Personal Touch – A Viewing-Angle-Compensated Multi-Layer Touch Display

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Abstract. Large format touch screens have become an important means of interaction for collaborative and shared environments. This type of display is particularly useful for public information display in museums and similar contexts. Similarly augmented reality displays have become popular in this context. Both systems have benefits and drawbacks. *Personal Touch* is an augmented-reality display system combining real objects with superimposed interactive graphics. With increasing display sizes and users moving in front of the display user tracking and viewing angle compensation for the interactive display become challenging. *Personal Touch* presents an approach combining IR optical tracking for gesture recognition and camera-based face recognition for the acquisition of viewing axis information. Combining both techniques we can create a reactive augmented-reality display establishing a personalized viewing and interaction context for users of different statue moving in front of a real object.

Keywords: Embodied interaction, gesture-based interaction, multimodal, tangible user-interface; body-centric design; augmented reality; physical navigation; museum, proxemics

1 Introduction

The use of large format touch screens for public locations such as museums or libraries has become widely popular. A recent survey [1] indicates that the common usage of this type of display has transformed established concepts of human computer interaction and shaped the expectations about interactive possibilities in public and semi-public spaces. Research about museum visitors has shown that young visitors prefer museum collections to be displayed in innovative ways. Having grown up with interactive multi-touch technologies young visitors respond positively to interactive information displays presented on touch screens [2]. While maybe particularly popular among younger users, touch screen interaction is now widespread and easy to use for a wide range of age groups [3]. Traditionally museum displays have been focusing on objects from their collection in combination with introductory texts and explanations. But as textual and visual information going beyond the existing physical evidence in form of collection objects, for example various forms of information visualization, interactive screens have become more prevalent [4]. Those displays are often dynamic interactive presentations in addition and in support of collection objects. The hardware of choice to realize these presentations are large format touch screens. Since the mid 2000s large touch-screen use has been more frequent due to more powerful and more economic technology [5].

For use in shared spaces large format touch-screens provide several benefits that make them specifically suitable for environments like museum or library displays. The most prominent among these are the visibility and attraction of large dynamic visualizations for museum visitors walking through the exhibition space. Compared to static printed text or small displays the ability to grab attention and direct the visitor's gaze is significantly stronger. Outside of the museum, for example in a shared office, the salience of the display is often less important. Large interactive displays also promote activity and social awareness among its users [6]. The conduciveness for communicative behavior and collaboration is generally one of the core benefits of this type of display system. In particular in complex tasks the opportunity for co-located problem solving can be highly beneficial [7]. Again the museum environment differs from other environments as it is less focused on collaborative solving of complex tasks rather than communication among visitors to foster learning and engagement. The increased screen size and the possibility to collaboratively interact in a shared environment have been shown to provide benefits for sense-making [8] and learning [9].

Another display technology that has become very popular in the museum environment is the augmented reality (AR) display. In particular in science and natural history museums this form of display has gained such popularity that it is sometimes referred to as a hype [10]. The popularity stems from the fact that it can simulate prior states of a real physical collection object. A popular example is the dinosaur skeleton, which can be seen as a complete dinosaur through an augmented reality display [11], [12]. Augmented reality displays blend a representation of a real context, for example a museum object, with a computer generated information layer. Both layers are displayed such that they are correctly superimposed. The additional information can be of various kinds, such as the virtual models of dinosaurs or simply additional textual information pertaining to an object. We can distinguish applications using a camera generated video image to represent the real context and those that use optical see-through techniques to show the real object [13].

