BaseLase: An Interactive Focus + Context Laser Floor

Jörg Müller[1,2] **Dieter Eberle**[2] **Constantin Schmidt**[2]
[1]Department of Computer Science, Aarhus University, Denmark
[2]Quality and Usability Lab, Telekom Innovation Laboratories, TU Berlin, Germany

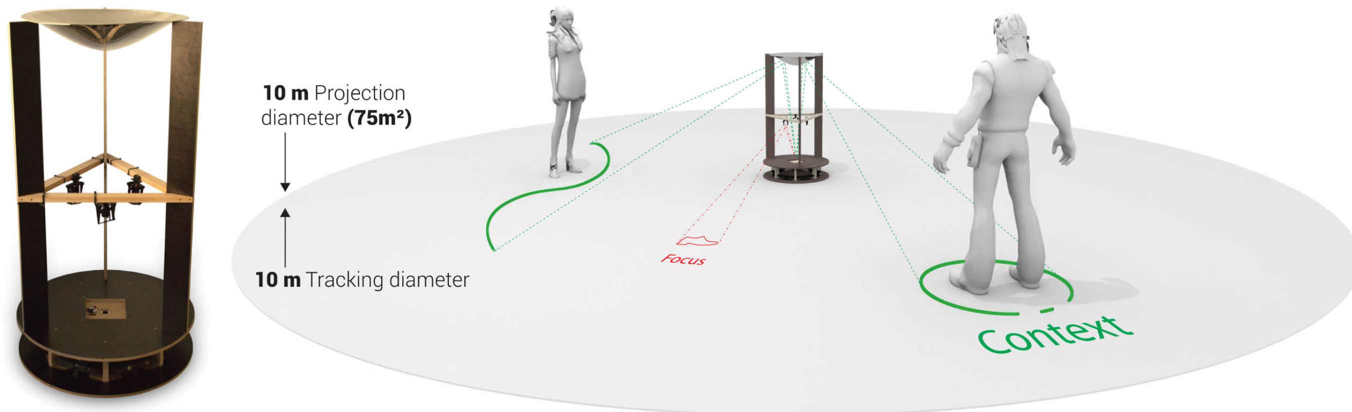

Figure 1. BaseLase is an interactive laser floor display, especially suited for large, and possibly public, spaces. BaseLase covers a very large projection area ($75\mathrm{m}^2$) with a low resolution context projector, while providing three movable high-resolution focus spots. Users can interact with feet, hands, and full-body, being sensed via depth cameras.

ABSTRACT
We present BaseLase, an interactive laser projected focus + context floor display. In order to provide a transportable system that works in areas where there are no ceilings, we provide an integrated unit (1.3 m height) that stands on the floor. One unsolved challenge for laser projectors is to cover large projection areas while providing high resolution at the same time. Our focus + context laser projector solves this problem. BaseLase can cover a large context area in low resolution, while providing three movable high-resolution focus spots. We provide a convex mirror design that enables the laser to reach a large area ($75\,\mathrm{m}^2$) with low resolution while decreasing the beam dispersion compared to spherical or parabolic mirrors. This hyperboloidal mirror shape approximately equalizes the point size on the floor independent from the projected location. We propose to add a number of planar mirrors on pan-tilt units to create dynamic zones of high resolution that can adjust to the user behavior. We provide example applications for BaseLase and report on user experience in preliminary trials.

INTRODUCTION
Public displays are rapidly appearing in many public places, for uses such as social gaming [19] or political participation [9]. Most of these displays are installed vertically, so that they compete for precious estate with shop windows and other signage, and are naturally limited in size.

Floor displays can potentially be very large [3] and enable users to walk through the content. Such displays also offer the advantage that the floor is often not used for other information. Furthermore, many pedestrians look at the floor regularly [26].

Interactive floor projections today are mostly realized using video projectors. Using such projectors, area filling raster graphics can be projected in high resolution on the floor. However, the projected light is distributed to the entire projection surface, such that these displays suffer from limited size and/or limited brightness. In cases where the displayed content covers a small fraction of the entire surface (such as vector graphics without area fill), laser projectors are able to achieve higher brightness in larger areas by concentrating the provided light on the actual content.

In this paper, we propose to use laser projection for large interactive floor displays. In order to prevent the laser beams from crossing the eye level of users, and to remove the need for ceiling mount, we provide an integrated unit (1.3 m height) that stands on the floor.

One unsolved problem for laser projectors is how to cover large display areas while providing high resolution at the same time.

Our main contribution is the design of a focus + context laser projector to address this problem. In order to enable the laser to reach the entire area, we use a convex mirror mounted above the laser. Convex mirrors have the problem that the laser beam is widened, and thus the resolution is decreased.

CHI 2015, April 18–23, 2015, Seoul, Republic of Korea

ACM 978-1-4503-3145-6/15/04$15.00
http://dx.doi.org/10.1145/2702123.2702246

We propose a mirror design that decreases the widening of the beam compared to spherical or parabolic mirrors. Our mirror shape is optimized such that for the entire projection area the projection point has approximately the same size. In order to create focus areas, we propose to add a number of planar mirrors on pan-tilt units to create dynamic zones of high resolution that can adjust to user behavior.

Thus, we present to our knowledge the first focus + context laser projector. It can cover a very large projection area from a small build height. At the same time, it provides multiple movable high-resolution spots, e.g., for text projection.

SCENARIO

Clara and Ben are tourists strolling downtown streets one evening, exploring a new city. When they come across a large plaza, they notice some halos surrounding their feet. They are standing on a map of the area, where a fisheye lens around their feet provides many details on their immediate surroundings, like attractions, shops and cafes. The portions of the map not surrounding their feet are only sketched broadly, but the entire map covers more than $70\,\mathrm{m}^2$ of the plaza. As they are walking around the map, they can obtain detailed information on different areas of the city. They decide which sight they are interested in, and tap on it with their feet to obtain some more information. They tap on a button to confirm they would like to navigate to this site. Upon this action, a school of fish appears around their feet and slowly starts to swim into the direction they need to go. When they leave the plaza down one street, the fish disappear, but they reappear on crossings that are also equipped with BaseLase to show them the way. The fish are swimming faster as they cross a street and the traffic light is about to turn red, and slower to notify them of some interesting vistas along the way. Because BaseLase supports a large projection area, only a limited number of units are needed along the way.

