Arbitrating Modalities of Interruption Using Ambient Displays

by

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Abstract

This thesis presents two experiments designed to test the effect of different modalities when used as interruptions. A multimodal interface explores the use of ambient displays in the context of interruption where visual and thermal ambient displays acted as external interruption generators.

This works shows and demonstrates that interruption modalities are perceived differently, trigger different reactions and have a different disruptive effect on memory. The thermal modality produced a larger decrease in performance than the visual modality. Disruptiveness and performance measures agree that heat causes more of a detrimental effect on performance than light when used as an interruption.

This thesis proposes to use users' physiological responses as feedback for a computer interface. Experiments in this thesis set the initial point for understanding how to build interfaces that use modalities appropriately by looking at the effect of different modalities when used as interruptions. Interruptions are disruptive and inherent to current computer interfaces. Properly selecting interruption modalities can control their disruptive effects.

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CHAPTER 1

INTRODUCTION

1.1. MOTIVATION

The use of interruptions is a key issue in the design of human-computer interfaces. Some research concerning the effects of interruption shows that if a person is doing a repetitive task, an interruption can actually improve their performance. Still most research about the effect of interruptions can be summarized in that a user performs slower on an interrupted task than on a uninterrupted task, that is, interruptions are perceived as disruptive. Research proposed in this thesis goes a step further by looking at what is the effect of different interruption modalities on performance and disruptiveness.

1.1.1. Increasing Workload and Interruptions

Advances in computer technologies have enabled the creation of systems that allow people to perform multiple activities at the same time. Interruptions are common to today's multitasking computing user interface experience. This kind of multitasking environment is useful and might seem natural, however it also introduces the side effect of causing people to be interrupted constantly. Unfortunately, people have cognitive limitations that make them susceptible to errors when interrupted. For instance, some researchers (McFarlane, 1999 and Czerwinski, 2000-A) have examined interruptions by looking at when to interrupt users in a multitasking environment. Current computer environments are becoming more and more complex, with an increasing number of tasks and an increasing number of issues computer users have to keep track of.

1.1.2. Human Computer Interaction (HCI)

Traditional human computer interfaces found in desktop computers focus only on a small number of modalities to interact with users. Acoustic and visual modalities are the most often used for conveying information. Current human computer interfaces generally ignore important modalities such as ambient and peripheral visual cues, heat, vibration, force feedback, smell, and even the sense of touch. Furthermore, these interfaces are not taking advantage of the fact that humans have extraordinary sensing capabilities that are in use all the time. According to Srinivasan from the touch lab at MIT, despite the progress made in the past two decades in the area of haptic interfaces, these interfaces have not yet become widely used in human computer interfaces (Srinivasan, 1985).

Even though past work provides evidence that there are substantial advantages in efficiency by using multimodal interfaces (Oviat, S.L, 2000), the main focus of multimodal HCI research has been on combining input modalities – such as speech, pen, touch, hand gestures, eye gaze, and head and body movements– rather than using multimodal outputs to take advantage of human sensing capabilities.

Human senses differ in both, precision and speed. Vision and touch are more precise and faster than hearing for the perception of object properties, such as shape, texture, direction, distance and size. Hearing allows for a better perception of temporal events, such as duration, pace and rhythm (Welch, 1986). Human factors literature offers some guidelines for interface designers, but do not explore the use of other modalities deeply. The common and unique characteristics of the human senses allow for the design of computer interfaces that use multiple output modalities and furthermore, computer interfaces that present each modality based on their disruptive effects.

1.2. APPROACH

This work explores the use of ambient displays in the context of interruption. A multimodal interface was created to communicate with users by using two ambient displays as channels for communication. Ambient displays present information in the modality and in the form that can be interpreted with minimal cognitive effort (Wisneski, et al, 1998). They also act as external interruption generators designed to get users' attention away from their current task, such as writing e-mail or playing a game on a desktop computer. Haptic displays have been explored in the form of vibration. Thus, heat was used as a novel ambient display to generate interruptions. In this work, interruptions are presented in the form of heat and light. Ambient displays will serve a purpose other than the mere presentation of information—they will serve as a media for interruptions.

This thesis presents two exploratory experiments, designed for testing the effect of different modalities when used as interruptions. The purpose of these experiments is to identify the key factors that influence the perceived effect of each of the modalities. One of the main hypotheses of this thesis is that users' performance differs based on the interruption modality used. These experiments are based on the methodology proposed by Gillie and Broadbent, who investigated the effect of the length of interruptions to the main task (Gillie and Broadbent, 1989). The experiments are also based on the work done by McFarlane, who presented the first empirical comparison to the problem of coordinating user-interruption in HCI (McFarlane, 1999). The experiments exploit the fact that people have selective memory relative to interruption, that is, users are able to recall details of an interrupted task better than the details of an uninterrupted task (Van Bergen, 1968).