One of the important issues for both techniques, the touch-screen as well as the augmented reality system (of course the same applies to the traditional static text panel), is how the relationship between the additional information and the real object is established. The touch-screen is often used as a self-contained unit placed in proximity to the objects it refers to. If close relationships are established it is mostly through the display of visual representations of the objects nearby that the information refers to. Screen and objects have very different viewing conditions and are rather in competition than in support of each other. Augmented reality systems deliver a much closer relationship between object and additional information. By superimposing both object and additional information users can see directly how they relate to each other. For this reason the alignment between the two is a distinguishing quality factor [14]. The earliest way of establishing the connection between real and virtual was through markers, coded visual symbols such as QR-codes, that can be read by the AR-device and interpreted such that the correct information overlap can be displayed. The display orientation is calculated according to the perspective on the marker [15]. The downside of those markers is that they have to be placed very close to the actual object in order to give a tight connection, but the actual object cannot be used for augmentation. The markers add a visual element that is often difficult to integrate with the aesthetics of the presentation. Another downside is that users must carry a correctly equipped device that can be used to scan and resolve the codes. Later approaches do not have to rely on markers but rather use feature constellations of the object itself. They are suitable for a more seamless and more aesthetically pleasing integration between the real and virtual layers. In both cases the hardware platform to display the augmentation layer are smart phones or tablets. This reliance on AR-capable devices also introduces the problem that the screen that can be used for the additional information display is comparatively small [16].

An example for a custom solution to stimulate a more specific and precise relationship between the object and the augmentation layer is the use of a laser-pointer-like device[17]. Here users can point to specific parts of a real exhibit to trigger the information overlay. The laser works almost as an extension of the hand that ‘touches’ the exhibit, an action normally not permitted in a museum context. In this sense the AR solution allows a more direct engagement with the object with visible light than pointing the camera of a phone at an object. The possibility of pseudo-touching an object has the potential to make for a highly engaging experience in rather direct relationship to the real object.

Both display systems large collaborative touch-screens as well as augmented reality systems, have their benefits and drawbacks. While the augmented reality systems has the opportunity to establish a much tighter connection between the real object and the augmentation layer than the touch screen, it does not offer the opportunity for collaborative exploration in a way the large touch-screen does. The use of handheld devices necessary to enable the personalized pointing and exploration of real exhibits forces the use of smalls screens, which are limited to one individual user. Handheld devices are made specifically to be used by only one person and the experience of standing next to someone engaged with a handheld device and being excluded from the experience is all too well known [18],[20]. Handheld devices and collaborative exploration thus seem to be mutually exclusive. This dilemma has been addressed for example in combining several different interfaces for the same content so users can choose the preferred mode of access. A comparative study traces the benefits and drawbacks of both systems and investigates whether a combined approach is successful [21].

For *Personal Touch* we are using a display set-up that combines the properties of large touch-screens and those of an augmented reality display not through combining two separate implementations but by integrating them into one. Our approach is to use a transparent touch screen placed in front of the real object to which the augmentation layer refers. This approach unites the collaborative aspect of a large format touch screen permitting several users to share the display and to collaboratively explore the exhibit. At the same time, through the optical superimposition of the screen, it serves as an augmentation layer and a close relationship is established between the additional information and the object. The touch-screen consists of a large glass panel which is suspended in front of the object and it displays information being projected onto it. The users can see both the information on the screen as well as the object, looking through the glass panel. Not only combines this system some of the main benefits of AR and touch-screen systems, it also implements a way to reach out to the object and actually feel a physical resistance when touching the screen.

2 Challenges

The system we implemented for *Personal Touch* faces several challenges. Design problems existing in each individual display technology present themselves in a somewhat different light when combined. It is a challenge to design for a satisfactory multi-user experience in large format touch screens that allows for all members of the group interacting with the system to partake equally and also balances ease-of-use on the first approach and a meaningful deep scaffolding of a longer interaction. A study of these challenges is discussed in [22]. For our purposes the problems of accommodating several users on front of one object is potentially compounded for reasons of limited interaction space. In particular small objects do not provide sufficient space to accommodate several users in front of them at the same time.

The other challenge for our approach is to align the augmented reality display with the real object behind it correctly. Again the problem is compounded in comparison to an individual user experience with a mobile device. Restricting the experience to one person makes things easier and the fact that the user can carry the mobile device along with any movement makes the alignment question a lot easier to address. In our attempt to accommodate multiple users with one shared display, the challenge is to render both information layers in correct alignment to all of them. An additional difficulty for alignment is that museum visitors tend to move around and walk from one exhibit to the next, this means that they might look at objects from various angles and these angles change during the phase of observation of the same object. The augmented reality touch screen thus has to provide an option to adjust the display for a certain range of varying viewing angles and correct for the parallax resulting from user position in respect to the object.