RELATED WORK

Interactive Public Displays

Interactive Public Displays are often installed outdoors [23, 19] or in large indoor spaces. In such areas, vertical displays are often integrated in an ecosystem of other content, and may be overlooked or ignored [13, 20]. Because pedestrians look at the floor regularly [26], it may be an interesting alternative placement for displays.

Interactive Floors

Top projection systems like iFloor [16] usually use a video projector and cameras mounted on the ceiling. iFloor for example was installed in a library, and users could move a cursor by walking around. One benefit of top projection systems is that sensitive equipment is out of reach, and occlusions between users are minimized. The main limitation is that they are only applicable when ceiling mount is feasible, and that there may be self-occlusion issues for both projection and tracking. Commercial deployments have used short throw projection to remove the need for ceiling mount[1]. The resulting interactive floor is however still relatively small.

[1]http://www.gesturetek.com/cube/introduction.php

One solution to the occlusion issues is to use a diffusely transparent floor and project and/or sense from below. The iGamefloor [12] used a diffuse transparent glass floor with back-projection and diffuse illumination based camera tracking from below. Multitoe [3] uses FTIR, diffuse illumination, and back-projection to create a high-resolution sensing and displaying interactive floor. GravitySpace [7] uses the high-resolution FTIR sensing floor to track users and their poses. Back-projected systems solve the occlusion problem and can provide high-precision input. Their main drawback are the high installation costs for the floor and the room needed below.

An alternative to projection and camera based systems are lights and sensors embedded into floor tiles. Orr [21], for example, integrated pressure sensors into floor tiles to identify users. Paradiso [22] used piezoelectric wires to detect foot position and pressure and doppler radars to detect upper-body kinematics with audio feedback. The tactile luminous floor [11] consists of 360 tiles of 66cm that integrate pressure sensors and lights for interactivity. Rogers [25] used LEDs and a pressure mat embedded into floor tiles to influence passers-by to take the stairs instead of the elevators. Dalton [10] integrated LEDs in carpet tiles and also used the LEDs as input to determine whether they are covered by users' feet. Such integrated floor tiles can lower the installation costs compared to back-projection and solve the occlusion problem compared to top-projection. Their main drawback is that the currently achievable resolution is relatively low, and most floor sensors can only sense the users' feet.

In this paper, we propose laser projection on floors as an alternative to video top- or back-projection and interactive floor tiles. Laser projection has the benefit of achieving potentially very large displays, especially when the content covers a relatively small percentage of the projection area. Our mirror design also enables an integrated mobile unit containing the entire system.

Interactive Laser Projection

Laser projectors are less frequently used in HCI compared to video projectors. Among the few examples of interactive laser projectors are the works by Cassinelli. The Camera-less Smart Laser Projector [8], for example, uses a laser that is controlled by galvanometers (further used as galvos) simultaneously as a display and 3D-position sensor. A non-imaging photodetector is used to measure the reflection of the laser beam at any point in time. By drawing circles, the system can measure the shape of the object the laser is reflecting from.

Laser projectors like other projectors face a dilemma between providing a large display area or maintaining high resolution. BaseLase solves this dilemma.

Focus + Context Screens

In HCI, there are two different meanings associated with focus + context. In focus + context visualizations, like fish-eye views [17], usually a display with constant resolution over the entire display area is used. More screen real-estate is used for portions of the content (e.g., a map) where more detail is needed. This *focus* region can usually be moved relative to both the virtual content and the physical display. In contrast, Focus + context screens [4] provide a smaller area with physically higher resolution for detailed information, while simultaneously providing a very large area of lower resolution on a screen. Usually, the high resolution area is movable relative to the virtual content, but not to the physical screen. BaseLase is a focus + context display in the latter sense. In [4], such a display is presented in an desktop context, where the focus area is provided by a desktop display, while a projection around it enlarges the display area with lower resolution. The Escritoire [2] is a tabletop system using two video projectors. One projector creates a high-resolution *foveal display*, while the second projector covers the entire table area in much lower resolution. Lee [18] presents a system for tracking interactive surfaces (like touch surfaces or tablet computers) while a projector projects on them. They present an application where a tablet computer is used as a magic lens, providing high-resolution focus on a map display, while the video projector provides the context area. Illumiroom [15] combines a TV with a wide-angle projector that provides contextual content around the television. They provide numerous visual illusions, such as focus + context screen, peripheral flow, color augmentation, texture displacement, lighting or physical interactions.

A number of focus + context systems have been presented, mostly in the desktop or tabletop area. We provide 1) the first focus + context laser projector that 2) uses the same projector for both focus and context display, which 3) provides movable focus areas, and 4) is a floor display.

Omnidirectional Displays

The Pinch-the-Sky Dome [5] uses a video projector projecting upwards through a wide-angle lens on a dome. Such wide-angle lenses enable surround projection, but the resolution of the video projector is distributed to the entire dome surface and thus comparatively low, and significant distortions are introduced that need to be corrected in software. More recently, RoomAlive [14] proposed integrated camera-projector units that can be combined to make an entire room interactive. PlayAnywhere [27] uses a short-throw projector together with IR illumination and a wide-angle camera to create a mobile system that can be placed on arbitrary tables to make them interactive. The setup allows the creation of projection areas from a relatively low height, but the use of the video projector limits the projection size, and the projection is only to one side of the projector. The ubiquitous cursor [28] used projection on a hemispherical mirror to provide the cursor location when the cursor is travelling between displays (such as from a PC to the TV).

The work most related to our system is the Everywhere Displays projector (ED) [24]. It consists of a video projector with a movable mirror mounted above that can steer the projected image to arbitrary surfaces in the environment, including floors and walls. The system includes an environment model that is used to undistort the projected image when the projector projects on a surface at an oblique angle. The system also adjusts the focus of the projector according the distance to the projection surface. At oblique angles, the entire projection area can not be in focus, but the system works satisfactorily "up to 30° of inclination". ED further includes a camera, and the authors worked on enabling gestural interaction through computer vision.

The main difference to our system is that ED can only project on one surface in the environment at a time, because of the inertia of all moving parts and their thus relatively slow motion compared to galvos. In contrast, our system can project on the entire environment simultaneously while providing multiple high-resolution focus spots, similar to ED. Further, because our system uses a laser, it does not have focus issues.

BASELASE

Our system is an interactive focus + context laser floor display. BaseLase can project in two different resolutions: The context projection covers the area of up to 5 m radius around its center which results in approx. $75\,\mathrm{m}^2$ of low resolution images while there are multiple focus areas that are smaller but can project images at high resolution. The projector itself has a height of 1.3 m and a diameter of 0.7 m. The system is able to detect and track users through depth cameras, and can thus let them interact with the projection.

