Ceiling Interaction: Properties, Usage Scenarios, and a Prototype

Raphael Wimmer
University of Regensburg
93040 Regensburg, Germany
raphael.wimmer@ur.de

Alexander Bazo
University of Regensburg
93040 Regensburg, Germany
alexander.bazo@stud.uni-regensburg.de

Markus Heckner
University of Regensburg
93040 Regensburg, Germany
markus.heckner@ur.de

Christian Wolff
University of Regensburg
93040 Regensburg, Germany
christian.wolff@ur.de

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Abstract
We propose utilizing the ceiling of personal and office spaces as an additional interactive display for both single-user applications and collaboration. Ceilings offer a display space that is unobtrusive, allows unobstructed viewing from many positions, and allows direct mapping to the room below. Previous research on ceilings as interactive displays has focused on providing ambient information. We argue that interactive ceilings are even better suited for supporting collaboration between persons in a shared room, and as an unobtrusive extension of a user's desktop. Also, interactive ceilings can display status information directly above persons or objects on the floor. We discuss perceptual and ergonomic properties of interactive ceilings, propose concrete applications that benefit from interactive ceilings, describe a rear-projected prototype that we built with a size of 1.82 x 1.02 m, and present the design of a study investigating perceptual limitations of interactive ceilings.

Author Keywords
ceiling interaction, ambient displays, large scale displays,

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: Miscellaneous.

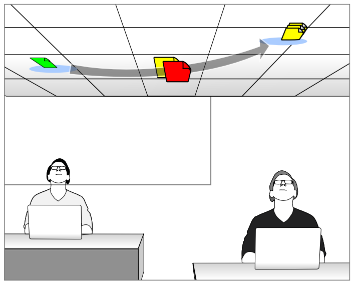

Figure 1: Interactive Ceilings facilitate collaborative workflows by providing a shared display space.

Introduction

Most current workplaces for knowledge workers feature laptops or desktop computers with one or more attached screens, supporting only limited multi-user interaction. Researchers have investigated how interactive whiteboards and interactive tabletops can facilitate collaboration. However, whiteboards and tabletops can get occluded by other users and furniture and require users to walk up to them . While an interactive floor allows for several interesting applications[1], floor space is usually occluded by furniture and people. A room's ceiling is visible from most positions within the room, and with the exception of lamps and fans, little is attached to a ceiling. Therefore, we propose utilizing room ceilings as unobtrusive and unobstructed interactive surfaces for both personal and collaborative work. We define *interactive ceilings* as a combination of a display surface on the ceiling and input methods that allow for manipulating information displayed on it. Interactive ceilings offer a place for displaying ambient information and documents without intruding into the focus of the users' attention. At the same time, the ceiling supports collaboration by acting as a shared workspace that is visible to all persons in a room. Additionally, locations on the floor can be mapped to screen areas on the interactive ceiling - and vice versa. This allows for showing status information, notifications, and navigation hints above persons, objects, or waypoints.

In this paper we present a survey of existing research on interactive ceilings, and a discussion of their unique properties and application scenarios. We also discuss insights from building our own prototype and from the design of a first user study that investigates which areas of the ceiling work best for notifications.

Related Work

Ceilings have been used for displaying imagery for a long time, beginning with cave paintings around 40.000 B.C.[5, p. 36ff]. Only recently have ceilings been used for displaying and interaction with digital information. Pieper and Kobsa[4] constructed a speech-controlled computer system for a bed-ridden, manually impaired user. It allowed him to write poetry while lying in bed. Due to ergonomic and safety reasons, the screen was projected onto the ceiling. This allowed the user to look at the screen without straining the neck muscles. The user did not report any vision problems when working on the system for up to two hours and was generally satisfied with the ceiling-mounted system. Tomitsch has conducted extensive research and design on interactive ceilings[5, 7, 6] focussing mainly on ceilings as ambient information displays but also encompassing experimental interactive applications. He has used a very broad definition of *interactive ceilings* that includes displaying ambient information but without any means for direct interaction. The prototypes presented include an ambient display intended to create remote awareness between physically separated couples by projecting light patterns onto the ceiling [7]. The patterns indicate the mood and position of the remote person. Another prototype displays weather forecasts in a peripheral visualization [5]. The system only renders temperature information as text, while visualizing all other information through colored backgrounds, animated water ripples or snow flakes. Results of informal tests by Tomitsch have shown that notification levels are crucial for ambient displays: Water ripples that flow too fast distracted people by drawing too much attention. Tomitsch also conducted a Wizard-of-Oz study comparing different input methods. Users had to aactivate one of nine panel displayed on the ceiling by pointing with their hand, pointing with a laser pointer,