Viewing angle correction is not only of interest to users in motion but it also is a way of providing a comfortable interaction situation for users of different body heights. In the museum environment it is to be expected that the users of such a system range from children all the way to adults, thus what is a comfortable interaction situation for one maybe be inappropriate for another user. Our requirement to accommodate groups of users for collaborative interaction further compounds the problem of alignment because the viewing axis correction has to take into account whether the object is looked at from several different angles at the same time. In an earlier study of this system without any viewing-angle-compensation we found that users while benefiting from the optical superimposition and touch-screen functions they struggled with the alignment of real and virtual display [23]. Based on body height these problems were more or less strong, in general indicating a linear correlation between proximity to the position of optimal alignment and ease-of-use. The challenges addressed in the *Personal Touch* project can be described as a triplet of issues surrounding viewer-dependent display adjustment:

- Viewing-angle-compensation for users of varying body height;
- Viewing-angle-compensation for users in motion;
- Viewing-angle-compensation for multiple users in varying group sizes and constellations.

3 Related Work

Camera-based tracking of users in front of a large screen has been explored in order to track touch gestures and turn the screen into a large format touch screen [24]. Given that large touch sensitive screens are becoming more available research has started to focus on the notion of body-centric design to conceive of interaction models combining various forms of sensing of users and different input devices. A solution implementing large format screen for full body interaction is described in [25]. It uses camera or magnetic tracking to determine the skeleton of the user and determines interaction gestures from the analysis of the skeleton. The same data also serve to render a virtual representation of the user(s) [26] on the screen for visual feedback to improve gesture performance. The display system does not implement augmented reality components. A similar system based on infrared tracking that extends the interaction patterns to multiple surfaces using touch and mid-air gestures is described by Wagner et al. [27] The approach focuses on developing a body-centric design language. The combination of touch interaction with mid-air gestures is also explored in Müller et al. [28]. The study focuses on the role of different design affordances to communicate the interaction techniques available in installations in public space. A strong dependence is on environmental factors and the sequence of use of different affordances (touch versus gesture) was found. If gestural mid-air interaction was available, strong affordances for touch interaction had to be present to serve as a "call to action." While most research focuses on screen-based interaction and the combination of touch and gesture, few works investigate the combination of touch and augmented reality displays. One example exploring augmented reality interaction and haptic interaction with real physical objects is described in Kim et al. [28] To ensure correct alignment of multiple interaction and display contexts, in particular pointing gestures in respect to large screens the mathematical modeling of the pointing gestures and their spatial properties are important. A model for the calculation of the gain of pointing gestures is discussed in Shoemaker et al [29].

Another important aspect for the implementation of a display system that dynamically adjusts to user action and the configuration of changing user constellations is the successful analysis of the actions and movements of the users. Dim and Kuflik [30] describe a series of simple behavioral patterns of visitor pairs and discuss a system that can automatically track these patterns and, in a second step, potentially offer customized services based on the analyzed pattern. In [31] an automated system for the mining of behavior patterns is discussed.

4 The *Personal Touch* System

4.1 Design Considerations

The design goals we defined for *Personal Touch* are revolving around three main aspects. The first is the superimposition of information and a real object. For the first implementation we limited the set-up to one single object in order to keep the components influencing the evaluation to a minimum. Our hypothesis is that depending on the number of objects, object size and relative screen-size the results in interaction patterns will be different. We are assuming that large touch-screen sizes will become more and more affordable so it is conceivable that an interaction screen can span several objects and thus several interaction contexts. For our study we also wanted to observe if the screen is small enough that it also allows viewers to easily get close to the objects viewers would also examine the object directly. We were curious what the sequence of observation was going to be, if viewers first examine the object and then access further information about it or vice versa, or if users look at only the object or only the screen.

