lamps around. In complete darkness a projection size of approximately up to 7-8m in width can be achieved. We tested this by placing our pico-projector into a location of completely dark surroundings while projecting onto the facade of a house. Also, projecting on surfaces above the level of street lamps helps to achieve much better results.

Forms of display content. For the test flight described in this paper we used only audience generated words as display content. However it is possible to display a rich variety of content with the Displaydrone, such as

- still graphics in the form of text and images; for example slogans or logos
- animated colored clips for example animated banner ads
- video content: for example filmtrailers etc.

- generatively produced visuals

Legal implications. In some countries there are legal implications to what extent flying robots or drones can be used for commercial purposes. There can be restrictions regarding locations where not to fly e.g. near certain locations such as nuclear power plants or airports. Certain situations or scenarios are also problematic; for example flying directly above groups of people which can pose high risks that crashing systems may lead to severe injuries.

Attention grabber. The Displaydrone system features three main aspects that create attention. 1. Flying objects have always had a certain mystery to them. Especially as long as multicopters are not a common sight, this will remain a key attention grabber. This was expressed also by audience members that took part in the experimental evaluation (see section 4). 2. The propellers of the drone create a reasonably high amount of noise, which you can hear from a distance. 3. The drone is set to fly during the evenings and night time. Equipped with flashing LEDs and a projector, light is another hook for attention.

Symbolic power. Usually projectors are placed hidden to passersby, so as not to draw too much attention to the system itself that creates the display. In the case of our proposed flying projector, there are interesting possibilities in purposefully using the symbolic power of a flying object. Drones have been disguised as UFOs, flying cats or 'Back to the Future's' Delorean. While these examples may sound playful, they do touch the fantasy of people watching the drone and thereby create attention and animation for certain kinds of interaction.

Accessing places that are difficult to reach. While mounting a projector to a wall or ceiling might be easily done indoors, there are more problems in an outdoor situation. In free space, the projector can only be fixed to the floor with limited possibilities to elevate it from the ground. To access surfaces that are far above the ground (like the wall of a tall building), one needs a very powerful projector. These projectors are bulky, costly and need a strong power-supply, which in many cases can only be provided by a gas consuming transportable generator. The Displaydrone system described in this paper is a much more lightweight solution to this problem. The drone can easily alter it's elevation from the ground, reaching any corner of the provided surface without causing any keystoning problems.

Continuous movement. Interesting example project works can be found in which projectors are mounted to a car that drives down a street while projecting on the passing shop fronts and outer walls of house. This can create e.g. example the illusion of a moving skateboarder or running Nike shoes along the street. A flying projector would yield even more creative freedom and would allow for moving projections in pedestrian areas or indoor situations.

Projecting from above. Projecting on the ground is well suited for some types of interactive installation as reported by Ananny et al. [1]. Their installation was projected onto the ground from an adjacent building. Ananny et al. state that "this arrangement afforded several interesting full-body interactions. Participants frequently walked around (and across!) the installation, crouching near parts of it and gathering in small groups around various parts of the projection." [1]. When using wall-mounted projectors to project on the ground, severe keystoning problems can emerge. Our proposed Displaydrone system could easily hover above the ground, creating minimal occlusion when people are getting closer to or even stand in the display.

Figure 6. Adjusting the focus of the projection manually before take-off using a coloured full screen image.

Following an object. Related to the possibility of the fore mentioned 'continuous movement', the drone can also project on moving targets or follow an object around. Moving targets as backdrops may include cars, cyclists or walking people on the street. In a guerilla marketing campaign by the design agency HoverKraft varying speech bubbles were projected above people's head or on their backs, advertising the cultural program of the city Utrecht in a playful way. Due to the fast movements of the Displaydrone its projection could also follow a person directing her to a promoted vendor location.