The experiments use a combination of two ambient display devices. A preliminary experiment showed that heat was a good interruption modality because of its novelty and its sense of immediacy. The experiment also proved light was a good interruption modality because of the domination of the visual system over the other senses. The first device is a thermo-mouse pad, which works as a heating apparatus using Peltier devices. The thermo-mouse pad serves as a thermal ambient display, increasing temperature to indicate an interruption. The second device is a dimmable night lamp, the light from this lamp can change intensity from to no brightness to full brightness at different rates of appearance or instantly if desired. The dimmable lamp serves as a visual ambient display, changing its intensity to signal an interruption.

1.3. CONTRIBUTION

This thesis presents experiments designed to test the effect of different modalities when used as interruptions. This work adds to previous research by showing an interruption effect on performance caused by different modalities. Thermal modality produced a larger decrease in performance than visual modality. A thermal modality has a greater disruptive effect on interrupted tasks than light. Disruptiveness and performance measures agree that heat causes more of a detrimental effect than light when used as an interruption.

Interruptions are disruptive and inherent to current computer interfaces. Selecting interruption modalities can control their disruptive effects. The results of the experiments presented in this thesis are in agreement with previous research about interruptions in that interrupted performance in tasks decreases when interrupted. The distracting effect of interruptions is demonstrated.

1.4. THESIS ORGANIZATION

The remainder of this thesis is organized into four chapters and five appendixes. This chapter explained motivation, and purpose of this work. Chapter 2 focuses on background about the physiological aspects of vision, touch, and pain. Chapter 2 also presents an overview of interruptions and ambient displays. Chapter 3 explains the experimental protocol and results after testing the effect of interruption modalities. Chapter 4 discusses future work and concludes with a summary of the results and their implications. Appendix A describes the implementation of ambient displays used in this thesis, a thermo-mouse pad for heat, and a dimmable lamp for light. Appendix A also describes he necessary theoretical information to replicate these devices Finally, appendixes B through F present experiment materials used for testing the effect of interruption modalities.

CHAPTER 2

BACKGROUND

In order to realize the possibilities of using ambient displays to present information via the sense of vision and the sense of touch, it is useful to know about the structure, operation, and characteristics of these systems. It is also really important to understand what are the functions of these senses for the human body.

2.1. VISION

Visible light is the stimulus that activates the visual system and provides us with information about the world. For humans and many other animals, the wavelength of visible light ranges from 400 to 700 nanometers. These wavelengths are associated with colors of the spectrum. Light reflected from objects enters our eyes and causes us to perceive the world. The eye focuses the light reflected and creates an image within the eye. The optical system translates this image into electrical impulses and transmits it to the brain. The human eye consists of a spherical organ with a transparent lens, and a photosensitive region filled with several different types of photoreceptor cells: rods and cones. They serve to offer sensitivity to different colors of light. They differ in shape and in the way they are distributed on the retina. There is one small area in the retina, the fovea, which contains only cones and is located in such a way that anytime we look directly at an object, the center of the image falls on the fovea. Since the area of the fovea is so small, it contains only about 6 million cones. Most of the cones are in the peripheral retina, however, the rods outnumber the cones by about a twenty to one ratio, with about 120 million rods in the periphery. Visual acuity, or the ability to see details is better in the fovea than in the periphery. Visual ambient displays are designed to work on the periphery, where visual acuity is lower, so as not to interfere with the user's current task. Figure 1 shows the different distribution of cones and rods, more specifically in the periphery where visual ambient displays are designed to operate. Section 2.3 discusses speeds in perception of brightness.

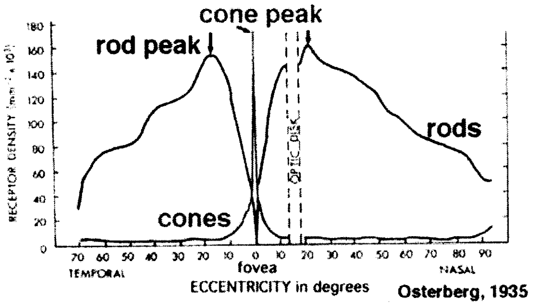


Figure 1 Cones and Rods Distribution in the eye

For the human visual system, a light detection threshold exists at zero background light intensity. Under an environment of no background light intensity, a minimal light contrast must exist in order for our eyes to detect; it usually takes 200-600 msec to be detected (Teichner, 1954). A minimal amount of light energy is needed for the cone and rod cells at the surface of the retina to generate an electric neural signal for vision. Humans can detect contrast difference more easily if there exists small background intensity rather than zero background.

2.2. TOUCH

The skin is the heaviest organ in the human body and; like the retina, it contains a number of different kinds of receptors. Some of the functions of skin are to warn of danger, prevent body fluids from escaping, separate our insides from the environment, provide us with information about the environment, help exert pressure on objects, sense temperature and protect our body from external bacteria and chemical agents.

2.2.1. Somesthetic system

The somesthetic system in the human body is in charge of the sense of touch. Cutaneous sensations are sensations based on the stimulation of the skin, Goldstein divides cutaneous sensations into three types (Goldstein, 1999):

1. Tactile perceptions, caused by mechanical displacement of the skin (all perceptions, except pain).
2. Temperature perceptions, caused by heating or cooling the skin.
3. Pain perception, caused by stimuli that are potentially damaging to the skin.

This thesis is concerned primarily with sensations that fall into the temperature perception type by the use of thermal stimulation.