Our interest in superimposing information in an augmented reality style was to establish a very close and precise relationship between the object and the additional information and to foster the self-guided exploration of different information layers. The superimposed delivery of additional information caters to users who do not like to read long texts and get turned away when they see long explanations about an item, as it is often the case with static printed text plates. Users also are often unwilling to refer back and forth between object and text information. Most users tend to read the text and then look at the object. A minority of the viewers we observed in a traditional museum exhibit with static text plates looks at the object first, then reads the text, and then looks at the object again. The superimposed information caters to users who want to be able to determine how much information they need about a specific item. They may be fine with a superficial level of information simply identifying the object. In other cases they may want to have the opportunity to request more information. Our hypothesis is that the combined augmented reality touch display allows for a seamless scaffolding of further information pertaining to elements or areas of interest.

Even though in our first implementation we are limiting the display to one single object the system should be able to clearly distinguish the object to which the displayed information pertains in case several objects are visible behind the screen. The second main design goal is thus the implementation of effective viewing axis compensation. The viewing-angle compensation should be able to establish for a given viewing axis which object and which part of the object the information belongs to. Based on data about the position of the viewer the information display should be adjusted for several aspects: It has to correct for changing positions of the users as they move through the exhibition and past the object with the augmented display; it also has to adjust for different body heights of the viewers. Our hypothesis is that an optical tracking of the viewers in front of the screen should be able to deliver the data necessary for an adjustment that can satisfy the formulated requirements.

The viewing axis compensation should also be able to deliver a certain degree of personalization and responsiveness to the viewers. We are aiming in this sense for an "adaptive interface" that can adjust for several individual factors of the viewers, similar to the concept discussed in [32]. Our hypothesis is that the dynamic adjustment can direct the viewer's gaze towards the object of interest. As a viewer walks past an exhibit the position of the exhibit gets continuously adjusted such that it frames the object the information refers to. We assume that the viewer is less likely to walk past such a constantly updated display "circling" the object of interest, than she would with a static display.

The third main design goal is to accommodate and stimulate collaborative interaction between groups of viewers in front of the display. The display adjustment system therefore has to have a heuristic to determine how to adjust for the viewing axes of several users versus individual users. The touch-screen has to be multi-touch enabled, which is more or less the norm nowadays, in order to allow for several people to interact simultaneously.

4.2 Implementation

The *Personal Touch* system consists of glass panel suspended in front of a physical object. The panel is mounted on thin metal wires fixed tightly to the ceiling and the floor. The wires are tight such that the screen does not move when users interact with it. Our decision to use this kind of mount was to integrate the screen as seamless as possible into the space around the exhibit and avoid a noticeable frame mount around the screen. The aesthetic ideal for the mounting solution was to come close to a “free floating” text, inviting users to interact with the screen as well as to go past it and examine the object directly. The screen is not supposed to be perceived as an obstacle blocking the view to the object, which was the sense we had with a more massive mounting frame. This design decision made it impossible for us to use an IR tracking frame with integrated IR lights and sensors. Our solution was thus a “Leap Motion” controller mounted on a bar beneath the screen that tracked the surface area of the glass panel allowing to determine touches on the screen surface as well as hover-states close to the surface of the panel. The distinction between hover-states and touch events is a benefit that other touch-screen solutions do not provide. In the current version of *Personal Touch* we are not using hover states, but we intend to do this in future iterations.

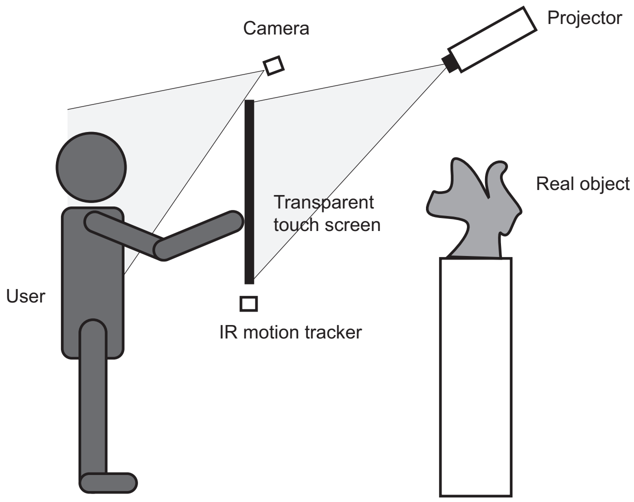

Fig. 1. Schematic of the system set-up of the *Personal Touch* installation

The glass panel has a “holoscreen”-film glued to the back, which is a plastic film with embedded micro-prisms that allows to project onto the screen in an angle of 45 degrees and produce a visible image on the transparent glass. The “holoscreen” is transparent (with a slight matte optic) and allows the viewer to look through the glass at the object behind it. In this way we are realizing a multi-layer augmented reality display. The projector for the display is mounted to the ceiling in a 45-degree angle projecting downwards to the viewer. Since the projector is reasonably steeply inclined the viewer does not get blinded by the projection beam.

