A Mobile Interactive Mapping Application for Spatial Augmented Reality On The Fly

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Abstract: Observing the evolution of virtual reality (VR) and augmented reality (AR) applications, a shift from professional users towards a broader public can be noticed in the last few years. This trend creates a demand for intuitive and easy-to-use tools that support people in utilizing VR or AR for their own projects. In this paper we present an open source tool, which we developed to allow non-professional users to project images onto the surface of real-world objects on the fly. We designed a web application that runs both on mobile and desktop devices and therefore can be used in a versatile and flexible manner. We conducted a user study to compare the usability and performance of the mobile and the desktop version of our tool. The results show that users prefer the mobile version for spatially challenging projection tasks.

Keywords: Spatial augmented reality, 3D projection mapping

1 Introduction

Spatial augmented reality (SAR), also known as projection mapping, combines the advantages of real-world augmentation and tangible user interfaces by projecting computer-generated images directly onto the surface of physical 3D objects [RWF98, BK03]. This technique allows users to perceive objects in a natural way [KSF10], for example by walking around them or touching them [Sch01], while the objects' appearance can be changed in a variety of ways [Kau03]. Such integration of virtual content into our real-world environment found its way from projects in research and industry to our everyday life with applications including art, entertainment, education and home automation [JBOW15, JSM^{+}14].

A fundamental task in SAR is the precise alignment of the physical object surfaces and the projected images [BR05]. If the geometry of the object is known, e. g., after reconstructing it with a laser scanner, the textures can be applied to its virtual representation. An additional calibration step is necessary to determine the relative position and orientation of the projector. These two computationally expensive steps make this approach unfeasible for inexperienced users who wish to take advantage of SAR for ad-hoc projects [Cat13].

In order to avoid extensive calibration processes, an alternative approach can be to set up a feedback control system instead of precomputing the projected images [YK14]. With this approach, all textures are transformed in 2D space manually by the user while every state is projected directly onto the 3D object on the fly. The user continuously adjusts the projected images until the results meet his expectations.

In this paper we present a flexible software solution that can be used by non-professionals and is based on a feedback control user interface. Using this technique, the quality of the mapping highly depends on the capability of the user to observe the current state of the mapping at close range. For this purpose, desktop applications are limited as they confine the user to a particular location. Our approach is to provide a tool that allows users to move freely around the physical object while adjusting the projection on a mobile device. We evaluated our mobile application in terms of the mapping quality in comparison to an analogous desktop version.

The remainder of this paper is structured as follows. Section 2 resumes existing tools that are used for SAR purposes and summarizes challenges and requirements for the implementation of our tool. Section 3 describes both the system architecture and the user interface of our tool. In Section 4 the mobile and desktop versions of our tool are compared in a user study. Section 5 concludes the paper.

2 Background and Challenges

Along with the growing interest in SAR and the resulting demand for supportive software solutions, a variety of commercial tools have been developed. Some popular examples are MadMapper[1] or TouchDesigner[2], which are widely used both for artistic and commercial projects. While such tools perfectly fit the requirements of SAR professionals, they are mostly unsuitable for occasional users both in terms of price and complexity. In addition, most software solutions require a specific set of hardware, resulting in even higher costs.

In contrast, a range of tools exists that are open source such as VPT[3] or LPMT[4]. They have limitations, for example the number of supported projectors, but still can be a good choice for smaller projects.

A low cost solution for tablets and smartphones comes with DynaMapper[5], an application which was primarily developed for iPads, but was expanded to other iOS and Android devices recently. DynaMapper offers an intuitive user interface, enabling users to project images or videos both on rectangular and curved surfaces without need of extensive practicing. At first sight, the usage of mobile devices pretends a high freedom of movement for the user. However, the mobility is very restricted as the device is connected directly to the projector

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[1] http://www.madmapper.com/