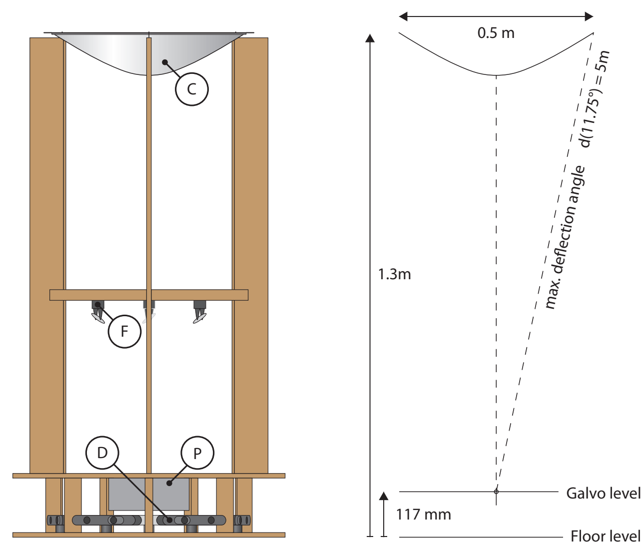

Figure 2. Left: projector construction, right: main dimensions

Figure 2 shows the components of BaseLase. There is the actual laser projector (P) that generates the images and deflects them over the context mirror (C) and the three focus mirrors (F), which allow us to create up to three focus areas simultaneously. On the bottom, there are depth cameras (D) that track the users.

When BaseLase detects a user it can generate feedback that is then projected on the ground using either the context mirror, one or multiple focus mirrors, or both, depending on the situation. The setup is designed to explicitly detect feet close to the ground but the user can also interact with hands and the whole body.

Laser Projector

The central issue of the curved mirror is the increase of the width of the laser beam, and the narrower the beam the smaller the increase. In order to have greater control of the laser beam, we decided to build a custom laser projector. A custom projector enables us to easily replace the laser source with a narrower beam width and more power in the future. We can also design the laser projector to fit in the frame of the unit. Furthermore, it allows us to pick the components that fit our needs best, such as galvos with larger angles resulting in the possibility to use a larger mirror and increasing the projection area, and also picking a low-power laser source to safely experiment during the developing phase. Finally, it gives us the possibility to run the projector from a battery source and overall results in a cheaper price than a commercial laser projector. In summary, we have built a compact and cost-efficient prototype that helps us study the possibilities of such a projection unit.

The projector is a unit of 3 different parts: a laser, galvos and electronics. The laser source is a low-power bright green laser pointer with $< 5\,\text{mW}$. It generates a coherent laser ray of $1.5\,\text{mm}$ diameter and diverges $< 1\,\text{mm}$ on a distance of $1\,\text{m}$. This point is directed at three fast rotating mirrors mounted on galvos. Each galvo is controlled by an analog voltage which adapts the orientation of the attached mirror in a linear manner to the applied voltage. Two galvos are placed perpendicular to each other to deflect in two orthogonal directions achieving an X-Y projection plane. The third galvo guides the ray either into a light trap or onto the other galvos allowing us to interrupt the laser line to project separate objects. When the third galvo moves the ray into the light trap, another galvo counter-acts this movement to prevent motion of the point within the image. The controlling signals are generated by a sound card which we modified to allow DC current. We subsequently designed a circuit that subtracts the DC offset of the audio signal and outputs a $5\,\text{V}$ signal and its inverted opposite to make use of differential signaling. These signals are fed to the galvo amplification board, subtracted by each other, and amplified to a higher voltage and current to power the galvos.

MIRROR DESIGN

Common galvos have a rather small scan angle (e.g., $20°$). To project big pictures, it is necessary to place the projector far away from the projection plane. In case of a floor projection this could mean high above ground or very far from the projection. In outdoor scenarios, for example, both are rather difficult or even impossible to accomplish. Assuming a laser projector has a rather high scan angle of $60°$, one would need to mount the projector $8.6\,\text{m}$ above the floor to achieve a projection area that is similar to our setup. One way to decrease this distance is to position the projector on the ground facing upwards to a mirror which then reflects the laser rays to the ground. A planar mirror facing the projector would halve that distance if the projector is close to the ground. Using a planar mirror with a radius of $0.25\,\text{m}$ in $1.3\,\text{m}$ height like BaseLase a projection area with only $0.5\,\text{m}$ radius would be achieved. Projecting in a flat angle from a large distance introduces severe occlusion problems. Uneven floors also lead to distortions when projecting at a very flat angle. To further increase the projection area while keeping the mirror in a realistic size we decided to use convex mirror (similar to a surveillance mirror). Using such a mirror the projector can cover a $10\,\text{m}$ diameter surface. The main downside of a convex mirror is a spread laser beam.

Mirror Shape

First we tested the reflection over a standard spherical surveillance mirror with a diameter of $0.6\,\text{m}$. For close distances the laser beam was quite small and sharp but with larger distances the laser beam was heavily distorted in radial direction. To understand this effect better we implemented a simulation to generate and analyze different mirror shapes.

For all further analyzed mirror shapes we defined the following requirements for comparability:

1. Mirror radius should not exceed $0.25\,\text{m}$, and height $1.3\,\text{m}$
2. A ray of $0°$ off-axis should deflect to $0\,\text{m}$ and a ray with the max. angle should deflect to $5\,\text{m}$, which is our maximum projection distance ($d(0°) = 0\,\text{m}$ and $d(max\ \alpha) = 5\,\text{m}$)
3. Radial point size $p(\alpha)$ should be as independent of projection distance and as small as possible, $p(\alpha)' \approx 0$

Common mirrors are often spherical or parabolic. The simulation shows that both types do not comply with the requested design because they break requirement 3 (see Figure 4). Even in the case of a perfect fitting spherical mirror (Requirement 1 and 2) the beam would be 120 times larger than the originally emitted ray. A conical mirror does not allow projecting very close to the projector and at 5m distance simultaneously.