6. CONCLUSION & OUTLOOK

This paper introduced the Displaydrone, a novel system that combines a multicopter (flying robot) with a video projector and a mobile phone into a flying interactive display for projecting onto walls and arbitrary objects in the physical space. It reported how the Displaydrone was realized with an octocopter, an off-the-shelf pico-projector and an Android phone to carry out test flights for exploration. The paper reported an experimental evaluation to gain first impressions on how the Displaydrone is perceived by a viewing audience. For this we programmed and installed an SMS moving text application for the Displaydrone in order to facilitate mobile group interaction. While everyone in the audience group was able to see the shared public screen projected by the Displaydrone, individuals of the group were able send individual SMS text messages from their mobile phone to the drone. The Displaydrone then projected the SMS content in form of a moving text via its pico-projector to a wall.

This paper highlights the Displaydrone's potential of becoming a future enabler of new kinds of interesting social group interactions in the physical space, turning that space gradually into highly location and context specific interaction environments. However aspects like legal issues, short battery life or the low ANSI lumen numbers of pico-projectors still limit the scope of deployment of the Displaydrone.

Our next steps will focus on developing more sophisticated interactive display applications for the Displaydrone including those, which incorporate a private return channel. Potential application areas are pervasive advertising, augmented reality games and new forms of social interaction and communication.

Currently, the drone has to be controlled remotely by a person when flying. In the future the drone shall be able to fly autonomously, estimating the distance to the projection surface by itself and refocusing the projector accordingly. Therefore further enhancements have to be made to stabilize the drone when it's in the air, as well as stabilizing the projected image. In the longer term it will be exciting to see multiple Displaydrones fly in formation. While this may seem to be a rather trivial next step, it does bring new and complex challenges to the flight control.

7. REFERENCES

[1] Ananny, M., Strohecker, C., Biddick K. 2004. Shifting Scales on Common Ground: Developing Personal Expressions and Public Opinions. *International Journal of Continuing Engineering Education and Life-Long Learning* (In Press).

[2] Baldauf M., Lasinger K., Fröhlich P. 2012. Private public screens: detached multi-user interaction with large displays through mobile augmented reality. *In Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia* (MUM '12). ACM, New York, NY, USA. DOI= 10.1145/2406367.2406401.

[3] Deller M., Ebert A. 2011. ModControl - mobile phones as a versatile interaction device for large screen applications. *In Proceedings of the 13th IFIP TC 13 international conference on Human-computer interaction - Volume Part II (INTERACT'11)*, Campos P., Nunes N., Graham N., Jorge J., Palanque P. (Eds.), Vol. Part II. Springer-Verlag, Berlin, Heidelberg, 289-296.

[4] Holopainen J., Lucero A., Saarenpää H., Nummenmaa T., El Ali A., Jokela T. 2011. Social and privacy aspects of a system for collaborative public expression. *In Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology* (ACE '11), Romão T., Correia N., Inami M, Kato H, Prada R., Terada T., Dias E., Chambel T. (Eds.). ACM, New York, NY, USA, Article 23, 8 pages. DOI= 10.1145/2071423.2071452.

[5] Huber J., Steimle J., Liao C., Liu O., Mühlhäuser M. 2012. LightBeam: Interacting with Augmented Real-World Objects in Pico Projections. *In Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia (MUM '12*). ACM, New York, NY, USA, Article 16, 10 pages. DOI= 10.1145/2406367.2406388.

[6] Kurdyukova E., Obaid M., André E. 2012. Direct, bodily or mobile interaction? Comparing interaction techniques for personalized public displays. *In Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia (MUM '12).* ACM, New York, NY, USA, Article 44 , 9 pages. DOI= 10.1145/2406367.2406421

[7] Lucero A., Holopainen J., Jokela T. 2012. MobiComics: collaborative use of mobile phones and large displays for public expression. *In Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services (MobileHCI '12)*. ACM, New York, NY, USA, 383-392, DOI= 10.1145/2371574.2371634.

[8] Müller J., Alt F., Schmidt A., Daniel M. 2010. Requirements and Design Space for Interactive Public Displays. *In Proc. 18th Int'l Conf. Multimedia (MM'10),* ACM, New York, NY, USA,,1285-1294. DOI= 10.1145/1873951.1874203.