[2] http://www.derivative.ca/

[3] http://hcgilje.wordpress.com/vpt/

[4] http://hv-a.com/lpmt/

[5] http://dynamapper.net/

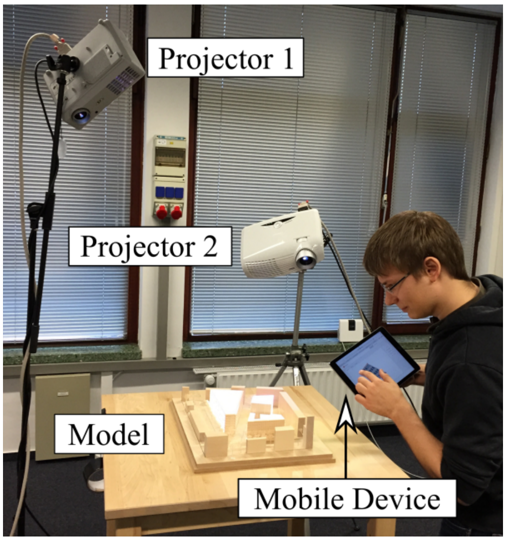

Figure 1: Annotated photo of a SAR setup with two connected projectors.

via a video adapter, forcing the user to stay close to the projector. The physical connection between projector and mobile device also complicates the usage of multiple projectors.

Considering these existing solutions, our contribution is not to outdo them by providing a tool with an even higher range of functions, but to enable non-professional users to build their own SAR setup on the fly instead.

We focused on five key challenges and requirements for our application:

- *Simplicity*: The user interface of our tool is designed to be easy to learn and use. Hence, we intentionally waive more complex functionalities. Moreover, no complicated and time-consuming calibration is required.
- *Mobility*: By decoupling the client application and the server, which is connected to the projectors, the user is not confined to a particular location. By using a mobile client system, he can walk around the projection surface to facilitate the mapping process or move the projection setup independently of the location (see Fig. 1).
- *Flexibility*: The client application is browser-based and therefore can be run on tablets, smartphones and desktop computers. In contrast to most existing SAR tools, it is not restricted to a specific operating system.
- *Multi-projector support*: If the server is connected to multiple projectors, the web application adapts by appending additional canvases (see Fig. 1). In the same way, the two input ports of a projector with stereoscopic display can be accessed.
- *Free licensing*: The whole software is open source and can be downloaded from the project website[6].

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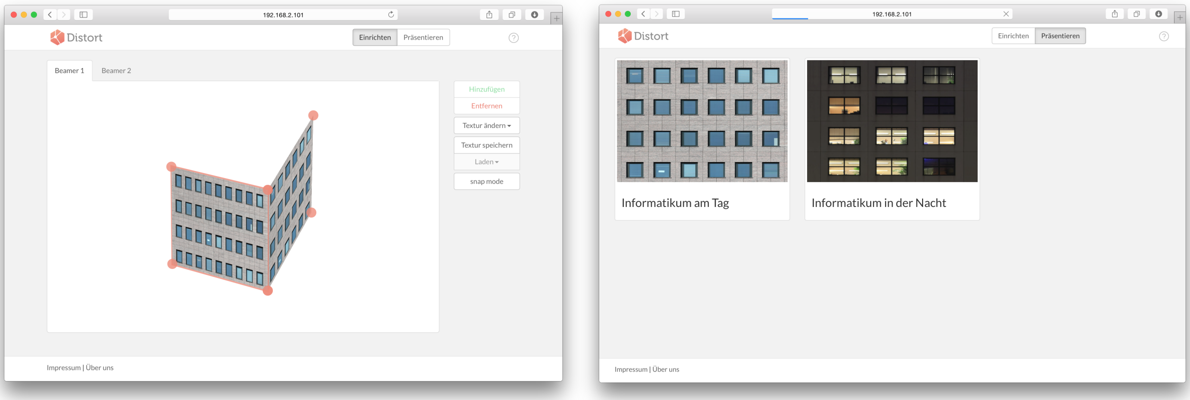
[6] `http://github.com/Distort-Mapping/distortion`



(a) Editor mode (b) Presentation mode

Figure 2: Illustration of the two different application modes.

3 Implementation

In this section we describe the implementation of the SAR application.