Above the screen we mounted a small USB camera equipped with a wide-angle lens that tracks the area in front of the screen. We are assuming that users will always keep a minimum distance of ca. 50 cm from the screen to be able to comfortably interact with it; in order to allow the camera to track the entire area in front of the screen we placed it above the screen and 20 cm behind the glass panel. The camera delivers a constant video feed to the controlling computer. The screen itself is placed 150 cm in front of the object. Around it is enough space for the viewers to approach the object and look at it directly.

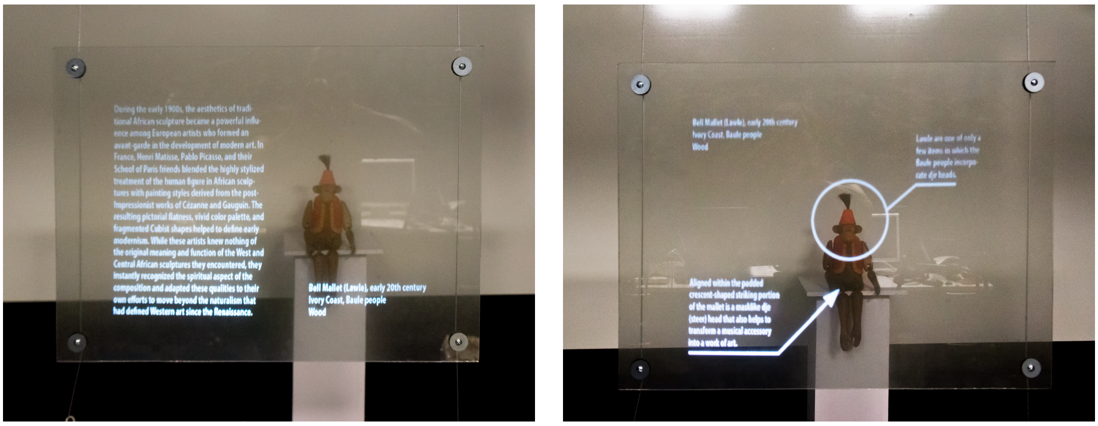

Fig. 2. Two of the three layers of information: General background information (left), and information on specific details of the object (right)

We implemented three information layers of different depths. The first shows a minimal record including the name, date and description of the object. This is the default state when no user is interacting or when users are approaching the screen without touching it. Upon touch the second level providing a general explanatory text about the background of the object is displayed. This information layer can be enhanced for example with maps or other illustrations. The third level has detail information on individual parts of the object, allowing viewers to explore for example the different elements of clothing of the object. The third level is invoked touching "hot spots" indicating further information. The "hot-spots" are visible in both the second and third levels of the display hierarchy. Viewers have full control over how far and how long they explore the provided information and which levels they access to which extent.

4.3 Heuristic for Viewing-Angle-Compensation

For the tracking of users in front of the screen we use the Open CV library to recognize and track faces. This means whenever a user is in front of the screen and looks at it we can recognize the face and determine its position. With this information we can calculate the viewing axis to the object. In this first implementation phase we are using a normal camera delivering a flat matrix image. For the z-axis, i.e. the distance of the viewer from the screen we assume a comfortable touch interaction distance of 50 cm. Based on these data we can calculate an offset for the image projected on the screen to accommodate both horizontal viewing position differences due to varying positions of viewers in front of the screen, as well as vertical differences due to variance in body height. This offset is constantly calculated as long as a face is recognized and can thus be dynamically updated to compensate for changing positions of moving viewers. In default mode, i.e. when no face is detected the image is set to an average centered value. All adjustments are smoothly interpolated such that no sudden jumps of the image occur.