[9] Peltonen P., Salovaara A., Jacucci G, Ilmonen T., Ardito C., Saarikko P., Batra V. 2007. Extending large-scale event participation with user-created mobile media on a public display. *In Proceedings of the 6th international conference on Mobile and ubiquitous multimedia* (MUM '07). ACM, New York, NY, USA, 131-138. DOI= 10.1145/1329469.1329487.

[10] Pinhanez, C. 2001. The Everywhere Displays Projector: A Device to Create Ubiquitous Graphical Interfaces. *In Proceedings of the 3rd international conference on Ubiquitous Computing (UbiComp '01), Abowd G. D., Brumitt B., Shafer S. (Eds.). Springer-Verlag, London, UK, UK, 315-331.*

[11] Raskar, R., Beardsley, P., van Baar, J., 2004. RFIG lamps: interacting with a self-describing world via photosensing wireless tags and projectors. *In ACM SIGGRAPH 2004 Papers (SIGGRAPH '04), Marks J. (Ed.*). ACM, New York, NY, USA, 406-415. DOI= 10.1145/1186562.1015738.

[12] Raskar, R., van Baar, J., Beardsley, P., Willwacher, T., Rao, S., Forlines, C. 2006. iLamps: geometrically aware and self-configuring projectors. *In ACM SIGGRAPH 2003 Papers (SIGGRAPH '03).* ACM, New York, NY, USA, 809-818. DOI= 10.1145/1201775.882349.

[13] Scheible J., Ojala T.. 2005. MobiLenin combining a multi-track music video, personal mobile phones and a public display into multi-user interactive entertainment. *In Proceedings of the 13th annual ACM international conference on Multimedia (MULTIMEDIA '05).* ACM, New York, NY, USA, 199-208. DOI= 10.1145/1101149.1101178.

[14] Schöning, J., Rohs, M., Kratz, S. 2009. Map torchlight: a mobile augmented reality camera projector unit. *In CHI '09 Extended Abstracts on Human Factors in Computing Systems (CHI EA '09).* ACM, New York, NY, USA, 3841-3846. DOI= 10.1145/1520340.1520581.

[15] Sheridan, J.G., Dix, A., Bayliss, A., Lock, S. Understanding Interaction in Ubiquitous Guerrilla Performances in Playful Arenas. In Fincher S., Markopolous P., Moore D., Ruddle R. (Eds.), People and Computers XVIII-Design for Life, Proceedings of HCI 2004, ISBN 1-85233-900-4, London, Springer-Verlag, Leeds, Uk, 2004, 3-18.

[16] Underkoffler, J., Ullmer, B., Ishii, H. 1999. Emancipated pixels: real-world graphics in the luminous room. *In Proceedings of the 26th annual conference on Computer graphics and interactive techniques (SIGGRAPH '99).* ACM Press/Addison-Wesley Publishing Co., New York, NY, USA, 385-392. DOI= 10.1145/311535.311593.

[17] Willis, K.D.D., Poupyrev, I., Shiratori, T. 2011. Motionbeam: a metaphor for character interaction with handheld projectors. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11).* ACM, New York, NY, USA, 1031-1040. DOI= 10.1145/1978942.1979096.

[18] Willis, K.D.D., Poupyrev, I., Hudson, S.E., Mahler, M. 2011. SideBySide: ad-hoc multi-user interaction with handheld projectors. *In Proceedings of the 24th annual ACM symposium on User interface software and technology (UIST '11).* ACM, New York, NY, USA, 431-440. DOI= 10.1145/2047196.2047254.

[19] Wilson, M.L., Robinson, S., Craggs, D., Brimble, K., Jones, M. 2010. Pico-ing into the future of mobile projector phones. *In Proc. In CHI '10 Extended Abstracts on Human Factors in Computing Systems (CHI EA '10).* ACM, New York, NY, USA, 3997-4002. DOI= 10.1145/1753846.1754092.