3.1 System Architecture

In order to achieve a physical separation of the projectors and their control interface, our application is based on the client-server model. All projectors are connected to a local graphics workstation that runs a Unity3D application. To initiate a communication session with the Unity3D server, a website must be opened on the client system. As the web application is based on AngularJS it works in most browsers of both desktop and mobile devices. The web application receives and logs all user inputs and processes them locally. Simultaneously, it sends basic information about the current mapping to the Unity3D server via WebSockets. From this data, the server can reproduce the mapping state to adapt the projected content accordingly.

3.2 User Interface

As the Unity3D application on the server is intended to run in the background and does not need manual input, we want to take a closer look at the user interface of the web application. Since the web application should be usable for tablets, smartphones and desktop PCs, it supports both touch and mouse input. For better encapsulation of different function groups, the tool offers two separate modes, which we describe in the following.

Editor Mode The *editor mode* allows users to create and transform textured surfaces while they are projected onto a physical object in real time. The form of each quad can be directly manipulated by dragging and dropping its corners to the desired position. At any point of the editing process, textures can be loaded into the user-defined distorted surfaces. Since the web application is currently limited to the creation and assembly of quadrangular surfaces, textures have to be preprocessed in order to project onto curved objects. The current state, including all transformed textured surfaces, can be stored in a so-called *texture set.*

Presentation Mode In this mode users can access previously stored texture sets (see Fig. 2b). By selecting a texture set, all projected textures are replaced. Thus, the presentation mode can be used for demonstrating different configurations of an object.

4 User Study

In this section we detail the user study which we conducted to evaluate the system.

4.1 Participants

We recruited 10 participants for our evaluation, 9 male and 1 female (ages from 24 to 38, $M = 30.3$). The participants were students or professionals of human-computer interaction, computer science or engineering. All of our participants had normal or corrected-to-normal vision. None of our participants reported a disorder of binocular vision. Seven participants had experienced AR before. Nine participants were right-handed, one was left-handed. The total time per participant, including instructions, experiment, breaks, and questionnaires was 30 minutes. Participants were allowed to take breaks at any time.