Since these generic shapes did not result in a satisfactory mirror shape for our projector, we manually generated a shape that complied with all requirements. The main problem is to keep the point size independent of the distance (requirement 3). There are three factors that have an impact on the beam expansion. For a simplified understanding of the laser, its ray

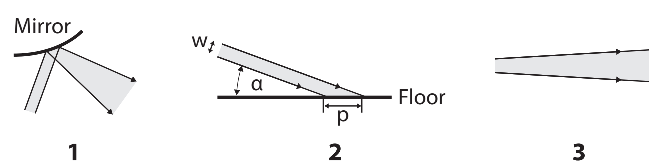

Figure 3. Increase of ray width due to 1) curved mirror 2) incidence angle 3) ray divergence.

can be interpreted as two parallel rays with an offset of the laser ray width (w). When these two rays hit a curved mirror surface both will reflect to different directions due to the different surface normals at the reflection points (Figure 3 (1)). Another issue results from the incidence angle. The steeper the angle the bigger the point becomes on the floor (2). Also the laser is diverging, which means that, unlike assumed in the simplification, both border rays are not completely parallel (3). The sum of each of these factors makes it difficult to design a parametric mirror shape. In the simulation we emulate a diverging laser with the diameter of d. We send two rays that represent the border of the laser beam and let them reflect at the mirror to the ground. The distance between these two points on the floor produces the point size p . Then the simulation calculates the point size for a given angle and mirror shape considering all effects that we mentioned previously (Figure 3). For a given mirror shape the mapping between *distance* and the *ray widening* is recorded (Figure 4). After a

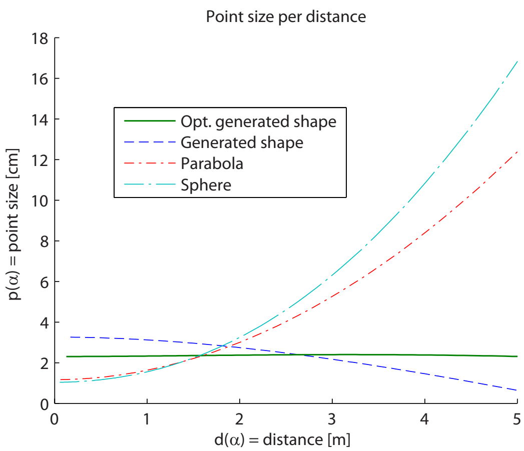

Figure 4. Laser point size on the floor after deflection over the context mirror for different mirror shapes. A laser diameter at source of $1.5mm$ with $< 1mm$ divergence per meter is assumed.

few unsuccessful trials with classical optical shapes like segments of spheres or parabolas, we started an iterative process to generate the mirror shape from very small linear segments. We optimized the shape to comply with our 3 requirements in an acceptable manner.

For the first generation we used a linear mapping from ray angle to the distance where the laser should hit the ground. As visible in Figure 4, for the resulting shape (Generated shape) the point size on the floor decreases for higher distances. We optimized the shape until achieving the point size shown in Figure 4 (Opt. generated shape).

The optimized generated shape appears similar to a hyperbola. We fitted a hyperbola to that shape using a regression for conic section like ellipses and hyperbolas[2]. The resulting parameters for 3339 points are $a^2 = 86.01048, b^2 = 190.0683$ in the formula for a hyperbola $\frac{y^2}{a^2} - \frac{x^2}{b^2} = 1$ with a normalized sum of squared residuals of $6.73 \cdot 10^{-12}\ m^2$.

MIRROR FABRICATION

Traditional flat mirrors are made of glass with a silver or aluminum coating on the backside. Curved mirrors are either ground and polished glass like *Zerodur*[3] or thermoplastics like Polystyrene, PMMA or ABS coated similarly. Of course metal blocks or plates can be milled or formed and finally polished as well.

BaseLase requires a very specific mirror shape. Since it was only a prototype, we wanted to minimize costs. Blocks of optical glass or metal are very expensive. Plates of metal are much cheaper but only few companies offer CNC metal spinning for small numbers of items. Afterwards these parts would also need polishing, which can be expensive. So the most realizable and low-cost process to produce such a shape for this projector is to use a thermoplastic with a metalization to achieve a reflective surface. To thermoform a plate of plastic, we needed a tool (positive shape) that defines the mirror shape. The heated thermoplastic is pressed onto that tool by a vacuum (vacuum forming). After cooling the material keeps the shape.

For our mirror we milled a tool for thermoforming out of polyurethane as shown in Figure 5 (1). This is a default material for tooling in industry for thermoforming. In a subsequent process we vacuum formed black high-gloss polystyrene plates over this milled shape (2). Finally, we used a sputtering process to deposit an aluminum layer on the polystyrene (3).

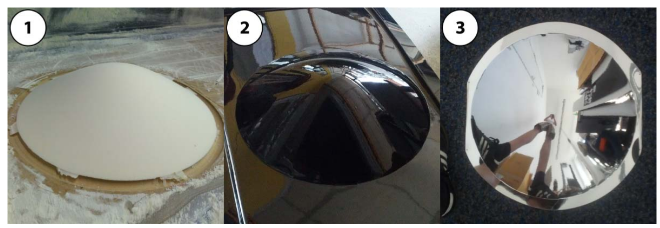

Figure 5. 1) Vacuum forming tool, 2) mirror body before and 3) after metalization

FOCUS MIRRORS

There are three small pan-tilt units attached at the outer region of the frame. These units each control a small flat mirror that can deflect the laser to a specific area which we call *focus area*. Unlike the curved context mirror, the laser ray is not widened by the flat mirrors. This shape makes it possible to project high-resolution pictures in those specific focus areas. The pan-tilt unit is designed to keep the mirror centered at a fixed position independent of its orientation. By rotating around the center it is easier to calculate the projection matrices to achieve the desired projection on the floor. Two servos rotate the mirror around two axes as shown in Figure 6 (1). The first servo turns the whole pan-tilt unit around the vertical axis which goes through the center of the mirror. The second axis is perpendicular to the first traversing the mirror's left and right side. Both axes intersect in the center of the focus mirror.

To remove the perspective distortion, the inverse physical projection is applied to all points. The physical projection matrix is obtained through simulation by shifting the projector to a virtual position shown in Figure 6 (2).

