Characterizing the Space by Thermal Feedback through a Wearable Device

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Abstract. Thermal sensation is a kind of a haptic sensation and is very familiar feeling. However it is difficult to realize a thermal display which gives realistic thermal feedback because thermal characteristic has a larger ambiguity and is late-response. Alternatively, thermal feedback could be used as a new channel for the transmission of imaginary characteristics. We are aiming to add characteristics to the existing space by providing people with location-dependent thermal information. By manipulating thermal information presented to people, we can change implicit partitioning of the space without physically reconstructing it. "Thermotaxis" is a system that gives sensations of cool and warm to users by controlling thermoelectric devices wirelessly. In this system, the space is characterized as being cool or warm. Users experience the difference in temperatures while they walk in the space. Preliminary analysis shows that people stay close in the area of a comfortable temperature.

Keywords: Ambient Controlling, Characterizing the Space, Thermal Sensation, Thermal Feedback, Wearable Computing.

1 Introduction

Thermal sensation is a kind of a haptic sensation and is very familiar feeling. However, force and tactile feedback are the main sensory inputs presented to an operator using a haptic display and there is few example of the utility as a thermal interface or a thermal display. For example, there has been work on incorporating thermal feedback into haptic devices [1, 2]. Thermal feedback can be used to convey information about the thermal conductivity of objects encountered in an environment which can assist in object identification, or in the creation of a more realistic image of the object [1].

A thermal characteristic has a larger ambiguity than that of visual and audio information. And the response time is longer than visual and auditory sensation. These are the reasons why it is difficult to realize a thermal display which gives realistic thermal feedback. Alternatively, thermal feedback could be used as a new channel for the transmission of imaginary characteristics.

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In this paper we propose a method of characterizing the space by presenting thermal information. Although thermal sensing is slower in response time and lower in resolution than visual and audio sensing, it is suitable for informing users gradually, without giving a clear border.

Our research aims to make spatial design flexible. New characteristics are added to an existing space, so the relationship between the space and people within changes. In spatial information design, there are many studies on presenting information, including pervasive, ubiquitous and ambient computing [3]. Most of them focus on presenting additional information or information of distant place remotely [4, 5]. The kind of information we are interested in is not explanations about a location but part of a spatial structure that implicitly affects people's activity in the spaces. We call it ambient controlling of human behavior by presenting non-visual information.

In the rest of paper, we discuss an experiment of presenting thermal information to characterize the space. We also describe analysis of people's behavior in that space.

2 Characterizing the Space by Presenting Thermal Information

As discussed in the previous section, we introduce a thermal characteristic to a space. A thermal characteristic has a larger ambiguity than that of visual and audio information. And the response time is longer than visual and auditory sensation [6]. However, among all types of sensations, thermal sensing is effective in ambient controlling for presenting information non-intrusively. There are two advantages of using non-visual information presentation.

First, screens and displays force the eyes of users on them. For example, ambient display [4] was studied as a way of implicit information presentation. Without regular computer displays, users become free from the desktop to get information. There is still a drawback in this approach, however, that users are required to pay attention to where the information is presented, which constrains their activities.

Another example is the concept of ubiquitous computing and pervasive computing, which try to transform spaces that are filled with computers into intelligent spaces with communication capabilities [7-10]. Many of these studies, users have to walk around with mobile terminal or hand-held communication device to get annotated information. If users expect desired information, this can be available. But using devices with visual monitors are not applicable to implicit information presentation. It is because we want to encourage changing user's behavior regardless of whether the user expects it.

Second, information representation using auditory properties is susceptible to surrounding sound environment. Besides the sound can be intrusive noise for unconcerned people. One solution is providing a wearable headphone for each user.
The combinations of information technology and architecture have argued [11, 12]. The Austrian Architect, Hans Hollein has explored several possibilities of a new electronic media with architecture in 1960's [13]. In his claim, a space is as sculpture, or as a "determined activated region in indefinite three dimension".