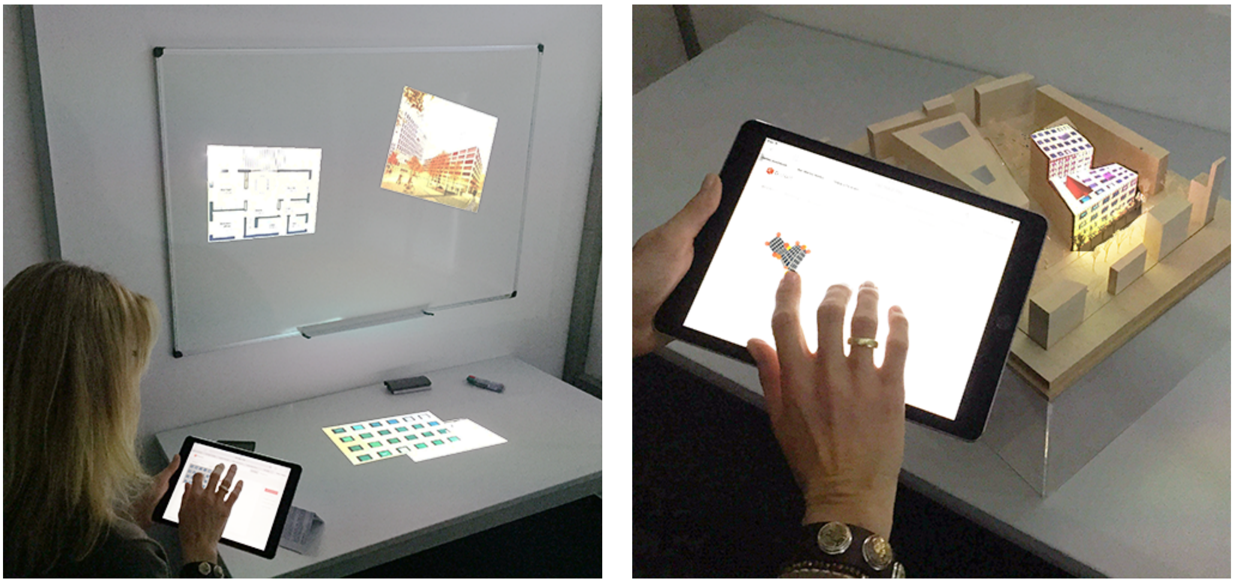
4.2 Materials

The user study was conducted in $5m \times 5m$ laboratory room, which is equipped with several pieces of furniture, including a whiteboard, a small kitchen with two wall and two floor units and a desk. All projection surfaces are colored in light gray or white. In order to demonstrate the flexibility of the approach, three different commodity projectors (Optoma HD20, Acer H5360, Panasonic PT-AX100E) were included in the setup. Two of them were directed to the walls, while the third one was placed at the ceiling to point directly at the top of the desk. All projectors were connected to an Intel graphics workstation with Core i7 3.4GHz CPU and Nvidia Quadro K5000 graphics card. For the desktop version of the web application, we used a 15" MacBook Pro and for the mobile version a 9.7" iPad Air 2, respectively. All devices were connected to the same local network.

4.3 Methods

In the user study we compared the desktop and the mobile version of our application. We focus on how the mobilty of the users, while mapping an image onto a projection surface, influences the mapping quality. To build a reliable basis of comparison, we chose four indoor scenarios in which the participants of the user study had to perform different tasks. The tasks differ in their complexity both in terms of the number of projected surfaces and the number of projection planes in 3D space (see Fig. 3).

(a) Poster alignment (b) Furniture redesign



(c) Desk organization (d) Facade projection

Figure 3: Illustration of the four scenarios that were tested in the user study.

We measured task load for the desktop and mobile version using the NASA Task-Load-Index (TLX) questionnaire. Additionally, we asked the participants to judge their preference of either the desktop or mobile version for the different tasks.

Poster Alignment In the first scenario, the participants had to position a single poster on a wall (see Fig. 3a). In order to evaluate the accuracy of the mapping, we asked them to align the poster's edges with a $1.50m \times 1.00m$ whiteboard.

Furniture Redesign The second task was to project a wood texture on a wall and a floor unit of a kitchen (see Fig. 3b). Both projection surfaces were lying in the same projection

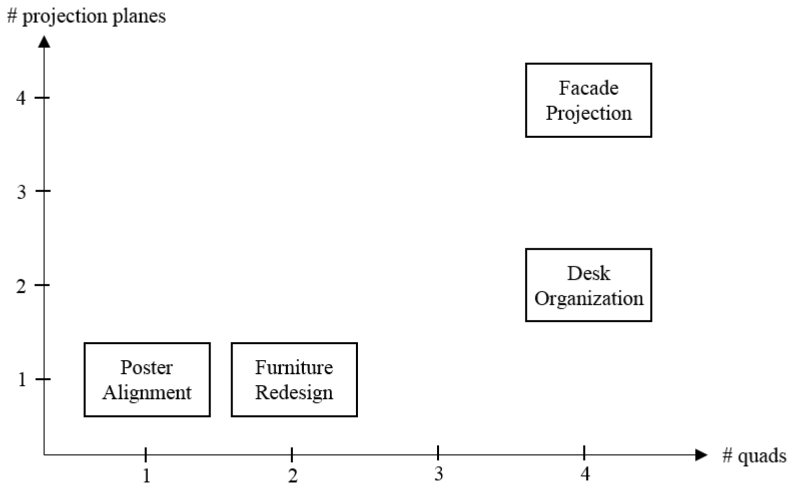


Figure 4: Complexity of the mapping task in four different scenarios.

plane. To cover all units of the kitchen with one projector, the projector was rotated 90 degrees. The participants were pointed to this modified setup, but no specific solution strategy was suggested.