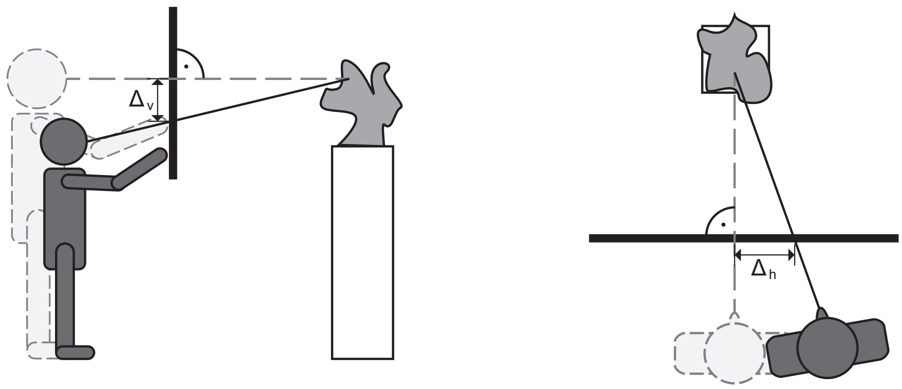

Fig. 3. Viewing-axis-adjustment for individual viewer: vertical adjustment for body height (left), and horizontal adjustment for changing viewer positions (right)

The main challenge is to formulate a heuristic that defines a viewing-angle-adjustment for collaborative interaction. When more than one user are working with the screen – what is the best way to accommodate their different viewing axes? Our heuristic is using an analysis of the constellation of viewers in front of the screen in order to determine how to adjust the display. The heuristic is based on the observations of Edward T. Hall [33] and his formulation of the "proxemics distances." Hall distinguishes four different social distances in humans, the closest being the *intimate* distance, extremely close proximity between two people who almost touch each other. This distance would only occur between people who are very familiar and close with each other, e.g. a couple looking together at something very closely. The *personal* distance ranges from 50 cm in its close phase to 120 cm in its distant phase. The *personal* distance is the normal distance between people who know each other and are comfortable together, this might also be the distance a couple keeps in a public space such as a museum. The *social* distance is the distance people who do not know each other normally keep to each other. It ranges from 120 cm in the close phase to 350 cm in the distant phase. Finally the *public* distance ranges from 350 cm to 600 cm and more. These distances may vary, and they are culturally specific, but they give a good orientation as to what scenarios we should be differentiating. The different proximities correspond to perspective shifts and thus require different display adjustments. The *public* distance is irrelevant for our set-up as the screen is not big enough to accommodate people who keep this distance between each other; if people are unfamiliar to this degree with each other they would tend to wait until one person is done with her interaction before they take over the space in front of the screen. If somebody happens to look at the screen from this distance they would not expect to see correct alignment between real object and information overlay for their viewing position. We decided to take the *social* distance and smaller into account and devise correction scenarios for them. Museum visitors in a group, like colleagues or members of a travel group, would keep the *social* distance. They should be able to interact and share the screen with each other. We assume, though, that they would not be so intimate that they would share the same interaction context. Sharing the same interaction context would potentially bring people closer together than they might feel comfortable with and create the opportunity to touch each other while interacting with the touch-screen. According to Hall in the *social* distance contact between people would not occur. Therefore when faces are tracked with a distance in the range of the *social* distance, the interaction context is duplicated and projected such that it suits the viewing axes of both (or more in case of a large screen) people. The viewers can interact in parallel and share what they see verbally. Users who are more intimate with each other and keep a distance that is in the range of the close phase of the *personal* distance are considered to be familiar enough that they can share the same interaction context. The placement of the context is averaged between their viewing axes and scaled such that it can better accommodate both (maximum three people). For both viewers the alignment is slightly less precise but there is the opportunity to look closely and invite the other "to share the individual's perspective." Finally for the *intimate* distance a scaling of the overlay image does not seem to be necessary and we only make a slight adjustment to average the position between the two viewers. In this scenario only two people can have the appropriate closeness, otherwise the adjustment goes back to the settings for the personal distance.