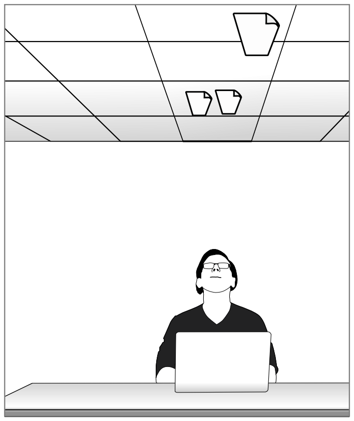

Figure 2: Ceilings may serve as virtual attics or personal clipboards, by storing information out the way but still easily accessible.

and throwing a ball at the ceiling[5]. Participants favored the laser pointer, reporting that they felt it was fast, precise and easy. Direct hand pointing was regarded as less precise, while ball activation was fun, but scored last in perceived performance. Tomitsch also hints that some participants reported neck pain during the study, presumably because they stood too close to the projection. Meagher[2] explores interactive ceilings as surfaces for displaying dynamic ornament. He reports results of a study where users had to play a racing game on a PC directly in front of them. Participants were required to glance at a separate display to gather task-related information (here: fuel gauge). This display was either mounted on the ceiling or on a wall. Meagher, in contrast to his intuition, found no difference in effectiveness between both variants. He notes, however, that these results might partially be caused by his experimental setup: Wall and ceiling display were rather close, minimizing the difference between experimental conditions. Although Meagher was not able to find differences in actual performance, users indeed believed that the task with the ceiling mounted display was harder to complete. We conclude that the ceiling appears to have a lower perceived usability when used during execution of a complex task. This may be due to lack of experience as well as to actual deficits in the ergonomics of interacting with a ceiling. The exploratory research prototypes by Tomitsch and Meagher probe the design space of interactive ceilings, showing potential use cases and hinting at ergonomic constraints that need to be taken into account. However, we identify a lack of systematic research on the basic ergonomic, perceptual, and interactive properties of interactive ceilings.

Properties of Interactive Ceilings

Interaction with ceilings is quite different from interaction with tabletops or whiteboards. We define three important groups of properties: perception, ergonomics, and interaction (see also [5, p. 22ff]), and discuss potential implications for interaction design.

Perception Ceilings are typically not occluded and are easily visible from many positions within a room. There is no limit on the number of people looking at the ceiling at the same time. Such a shared display space allows for showing important information to all persons in a room and supports collaborative content manipulation Our own experience indicates that peoples rarely look at the ceiling when they are not required to - except when lying down or leaning back in a chair. This makes interactive ceilings a promising unobtrusive, peripheral display space. However, users might not notice notifications on the ceiling.

The position of content on the ceiling relative to the users has a large effect on how it is perceived. The farther away content on the ceiling is, the more distorted it becomes for the viewer. This may be countered by adjusting the displayed image to individual user positions, e.g. pre-warping it so that it looks undistorted from the (single-) user's position. On the other hand, more distant parts of the ceiling more easily become part of the field of vision in a typical work environment. Like with interactive tabletops, content on the ceiling has no standard orientation. Depending on the location of the viewer(s), content on the ceiling has to be rotated or displayed in a rotation-invariant form.

Lamps that are mounted on the ceiling might be dazzling, straining the user's eyes when looking at the ceiling. One way to mitigate this issue might be to integrate lighting control into the interactive ceiling.