Desk Organization In the third scenario, the participants were instructed to place four rectangular notepads on two surfaces which were perpendicular to one another (see Fig. 3c). Two of the notepads should be aligned parallel to the edges of the projection surfaces while the remaining one should be rotated. The desk organization scenario included two projectors.

Facade Projection The last task was to change the facade textures of four predefined walls in an architectural block model (see Fig. 3d). All projection surfaces were arranged in different projection planes. Besides the higher number of quads and projection planes, the small size of the projection surfaces increased the level of difficulty in this mapping task.

4.4 Results and Discussion

The subjetive responses for preference show that only 4 of the 10 participants preferred the mobile version for aligning the poster on the wall, but 9 participants preferred the mobile version for the furniture redesign condition, 9 participants preferred it for the desk organization condition, and 9 participants preferred it for the facade projection condition. The results show that except for the simple case of aligning a poster horizontally and vertically on a wall, most of the participants preferred to use the mobile version while standing close to the object that is projected on.

We analyzed the questionnaire data with Wilcoxon signed ranks tests for a significance level of $\alpha = .05$. The results of the SUS questionnaire show a mean usability score of 64.50 ($SD = 14.80$) for the desktop condition and 76.00 ($SD = 16.25$) for the mobile condition. We found a significant difference between the two conditions, $Z = 2.49$, $p = .013$. The difference indicates that the usability of the mobile version was judged higher than that of the desktop version.

The results of the NASA TLX questionnaire show a mean task load of 43.05 ($SD = 17.00$) for the desktop condition and 34.65 ($SD = 15.96$) for the mobile condition, $Z = 1.38$, $p = .17$. In particular, we found a significant difference for mental demand between the desktop ($M = 51.00$, $SD = 27.99$) and mobile ($M = 26.70$, $SD = 18.90$) conditions, $Z = 2.09$, $p = .04$. We found a significant difference for physical demand between the desktop ($M = 23.80$, $SD = 25.37$) and mobile ($M = 34.20$, $SD = 25.99$) conditions, $Z = 2.08$, $p = .04$. We found no significant difference for temporal demand between the desktop ($M = 37.60$, $SD = 29.70$) and mobile ($M = 32.40$, $SD = 23.82$) conditions, $Z = .59$, $p = .55$. Also, we found no significant difference for performance between the desktop ($M = 34.20$, $SD = 17.84$) and mobile ($M = 18.40$, $SD = 15.14$) conditions, $Z = 1.79$, $p = .07$. Moreover, we found no significant difference for effort between the desktop ($M = 60.60$, $SD = 30.18$) and mobile ($M = 46.10$, $SD = 25.49$) conditions, $Z = 1.30$, $p = .19$. Additionally, we found no significant difference for frustration between the desktop ($M = 51.10$, $SD = 27.33$) and mobile ($M = 50.10$, $SD = 29.82$) conditions, $Z = .10$, $p = .92$.

The results indicate that the mobile version was significantly less mentally demanding than the desktop version. We collected informal responses of the participants, which agree that they appreciated the ability to easily rotate the tablet to the projection orientation, instead of having to perform a mental rotation as in the desktop condition. From the behavioral observation data we extracted that 8 of the participants quickly realized that they could rotate the tablet, whereas 2 participants always held the tablet in its landscape orientation during the experiment. Also, the results show that participants found the mobile version significantly more physically demanding than the desktop version. This may be explained by the fact that they were seated while using the desktop version and standing during the mobile condition.

5 Conclusion

In this paper we presented an open source application, which provides inexperienced users an intuitive and easy-to-use tool for 3D projection mapping on surfaces of real-world objects. The application runs both on desktop and mobile devices. While the desktop version restricts the user's movements, the mobile version allows users to walk towards the object onto which the virtual content is projected, and fine-tune the mapping. We found in an evaluation that users preferred this ability of the mobile version for spatially complex projection tasks. The results indicate that such a mobile projection application can provide users with more flexibility and allow for higher precision than traditional desktop-based solutions, which should be confirmed in future work with different approaches to 3D projection mapping. Future work may also focus on providing easy-to-use blending techniques for multi-projector installations with overlapping projection volumes.

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