SURROUND TRACKING

To be able to track users all around the projector, seven depth cameras (Asus Xtion Pro) are installed within the base of the frame. Because of their horizontal field of view of 58°, seven of these cameras are needed to cover the whole area around the projector with minimal overlapping as shown in Figure 7 (1). Figure 7 (2) shows that the cameras are tilted by 22.5° so

[2] http://nicky.vanforeest.com/misc/fitEllipse/fitEllipse.html

[3] http://www.schott.com/advanced_optics/english/products/zerodur-extremely-low-expansion-glass-ceramic/index.html

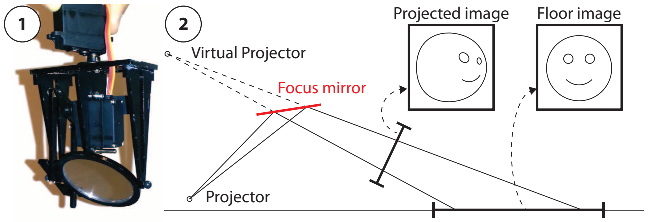

Figure 6. 1) Focus mirror, 2) projection through the focus mirrors

that the bottom of the frustum is parallel to the ground plane because their vertical field of view is $45°$. This simplifies the tracking of the feet, because we can assume that the feet are always on the bottom of the depth image regardless of the distance between the user and the camera.

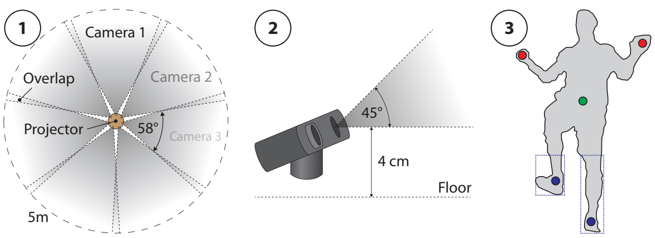

Figure 7. Camera alignment 1) top view, 2) side view, 3) debug view that shows the tracked elements: user contour, hands, feet and center position, bounding box around feet for hover detection.

For the general user tracking OpenNI and NITE are used. They allow simple access to the users' contours and skeletons for accessing the users' hand and feet positions as shown in Figure 7 (3). The user contour in the depth image is further utilized to detect the feet and especially whether the feet are on the ground or not. Thus, we are able to detect tap and hover events. For this, a contour finding algorithm is applied to the bottom part of the depth image. Each resulting contour is interpreted as a foot and the distance from the lowest part of that contour to the ground is interpreted as the height above ground.

Because the cameras have some overlapping areas, a single user can be detected by two cameras at the same time. To prevent this problem, a handover of users between cameras was implemented. If a user is on the left border of a camera's depth image, then the camera on the left checks if there is also a user on its right border. If that is the case, then we assume that both cameras track the same user, and thus we merge the data of these cameras to a single user. The resulting user data is the sum of the data from each cameras weighted by the coverage of the user.

PROJECTION PIPELINE

Drawing pictures on the ground requires a multi-stage pipeline. At first the drawable objects are sorted to minimize the trajectories between objects. The first object to be drawn is selected randomly. After that the object that is closest to the previous one is selected. Also special blanking points are added in between objects which tell the projector to move the laser into a light trap so that the line is interrupted. Because of the galvos' inertia, effects like overshooting and undershooting can happen. To prevent undershooting some points are repeated multiple times, thereby increasing the time the galvos spend for that point. The amount of repeats is decided by the angle between the previous and the next line. The larger the angle the more repeats are needed. To prevent overshooting, some points are added in close distance to the final point so that the galvos can decelerate. Additionally there are also new points that are added between longer distances, to ensure that a straight line stays a straight line after the projection due to the curved mirror shape. Finally, the image is projected.

Until this step in the pipeline the pictures were handled in world positions and now they need to be converted into sound volume values which represent angles for the galvos. The mapping between the sound volume and the angles is linear. We set the volume of the sound card to 100% and kept it constant. This way we only had to calibrate a global scale once. During the design of the mirror shape, we simulated the mapping between angles of the rays that we cast to the mirror and distances where the laser point hits the floor. We used the inverse of this mapping to fit a polynomial that we then applied to all world positions based on their distance from the projector in order to get angles. Our API provides a function where a focus mirror can be selected to draw a shape at certain position in world coordinates. The focus mirror is then automatically moved to point at the center of the drawn shape. Furthermore, the laser is automatically steered over the focus mirror instead of the context mirror. To undistort the focus images, we simulated the projection of a square on the ground using the current focus mirror's orientation. We then calculated a mapping between the real and the simulated projected square using OpenCV's *cvGetPerspectiveTransform()* function. The inverse of this mapping was then applied to the projected image in order to achieve an undistorted image on the ground.

LIMITATIONS

Occlusion is one major problem of BaseLase due to the flat projection angle. For top projection, occlusion is mainly self-occlusion due to the large torso. In contrast, with BaseLase users mostly occlude content for other users with their legs. People may not be aware that they occlude content for others. Because legs are relatively thin, only a small slice of the projection is occluded. While BaseLase is certainly not suited for crowds or dancefloors, according to our experiences, up to 10 users seem feasible. In particular, in using the silhouette, natural personal space management seems to lead users to avoid occlusions. In addition, it is more obvious where the projector is and what its line-of-sight is compared to ceiling-mounted projectors, so users simply adjust their locations such that they can see the projector. Possible solutions for occlusions include 1) monitoring occlusions via depth cameras and moving content (e.g., buttons) when necessary and 2) using multiple overlapping projectors.

Sunlight is the second major problem for BaseLase. Every projector creates contrast by brightening up a surface, competing with the ambient light. With strong ambient light, contrast may be low. Also the surface color, texture and reflectivity has an impact on the picture. The surround tracking uses depth cameras utilizing structured IR light to sense depth. In case of a strong ambient IR light source like the sun, the tracking may not function properly. Both issues can be addressed by using a brighter laser source and depth cameras which are less susceptible to sunlight.

In the current implementation, BaseLase is best suited for contexts where ceiling mount is difficult but with little sunlight. This may be because the ceiling is too high or does not provide structures to attach the projector, e.g., in big halls and lobbies. Another reason may be that the ceiling is too low to achieve a satisfactory projection size e.g., in shopping malls and hallways. While outdoor use is currently only feasible in the evening and at night, future versions might make daytime outdoor deployment possible.

A more minor issue, the number of focus mirror limits the number of focus areas. If every user gets an assigned focus mirror, the number of focus mirrors can be too small. To reduce this problem, groups of users can be detected to use one focus area per group. Like with ultra short throw projectors, the steep incidence has an impact on image distortions when the surface is uneven.

PROJECTION TECHNIQUES & APPLICATIONS

The combination of context and focus projections enables a number of interesting projection techniques that we discuss in this section.