Some applications have been developed that construct spatial structures using non-visual information presentation. "Monolith" is an LED sculpture by United Visual Artists [14]. This artwork is a symbolic responsive LED sculpture that makes a huge noise if the visitor comes close to it. By this behavior of the system, the visitor is forced to move toward moderately comfortable place. In this case, the sculpture creates a spatial structure by presenting audio information that affects users around it.

We have studied the recognition of a spatial structure without presenting visual information [15]. In this study, a spatial structure was not presented by blocking the visual information from the external world with the veil, and how the space was recognized by walking blind was investigated. This study indicated that people have more accuracy in recognizing topology than distance.

3 Thermotaxis

3.1 System Overview

In this section, we propose a system of controlling thermal characteristics and discuss how thermal information affects people's behavior.

Thermotaxis is a system that creates thermal sensory spots in an open space. It works as a spatial partitioning system without physical walls. Instead, it displays temperatures in several grades. In this system, we use earmuff like wearable devices that provide thermal sensation to ears depending on the location of people. We choose ears to present thermal information because cephalic part is the most sensitive to heat and cold stimuli [16]. By feeling the temperature, people distinguish different thermal areas, though there is no visual distinction between them.

Fig. 1. Thermotaxis

In Thermotaxis, space is divided into several thermal fields. The term "Thermotaxis" signifies a movement of a living organism in response to heat stimulation. Visitors are expected to walk around to find their comfortable position based on their thermal senses. Due to the variations of desired conditions and surrounding environment such as the air temperature, different positions are found to be comfortable by different visitors. For example, on a cold day in winter, a comfortable place would be warm unlike a summer day. People who have a similar preference would gather together. (Figure 1)

3.2 Hardware Configuration

The system is designed to be controlled by a computer as an operating unit via wireless communication, and all electronic modules that control temperature are installed in the earmuff.

This system consists of several earmuff-like wearable devices (Figure 2) and a control unit that controls the wearable devices and recognizes their locations. Figure 3 shows the configuration of devices.

Fig. 2. Earmuff device

An IEEE 1394 camera with an infrared filter for earmuff tracking is attached to the ceiling about 12 meters above the floor. Infrared LEDs are attached to the top of the earmuff device for camera tracking. Sensing with a camera is easy to install if the camera has a clear line of sight to all wearable devices. Figure 4 depicts the system layout. When the control unit requests locations of the wearable devices, the camera detects their positions by capturing blinking infrared LEDs mounted on their tops.

To build a wearable device that displays warm and cool temperatures, we use an Arduino Nano [17] as a microcontroller. It controls two Peltier devices in each side of the earmuff. It also controls infrared LEDs. There are five heating levels on the Peltier