Interaction As a ceiling is usually shaped like the floor below it, there is a direct mapping between both. This makes it possible to display information about an object/person on the ceiling directly above, and allows taking the user's position and posture as input. This requires an appropriate tracking infrastructure, however. Other modes of input, such as mapping the mouse cursor to the ceiling or throwing balls are also possible.Ceilings are usually out of arm's reach. Therefore, direct touch input is limited to special scenarios (e.g. in-vehicle ceiling interaction). Alternatively, users can interact with the ceiling by pointing with their hands or with a laser pointer[3, 8]. Perspective distortion makes it harder to accurately and precisely target an object on the ceiling, however.

Unlike with tabletops or whiteboards, users can stay at their desk when interacting with the ceiling. Thus, transferring information between a user's personal computer and the ceiling might be extremely effortless and fast. It is not yet clear how users might feel about who owns specific parts of the ceiling. Determining the relationship between personal space and shared space requires further research.

Ergonomics Looking upwards for longer periods of time strains the neck muscles and is quite fatiguing. This limits how long users are able and willing to interact with content on the ceiling. Additionally, looking at content right above oneself is much more straining than looking at a distant point on the ceiling. Applications need to cater to these limitations. Reclining office chairs might mitigate neck strain and fatigue. Lying on the bed allows for watching the part of the ceiling within one's field of view without experiencing fatigue. While looking up is usually considered a downside, it could also be seen as a potential benefit since this change of perspective might literally force users to look at problems or tasks from a different angle. Applications for interactive ceilings also need to address fatigue of the arm during pointing tasks.

There seems to be no empirical evidence regarding the perceptive, interactive, and ergonomic properties of ceiling interaction. Nevertheless, ceiling interaction is certainly no replacement for established interaction paradigms. It is not suitable for typical office tasks with a long duration like editing documents or preparing presentations. However, interactive ceilings might support these tasks and enhance existing workflows. In the following chapter we discuss possible usage scenarios before presenting our ceiling interaction prototype in more detail.

Usage Scenarios for Interactive Ceilings

Various scenarios might benefit from applications that incorporate an interactive ceiling:

Screen Extension For single users, the ceiling offers a huge area that can be used as an extension of their other screens (Figure 2). Information that should be available at all times without cluttering up the main screen can be presented on the ceiling. This includes clipboard contents, reference charts, to-do lists or calendars. Content might be transferred between displays by hand gestures, shortcuts or eye movement.

Collaborative Workflows Sharing an interactive ceiling between co-workers in the same room allows them to easily show and transfer content to each other via the ceiling (Figure 1). Content transfer routes on the ceiling might mirror existing workflows. For example, first-level support personnel might put incoming support tickets onto the ceiling where co-workers can accept them by moving them into their personal area on the ceiling. This system also allows everyone in the room to monitor the workload of indivdual co-workers and of team as whole with a quick glance to the ceiling.

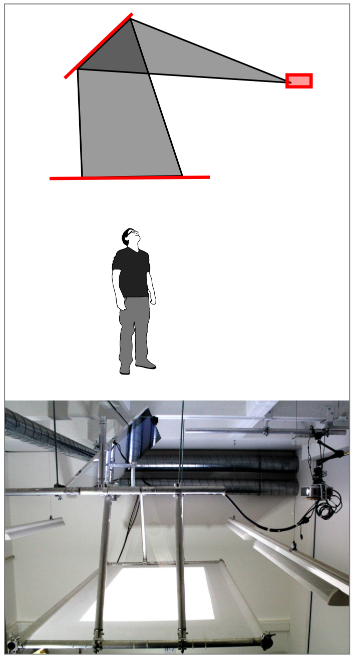

Figure 3: Our back-projected interactive ceiling prototype: 182 x 101.5 cm, 1920x1080 px (26 dpi), height above ground: 243 cm.