Dynamic High Resolution Insets and Magic Lenses

The focus mirrors can be used to create high resolution insets in the context projection, much like focus + context displays. In contrast to most existing focus + context displays, these high resolution insets are dynamic, and they can be moved to wherever higher resolution is needed. One possible example is a map that provides dynamic information. The broad outline of the map could be displayed as low resolution vector graphics. Then, on some parts of this display, high resolution text insets may be provided by the focus mirrors. These areas can also be dynamic, e.g., when the map is moving around, or when some dynamic items like cars are shown on the map in higher resolution. These areas may also show information different from that shown by the context projection, and be controllable by users, much like Magic Lenses [6]. Such a display could also show templates for street painters and sprayers. The overall image could be displayed in low resolution, and the part that is currently being painted in high resolution.

Projecting Outside of the Context Area

The focus mirrors also allow to project outside of the area covered by the context mirror. When no user is in the tracking area of the system, attracting texts and animations can move around in a larger area attempting to attract users into the context area. For example, footsteps could walk from farther distances towards the context area in the hope that passers-by might follow them. An evacuation situation is another scenario where projecting outside the context area would be useful. The focus spots could project moving arrows on the evacuation routes outside the context area. Within the context area, an evacuation map could be displayed.

Projecting on Users and Objects

Finally, the focus mirrors can also be used to project on users' bodies and objects in the scene. One possible application could be a display for traffic accidents or crime scenes. The display could be placed at the site of the accident and used to interactively create annotations on the road and vehicles or objects. The annotated image could be automatically synchronized with remote investigators, who could also create annotations from their personal computers. One can also imagine more fun applications. For example, the floor might show images of insects crawling around, and these can then also crawl up the feet and legs of users.

INTERACTING WITH BASELASE

In this section, we discuss three interaction paradigms we implemented for BaseLase. BaseLase offers direct interaction with the users' feet, indirect interaction with hands through a cursor, and indirect interaction through the users' silhouette projected on the ground, as shown in Figure 8.

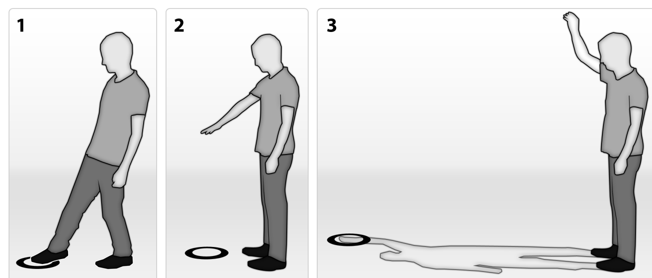

Figure 8. Interacting with BaseLase through 1) *tapping*, 2) *hand cursor* and 3) *silhouette*.

Direct Interaction with Feet

Users can step and tap on items to select them, while our vision based implementation cannot distinguish between stepping and tapping, as does Multitoe [3]. Thus, we cannot distinguish activation vs. walking, and non-interactive areas need to be provided for walking. Similar to Multitoe, we use jump for invoking menus.

Direct interaction with feet provides the advantage that input and output are co-located, much like with a touch device. Inherent downsides of this approach are 1) feet are used for standing, requiring users to change their posture and/or balance for interaction, 2) legs are heavier than arms, making quick interactions more difficult, and 3) feet are even bigger than fingers, rendering the *fat finger problem* even more grave.

Indirect Interaction with Hands through a Cursor

As an alternative to direct interaction with the users' feet, we implemented indirect interaction with the hands. In order to enable this, the user needs to be represented in the interface, such that the user can interact via this representation. In our implementation, the user's hand is tracked and mapped via a mapping function to movements of a cursor on the ground. We tried two different mapping functions. The first mapping function simply projects the hand position vertically to the ground. The second mapping function projects the cursor to a position in front of the user (same position as with the silhouette, see below). The second mapping function provides a much bigger reach without walking around, and a more comfortable head position. Users do not need to look straight down.

Indirect Interaction through the Users' Silhouette

We also implemented a representation of users through their silhouette. It is often easier for users to recognize and control their own silhouette than a cursor [19]. In our implementation, users' silhouettes are always oriented towards the projector, minimizing occlusions.

If users interact with their hands, a natural delimiter (like tapping) is not available. Possible delimiters (e.g., for selecting items) include dwell time, using a dimension that is not used for controlling the cursor (e.g., hand height), separate modalities (e.g., speech), crossing, dynamic gestures (e.g., Pigtail), or dedicated poses (e.g., touching one's hip with a hand) [1]. Because our foremost objective is immediate usability, we decided for dwell as delimiter. This option, however, enables inadvertent activations, when the user dwells over an item inadvertently.

Interaction with hands provides the main advantages that users are free to use their feet for balancing and walking while they interact, and that the hands are more agile than feet. Using a user representation can also increase users' reach, because the representations may be shown far from the users. The main disadvantages are that there is no natural delimiter (like tap), and that interaction is indirect, i.e., input and output are not at the same location.

APPLICATIONS

We implemented two example applications for our projector to show its potential.

Jump Ball

First we implemented a game where users can repel a ball by jumping close to it. The playing field is a circle of $4.5\,\mathrm{m}$ radius and to prevent the ball from stopping inside the projector there is also an inner circle of $0.35\,\mathrm{m}$ radius. If the ball collides with either of the boundary circles, it bounces physically. On two opposing sides, there are goals which are drawn as circles. If the ball moves into that circle, the other team gets a point. While everything game related is drawn using the context mirror, both scores are displayed in the focus areas to see the score more clearly. There is no limit of users that can play the game simultaneously as long as they do not occlude each other and as long as they stay within the tracking area of the cameras which is up to $5\,\mathrm{m}$ away from the projector.

Street Painting

As a second application we implemented a drawing application where users have a cursor that draws a line along the way when it is moved. This application is mainly intended to experiment with different interaction methods with BaseLase. Users are able to open a menu when jumping. In the menu they can select how the cursor is moved. They can switch between 1) foot position, 2) hand position orthogonal projected on the ground, and 3) silhouette projected on the ground where their right hand is the cursor (see Figure 8). The menu is represented with three circles where the currently selected mode is a smaller circle. When users hover over one of the circles, a high resolution icon is shown above the circle that describes the mode. Those icons were 1) a shoe, 2) a hand, and 3) a silhouette of a human. To switch to a different mode users hold the cursor over the circle for a dwell time of two seconds. To close the menu, users jump again.

PRELIMINARY USER EXPERIENCES

In order to explore the interaction paradigms presented in Figure 8, and to explore interaction with BaseLase in general, we conducted a qualitative user study. Our 12 participants were between 24 and 50 years old ($\mu = 31.3$) and 5 were female.