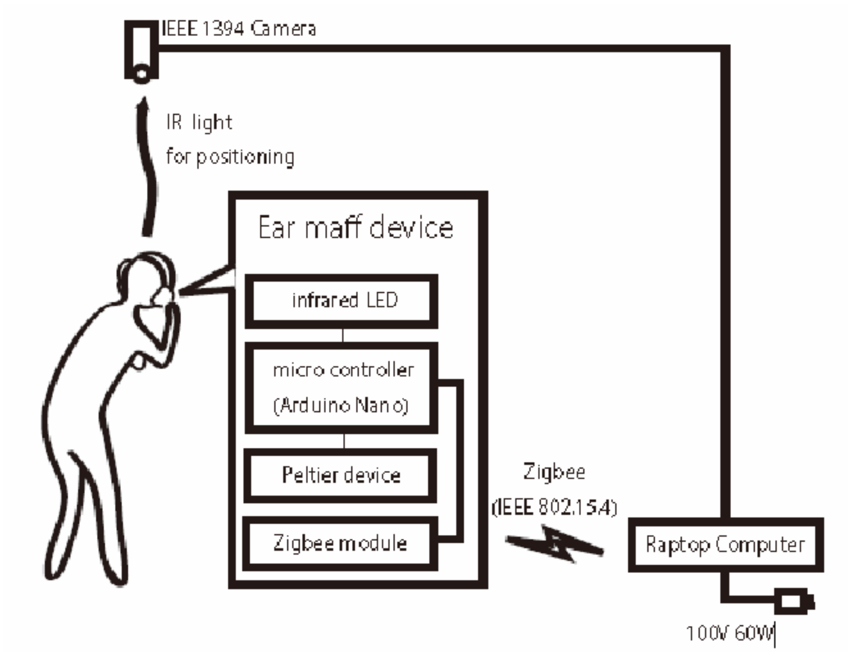

Fig. 3. Configuration of Earmuff Devices and Control Unit

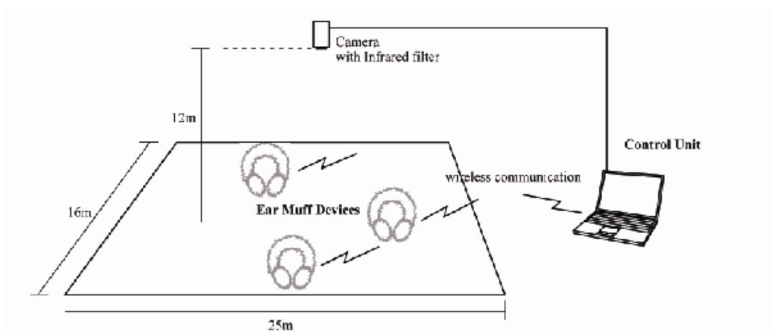

Fig. 4. System Layout

device control. Two of them are heating, two of them are cooling and one in the middle is without heating or cooling level. The difference in temperature created by these Peltier devices is about twenty degrees to forty degrees Celsius.

The control unit and the earmuff devices communicate via a Zigbee network. If the position is detected, the unit determines the heating level according to the thermal field and sends the temperature level to the earmuff device. Because the thermal fields are defined by software, we can change the map of fields dynamically.

4 Experiment

An experiment was performed to examine how the thermal characteristic of the space affects people's behavior in the space. There were six earmuffs, which allowed six people to experience the system at the same time. This experiment was conducted in December 2008 at the University of Tokyo as an art exhibition. The air temperature during the experiment ranged from a low of 8 degrees to a high of 12 degrees Celsius, averaging 10 degrees Celsius.

Approximately a total of 400 people ranging from teens to 60s experienced this system. All of them were told to put on the earmuff device and walk around in the open space to find comfortable areas. The dimensions of the open space were about 25m x 16m. In order to examine the trajectories of people in that space, the system was programmed to record logs of positions detected by the control unit. Figure 5 shows people were experiencing "Thermotaxis." The characterizing map was designed to have five thermal grades. (See the map of Figure 6).

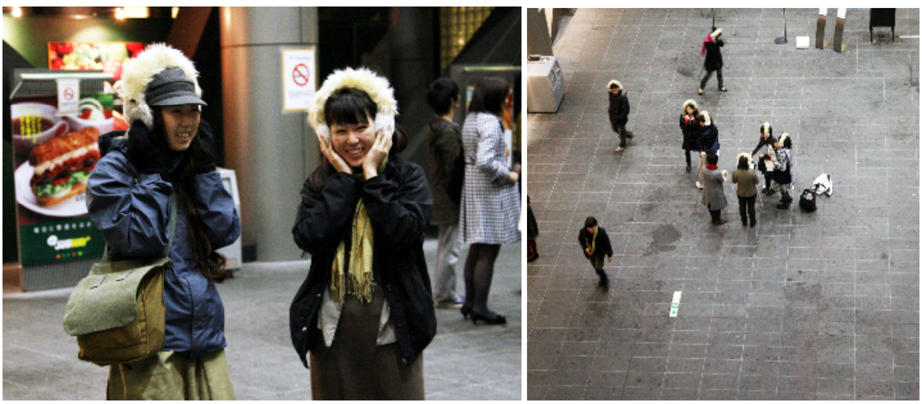

Fig. 5. Visitors who experience "Thermotaxis" and a Bird's-Eye View of "Thermotaxis"

5 User Behavior Analysis

In this section, we present analysis of recorded data described earlier and discuss people's behavior in the space. This analysis consists of composed of following two points.