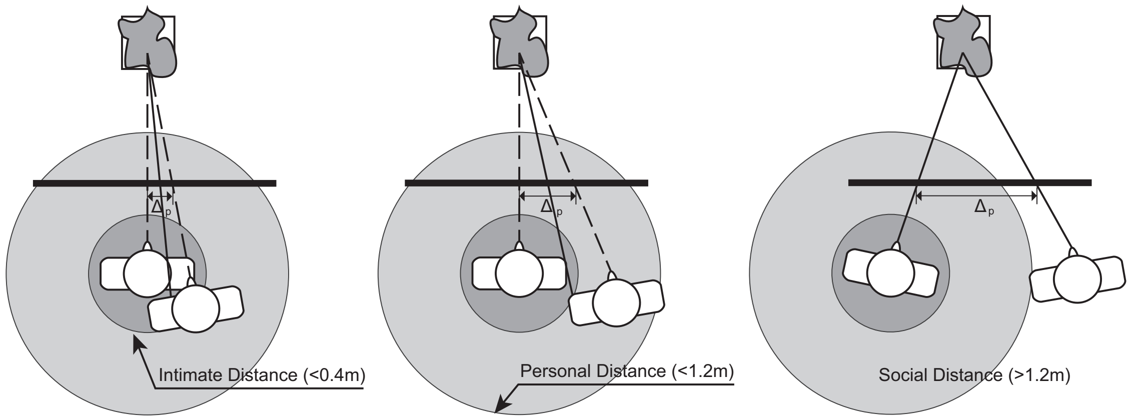

Fig. 4. Viewing-axis-adjustment for groups of viewers at different proxemics distances: *intimate* distance (left), *personal* distance (middle), and *social* distance (right)

5 Conclusions and Future Work

We have tested the first implementation of *Personal Touch* in a lab situation with a stand-in object. Taking into account that user behaviors will be somewhat different in a real museum environment with more objects surrounding the exhibit, this first test gives some notion of the performance of the system. We observed ten people, a mixed group of undergraduate and graduate students of mixed gender (age range from 20 to 29 years, 4 female, six male). We tested in particular for display alignment perception, general interaction comfort, and multi-user collaboration.

In a comparative observation with exit interview of individual users of an earlier version of the system without viewing-angle-compensation 50% of the users found that the alignment was significantly off, 30% found it slightly off, and 20% found that the registration was good. With viewing-angle-compensation for individual users 60% found that the registration was good, 40% found it slightly off and no user found the registration to be significantly off.

The results are different for multiple users in a collaborative interaction. Observing groups of two users interacting at *intimate* distance 100% found the alignment slightly off but workable. In groups of two users interacting at *personal* distance 60% of the groups found the registration to be slightly off but workable, 20% slightly off and difficult to navigate and 20% significantly off. Observing groups of three users (three groups with each 3 members observed) interacting at *personal* distance 33% of the groups found the registration to be slightly off but workable and 66% slightly off and difficult to navigate. In the constellations interacting at *personal* distance we observed that the users moved closer together to improve the shared alignment. At *social* distance we only observed groups of two users because larger groups could not be accommodated by the size of our screen. In this scenario 20% of the users found that the registration was good, 60% found it slightly off but workable and 20% found the registration to be slightly off and difficult to navigate. We observed that users adjusted their positions to accommodate each other, i.e. they moved such that they had similar amounts of screen space. All users found the interaction comfort good and appreciated the form of presentation.

For future iteration of *Personal Touch* we are planning to test for the relationship between the explorations of objects through the AR-screen versus direct object exploration. We are further aiming to implement a possibility to measure the distance between users and the screen. Another avenue of exploration will be to employ different screen sizes, which we expect will have an effect on the collaboration patterns between users. We will test the system with several objects questioning whether the presence of other objects influences the behavior of the viewers.

Another aspect of investigation is the value of the 'touch feeling' in a see-through display – does it provide more connection to the real object even though it is just the screen (with image matching) than just pointing as mid-air gesture? Does this haptic component provide anything beyond just a display?

As a long term goal we will examine if we can extend the user tracking across several exhibits and in this way deliver a more personalized experience for the museum visit. For this iteration the tracking approach has to be modified such that individual users are either recognized or continuously tracked.

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