Menu Selection

For direct interaction with feet, we were interested in comparing different delimiters. With the *foot dwell* method, whenever the foot crossed an interactive area (e.g., button), a dwell time visualization was shown. The item was selected after 2 s. With the *tap* method, items were selected when a foot transitioned from hover state to foot down state within an interactive area. This tap method is much cruder than the one used in [3], because our foot detection cannot distinguish between the ball and the heel touching the ground.

For indirect interaction with hands, we were interested in different mappings from hand movements to cursor movements. With *orthogonal* projection, the cursor was shown vertically below the users' hand. With *frontal* projection, the cursor was shown in front of the user, at the same position where the cursor was shown in the *silhouette* condition. In the *silhouette* condition, the silhouette of the user was shown on the ground towards the projector. A cursor was attached to the users' hand. All methods except *tap* used dwell time to select the button.

In the first part of the study, users had to select a specific button in a menu of three buttons. The users were instructed to explore how to interact in each mode. If they did not discover how to select objects within 1 min, we provided hints. Users rated each condition on a 7-point Likert scale regarding A) how easy the method was to understand (7 being very easy), and B) how well users were able to select items (7 being very well).

Drawing

In the second part of the study a simple painting application was presented where users could draw continuous lines. We tested four different conditions: painting with the 1) *foot* position, 2) hand position *orthogonal*, 3) hand position *frontal*, and 4) *silhouette*. The first task was to draw a square, and the second to draw a predefined Euler path in the form of a house. The drawings were saved and are shown in Figure 9.

Participants rated how precise they were able to draw in each mode on a 7-point Likert scale (7 being very precise).

Results

For the *silhouette* condition, no users needed explanation, followed by *frontal* (1), *foot dwell* (1), *orthogonal* (2), and *tap* (5). Silhouette was rated as easiest to understand ($\mu = 5.67$), followed by foot dwell ($\mu = 5.33$), frontal ($\mu = 4.67$), tap ($\mu = 4.67$) and orthogonal ($\mu = 4.33$). Foot dwell was rated as easiest to select items ($\mu = 6$), followed by silhouette ($\mu = 5.75$), tap ($\mu = 5.58$), orthogonal ($\mu = 5.42$) and frontal ($\mu = 5.33$). A Friedman test revealed a significant effect of condition on both questions ($\chi^2(5) = 14.03, p < 0.05$ and $\chi^2(5) = 15.35, p < 0.05$). Post-hoc tests using Wilcoxon tests with Bonferroni correction revealed no pairwise differences for either question. After the drawing task, users felt they could draw most precisely in the frontal condition ($\mu = 4.17$), followed by silhouette ($\mu = 4.08$), orthogonal ($\mu = 4$) and foot ($\mu = 3.92$).

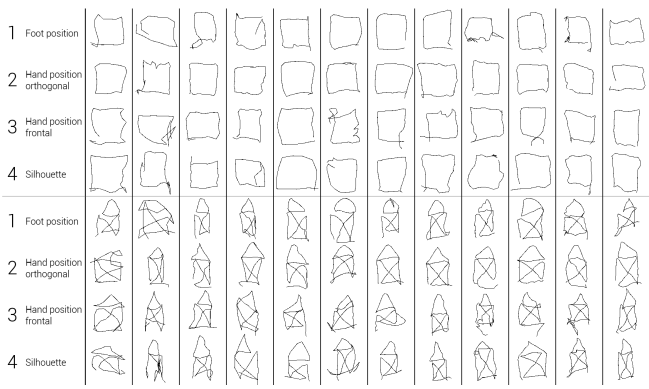

Figure 9. Drawings resulting from the user study. *Hand position orthogonal* seems to result in slightly more accurate drawings.

Users were very quick to understand how the silhouette works (P2: “Ah, I see - myself!”). With the other conditions, they had some difficulties to understand how to control the cursor. In particular, as the hands were often hanging down or sometimes in the pockets, users did not realize that they could control the cursor with their hands. In particular in the orthogonal condition, they sometimes had difficulties understanding whether the cursor was controlled with the hand, foot, or other body parts. Also, in the silhouette and frontal condition, it was a slightly easier for them to see the feedback, because they did not have to look straight down. For drawing, some users preferred to draw by walking around (foot, orthogonal) rather than moving their arms (silhouette, frontal), because they felt to have greater control. Some users found the silhouette to get in the way visually when drawing.

Discussion

As shown in [3], tapping is a very intuitive and efficient way to select items on floors. With the possibilities of depth cameras (no distinction between heel and ball), tap and foot dwell seem to be close alternatives, where both alternatives do not allow users to walk over interactive elements without activating them. Foot dwell was rated as easier to understand, but a combination of tap and foot dwell might be possible. Our results also show that silhouette and hand cursor might be promising alternatives to interaction with feet. Silhouette needed less explanation, and was rated as easy to understand and easy for selecting items. Especially when immediate usability is premium, and it is difficult to render strong affordances (e.g., due to the low resolution of the laser projector), silhouette can be beneficial. With cursor representations, a frontal cursor seems to be easier to see and understand. Designers should choose freely between these three interaction paradigms, weighing their benefits and drawbacks in light of their particular applications’ requirements.

FUTURE WORK

We plan to improve the safety for future iterations of the project. Our current prototype is safe in particular because it uses a low-powered laser source. Commercial laser projectors rated for audience scanning make sure that the laser always moves sufficiently quickly such that the maximum energy that can enter users’ eyes is always on a safe level. We plan to implement such a constraint in BaseLase. Safety could be also be increased by detecting faces and/or eyes and preventing the laser from projecting onto them, or by decreasing the height of the system.

Currently the projector has three bars that hold the context mirror and block thin vertical stripes of the projection. In future versions, we would like to use a cylindric acrylic glass that holds the context mirror. This would also protect the projector from environmental influences like rain.

A higher quality laser source with higher brightness and a smaller beam diameter would greatly increase image quality. This would also allow us to experiment with even larger projection ranges. Higher quality galvos could allow us to project more detailed images. Finally, we are very interested in mounting BaseLase on an autonomous robotic platform to have a self-driving interactive floor that can adjust to the surrounding situation.

CONCLUSION

In this paper, we have presented an interactive laser projected focus + context floor display. It covers a large display area in low resolution through a convex mirror design that approximately equalizes the point size for the entire display area. At the same time, the display provides multiple movable high-resolution focus spots. We introduced interaction with hands and full body on floors through cursors and silhouettes as an alternative to direct foot based interaction.