- The relation between area ratio and sojourn time in each area.
- The influence for other people on subject being in certain area.

The purpose of the first analysis is to determine which areas people prefer. The second analysis is to measure influences of one's location to other people.

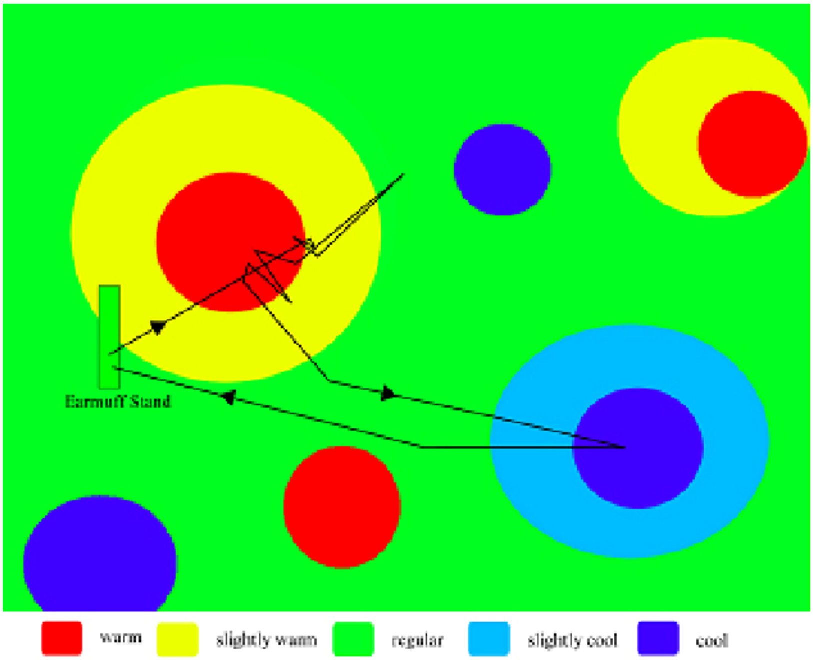

Fig. 6. The Trajectories of People. In this map, red areas are warm, yellow areas are slightly warm and green areas are at a regular temperature area. All people standing in red area.

5.1 Thermal Area Ratio and Sojourn Time

Like open fires in winter and water places in summer, thermal locations have been work as attractive location since early times. A thermal spot has power to encourage people to gather together.

Figure 6 illustrates an example of user's trajectory. In this map, red areas are warm, yellow areas are slightly warm, cyan areas are slightly cool, blue areas are cool and green areas are at a regular temperature area. Left graph in Figure 7 compares areas of the thermal fields indicated in Figure 6. The regular area is largest, followed by the warm area. The cool, warm and slightly cool areas are approximately of the same size.

Right graph in Figure 7 shows the total sojourn time of all people. The total time spent in warm is the longest although the regular area is the largest. This result means that people preferred to stay longer in the warm area.

Figure 8 depicts a Venn diagram of arrival rate of each area. About 83 percent of people reached the warm area, while only 22 percent reached the cool area.

This result can be attributed to the topology of the map. As shown in Figure 6, the warm and slightly warm areas are closer to the earmuff stand which is the initial position of the trajectory. In other words, 80 percent of people searched near the starting point and about 60 percent were satisfied with the warm area. The air temperature may be a factor of this result. It is likely that people preferred to the warm area because of the low air temperature.