Notifications Showing notifications on users' screens is often distracting. Putting less important notifications on the ceiling - and thereby in the peripheral field of view - lets these fade into the background while the user is concentrating on their main screen. When users look up from their work, they easily get an overview of all new notifications. Notifications on the ceiling also reach recipients when they are not at their desk.
Status Bars A printer's status and toner level might be shown directly above it on the interactive ceiling. Co-workers might put their name, mood, availability or caffeine level on a status display that hovers above them on the interactive ceiling. Approaching persons could directly observe their status before making direct, and potentially distracting, contact.
In-Building Navigation An interactive ceiling can act as virtual signposts, showing directions to other parts of the building. If the ceiling can also track a person's location, it might also show them the way to their current destination by displaying directions right in front of them. Additional use cases include solutions for people with special needs similar to the prototype for bed-ridden persons mentioned above.

Interactive Ceiling Prototype

Interactive ceilings can be implemented using front-projection, rear-projection, TFT display panels embedded into the ceiling, as well as (O)LED displays. Low-resolution techniques, such as using colored light bulbs are not discussed here. For deployment outside the lab, TFT or LED displays are preferable as they can be embedded into ceiling tiles[2] which allows for easily retrofitting existing ceilings. For research, projected displays are less expensive and more versatile. Front-projecting upwards onto the ceiling can be achieved easily. We also employed this approach in first tests. However, with front projection, persons often throw shadows onto the ceiling. Additionally, projectors might impede a person's movement below the ceiling. The high ceiling of our lab (4.5 m) allowed us to implement a rear-projected interactive ceiling which is 2.43 m above the ground (Figure 3). The projection area measures 1.82 x 1.02 m. The room itself measures about 4 x 3 m. The projection makes use of a full HD projector with resolution of 1920x1080 px mounted next to the display area. A foil mirror deflects the projector's output onto a white rear-projection screen, representing the ceiling. A camera mounted atop the projector tracks laser pointer input on the screen. We are planning to mount additional tracking infrastructure on the ceiling that allows us to track persons' movement and pointing actions.

Study: Determining Visibility on the Ceiling

In order to design applications for interactive ceilings, more knowledge about the basic properties of interaction on the ceiling is needed. To this end, we are currently conducting a study that is investigating which areas on the ceiling are best suited for displaying interactive content and notifications. Most of a person's visual attention is usually focused on desks, computer screens, or other persons. For placing notifications and ambient visualizations on interactive ceilings, it is essential to know what portion of the ceiling is within a (sitting, standing) person's field of view when attending certain tasks. The further a person is looking down, the less of the ceiling they will be able to see. In our study, we measure the field of view of different persons with regard to the inclination of their line of sight (Figure 4). Based on ergonomics literature and own experiments, we defined angles of inclination relative to the horizontal plane that correspond to common tasks such as: reading a book (-49°), looking at a computer screen (-15°), looking straight ahead (0°),

Figure 4: Study investigating what area on the ceiling users are able to see at different head inclinations. Participants stand at fixed positions on the floor and look at a marker on the ceiling or on the wall. A white square containing a letter slowly moves across the ceiling. Once the participant notices the square, he presses a button. Once he is able recognize the letter, he presses the button a second time. The inclination of the head is measured using an accelerometer strapped to the back of the head.

looking slightly upwards (8°), looking upwards with a comfortable neck inclination (38°), looking up at the ceiling (75°), and looking straight up (90°). Study participants are asked to stand or sit below the interactive ceiling and look at a certain marker in the room, each corresponding to a certain angle of inclination.

This study design has some limitations. For example, we are not able to reliably measure the lower edge of the field of view as our ceiling prototype is too small to completely cover the field of view in all conditions. Nevertheless, the study should give a good estimate of the ceiling area available for notifications and information display.

A follow-up study will look into the ergonomic limitations of ceiling interaction. We will measure both perceived and actual neck strain while users look at the interactive ceiling. This study should indicate how long and how frequent interactions with the ceiling may be without causing excessive fatigue.

Outlook

Our current research focuses on better understanding the basic properties of ceiling interaction through quantitative user studies. In the medium term, we plan to implement several of the scenarios presented in this paper in order to find out how interactive ceilings might support knowledge workers and other users. Furthermore, we are curious about the potential of interactive ceilings as virtual gateways to remote locations, and their relationship to other interactive surfaces.

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