Our design is able to cover entire plazas with very few display units and does not require a ceiling mount. We believe that focus + context laser projectors provide an interesting alternative to conventional projectors, especially on floors but potentially also on other surfaces where very large display areas from a small projector distance are important.

REFERENCES

1. Accot, J., and Zhai, S. More than dotting the i’s — foundations for crossing-based interfaces. In *Proc. of CHI’02*, ACM (2002), 73–80.

2. Ashdown, M., and Robinson, P. Escritoire: A personal projected display. *MultiMedia, IEEE 12*, 1 (2005), 34–42.
3. Augsten, T., Kaefer, K., Meusel, R., Fetzer, C., Kanitz, D., Stoff, T., Becker, T., Holz, C., and Baudisch, P. Multitoe: high-precision interaction with back-projected floors based on high-resolution multi-touch input. In *Proc. of UIST'10*, ACM (2010), 209–218.
4. Baudisch, P., Good, N., and Stewart, P. Focus plus context screens: combining display technology with visualization techniques. In *Proc. of UIST'01*, ACM (2001), 31–40.
5. Benko, H., and Wilson, A. D. Pinch-the-sky dome: freehand multi-point interactions with immersive omni-directional data. In *CHI EA '10*, ACM (2010), 3045–3050.
6. Bier, E. A., Stone, M. C., Pier, K., Buxton, W., and DeRose, T. D. Toolglass and magic lenses: the see-through interface. In *Proc. of SIGGRAPH'93*, ACM (1993), 73–80.
7. Bränzel, A., Holz, C., Hoffmann, D., Schmidt, D., Knaust, M., Lühne, P., Meusel, R., Richter, S., and Baudisch, P. Gravityspace: tracking users and their poses in a smart room using a pressure-sensing floor. In *Proc. of CHI'13*, ACM (2013), 725–734.
8. Cassinelli, A., Zerroug, A., Watanabe, Y., Ishikawa, M., and Ängeslevä, J. Camera-less smart laser projector. In *SIGGRAPH Emerging Technologies* (2010).
9. Dalsgaard, P., and Halskov, K. Designing urban media façades: cases and challenges. In *Proc. of CHI'10*, ACM (2010), 2277–2286.
10. Dalton, N. S. Taptiles: LED-based floor interaction. In *Proc. of ITS'13*, ACM (2013), 165–174.
11. Delbrück, T., Whatley, A. M., Douglas, R., Eng, K., Hepp, K., and Verschure, P. F. A tactile luminous floor for an interactive autonomous space. *Robotics and Autonomous Systems 55*, 6 (2007), 433 – 443.
12. Grønbæk, K., Iversen, O. S., Kortbek, K. J., Nielsen, K. R., and Aagaard, L. Igamefloor: a platform for co-located collaborative games. In *Proc. of ACE'07*, ACM (2007), 64–71.
13. Huang, E. M., Koster, A., and Borchers, J. Overcoming assumptions and uncovering practices: When does the public really look at public displays? In *Pervasive Computing*. Springer, 2008, 228–243.
14. Jones, B., Sodhi, R., Murdock, M., Mehra, R., Benko, H., Wilson, A., Ofek, E., MacIntyre, B., Raghuvanshi, N., and Shapira, L. Roomalive: Magical experiences enabled by scalable, adaptive projector-camera units. In *Proc. of UIST'14*, ACM (2014), 637–644.
15. Jones, B. R., Benko, H., Ofek, E., and Wilson, A. D. Illumiroom: peripheral projected illusions for interactive experiences. In *Proc. of CHI'13*, ACM (2013), 869–878.
16. Krogh, P., Ludvigsen, M., and Lykke-Olesen, A. " help me pull that cursor" a collaborative interactive floor enhancing community interaction. *Australasian Journal of Information Systems 11*, 2 (2007).
17. Lamping, J., Rao, R., and Pirolli, P. A focus+ context technique based on hyperbolic geometry for visualizing large hierarchies. In *Proc. of CHI'95*, ACM (1995), 401–408.
18. Lee, J. C., Hudson, S. E., Summet, J. W., and Dietz, P. H. Moveable interactive projected displays using projector based tracking. In *Proc. of UIST'05*, ACM (2005), 63–72.
19. Müller, J., Walter, R., Bailly, G., Nischt, M., and Alt, F. Looking glass: a field study on noticing interactivity of a shop window. In *Proc. of CHI'12*, ACM (2012), 297–306.
20. Müller, J., Wilmsmann, D., Exeler, J., Buzeck, M., Schmidt, A., Jay, T., and Krüger, A. Display blindness: The effect of expectations on attention towards digital signage. In *Pervasive Computing*. Springer, 2009, 1–8.
21. Orr, R. J., and Abowd, G. D. The smart floor: A mechanism for natural user identification and tracking. In *CHI EA '00*, ACM (2000), 275–276.
22. Paradiso, J., Abler, C., Hsiao, K.-y., and Reynolds, M. The magic carpet: physical sensing for immersive environments. In *CHI EA '97*, ACM (1997), 277–278.
23. Peltonen, P., Kurvinen, E., Salovaara, A., Jacucci, G., Ilmonen, T., Evans, J., Oulasvirta, A., and Saarikko, P. It's mine, don't touch!: Interactions at a large multi-touch display in a city centre. In *Proc. of CHI'08*, ACM (New York, NY, USA, 2008), 1285–1294.
24. Pinhanez, C. The everywhere displays projector: A device to create ubiquitous graphical interfaces. In *Proc. of Ubicomp'01*, Springer (2001), 315–331.
25. Rogers, Y., Hazlewood, W. R., Marshall, P., Dalton, N., and Hertrich, S. Ambient influence: Can twinkly lights lure and abstract representations trigger behavioral change? In *Proc. of Ubicomp'10*, ACM (2010), 261–270.
26. Schrammel, J., Mattheiss, E., Döbelt, S., Paletta, L., Almer, A., and Tscheligi, M. Attentional behavior of users on the move towards pervasive advertising media. In *Pervasive Advertising*, J. Müller, F. Alt, and D. Michelis, Eds., Human-Computer Interaction Series. Springer London, 2011, 287–307.
27. Wilson, A. D. PlayAnywhere: a compact interactive tabletop projection-vision system. In *Proc. of UIST'05*, ACM (2005), 83–92.
28. Xiao, R., Nacenta, M. A., Mandryk, R. L., Cockburn, A., and Gutwin, C. Ubiquitous cursor: A comparison of direct and indirect pointing feedback in multi-display environments. In *Proc. of GI'11* (2011), 135–142.