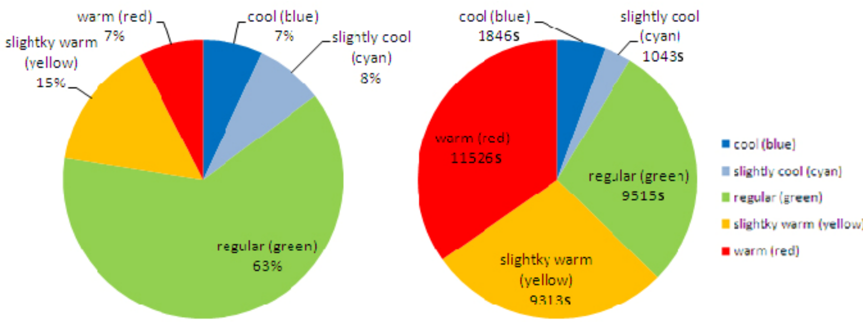

Fig. 7. Thermal Area Ratio (left) and Sojourn time summated all subjects (right)

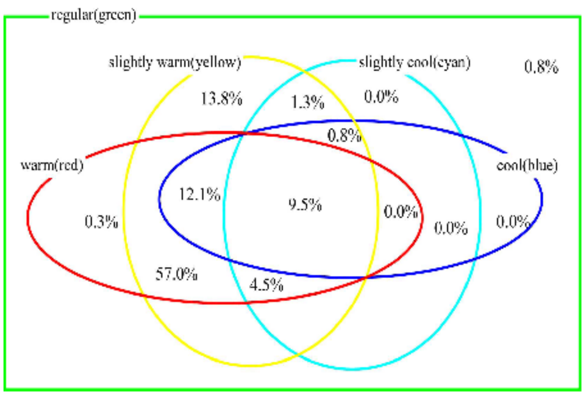

Fig. 8. Venn diagram of arrival factor

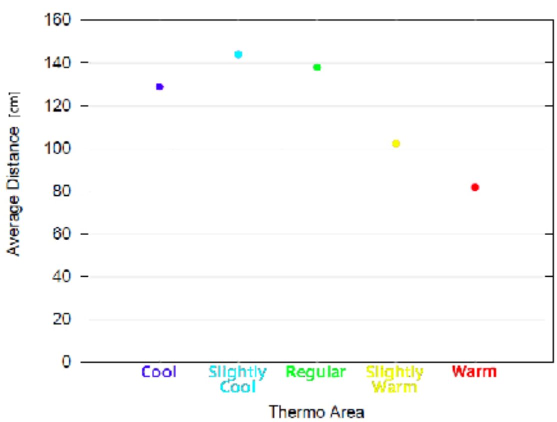

Fig. 9. Average Distance between People Sorted by Thermal Areas

5.2 Influences on Other Subjects

The visibility of other visitors also effects how visitors transition through the areas. In the open space, people can see each other. If one stays in a particular place, other people may be wonder why he or she is there. So, people influence each other by their positions.

Figure 9 shows average distance between people when one of them is in area. The average distances in the warm and slightly warm areas are small. There is little difference in the regular, slightly cool and cool area.

This result means that if there is at least one person in warm or slightly warm area, people tend to close each other. In other word, people stay close in the warm and slightly warm areas.

6 Conclusions

This paper discussed the idea of thermal feedback as a new channel for the transmission of imaginary characteristics. We proposed to characterize the space by presenting thermal information. Unlike physical walls or partitions, creating non-intrusive partition using information mapping onto an existing space enables us distinguish areas in space flexibly. In Thermotaxis, we characterize an open space with thermal information. Wearable thermal devices have been created to present an imaginary spatial structure.

We conclude that affecting people's behavior is possible by reconfiguring an open space with invisible spatial structure. In this paper, we have argued that the use of thermal information is useful for creating an implicit spatial structure. The result of our experiment shows that presenting thermal information affects people's behavior in making them get together in a warm area under certain conditions.

We need further investment about how people's behavior changes if the thermal map dynamically changes. We are also interested in using other media to perform ambient controlling. Although the use of visual or audio senses is reliable to deliver information accurately, there is an advantage of presenting information passively and unconsciously. We believe that it is worth investigating application of ambient controlling in new media.

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