Sensory receptors are located in the skin, muscles and joints. Receptors allow humans to sense pressure, vibration, temperature, pain, and proprioception. The sensory receptors respond to mechanical, chemical, thermal, or electrical stimulation by transmitting signals to the brain (Boff, et al, 1986).

2.2.2. Thermoreceptors

Receptors and fibers have a large influence on what we perceive. Thermoreceptors provide a natural response to temperature in the human body. They respond to specific temperatures and changes in temperature. There are separate thermoreceptors for warm and cold. On one hand, warm fibers behave in the following way:

- Increase their firing rate when temperature is increased
- Continue to fire as long as the higher temperature continues
- Decrease their firing rate when the temperature is decreased
- Do not respond to mechanical stimulation.
- Respond in the 30°C to 48°C range, with the best response at about 44°C.

On the other hand, cold fibers behave differently:

- Increase their firing rate when temperature is decreased
- Continue to fire at low temperatures.
- They respond in the 20°C to 45°C range, with the best response at about 30°C.

Figure 2 shows different ways that cold and warm fibers respond to steady temperatures (Duclaux and Kenshalo 1980).

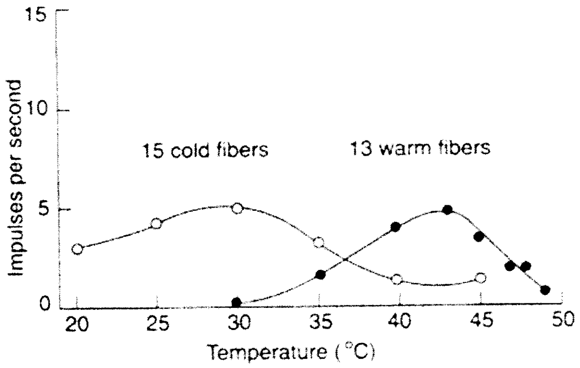


Figure 2 Responses of temperature-sensitive fibers
[Kenshalo, 1976]

Psychophysical and medical research about heat helps understand how heat is perceived and what are the human thresholds under different circumstances. The Human Factors Design Book describes some guidelines regarding the use of heat in the work environment. This thesis used the thermal thresholds guidelines suggested by Woodson (Woodson, 1981). They are summarized in table 1.

Temp of Skin °C	Response
82	Second-degree burn on 30sec
71	Second-degree burn on 60sec
60	Pain; tissue damage
49	Pain; burning heat
32	Warm
12	Cool
3	Cool heat sensation
0	Pain Response

Table 1 Effect of skin in contact with different temperatures [Woodson, 1981]

LaMotte reported that the threshold of pain varies from 36 to 47°C depending on the body zone, stimulus duration, and base temperature (LaMotte, 1978). Sherrick & Cholewiak showed that the facial region is the most sensitive area in the body to thermal stimulus, and that the lower extremities are considerably less sensitive (Sherrick & Cholewiak, 1986).

2.3. JND

The Difference Threshold (or "Just Noticeable Difference") is the minimum amount by which stimulus intensity must be changed in order to produce a noticeable variation in sensory experience. Ernst Weber a 19th century experimental psychologist observed that the size of the difference threshold relates to the initial stimulus magnitude. Weber's Law states that the size of the just noticeable difference is a constant proportion of the original stimulus value (Weber, cited in. Jones, 2002)

Teichner research shows that the JND for the brightness of a light is 8%. He found that reaction times for the perception of brightness vary from 200 msec in optimal conditions (i.e. high contrast), to about 600 msec. (Teichner, 1954). The literature also provides information on the

JND for changes of temperatures. Yarnitsky and Ochoa conducted experiments that looked at the JND of temperature change on the palm at the base of the thumb. They found that the rate of temperature change (1.5, 4.2, and 6.7°C/sec) had no detectable effect on the JND for warming temperatures (~47°C) or cooling temperatures (~0.2°C). They also found that subject's reaction time in warming (~0.7sec) was significantly longer than the reaction time for increases in cooling (~0.5sec) (Yarnitsky and Ochoa, 1991). In another work in this area, Zerkus reported that the average human can feel a temperature change as little as 0.1°C over most of the body, though at the fingertip a sensitivity of 1°C is typical. He also stated that the human comfort zone lies in the region of 13 to 46°C (Zerkus et al, 1995).

2.4. PAIN

Thermal stimulus used in this thesis never reached a painful level, but it might be useful to provide with the "official" definition of pain offered by the International Association for the Study of Pain (IASP), "An unpleasant sensory or emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (Merskey & Bogduk 1994).

Nociceptors are specialized somato-sensory receptors, which are excited by a wide range of tissue damaging (noxious) stimuli. Nociceptors transduce all three forms of exogenous noxious energy (mechanical, thermal and chemical) into action signals.

2.5. AMBIENT DISPLAYS

In ambient displays information is moved off the screen in a way that makes use of the entire physical environment as an interface for digital information (Wineski, et al, 1998). Information is presented in subtle changes in form, movement, color, smell, temperature, or light. One example is the representation of activity by a pattern of illuminated patches projected onto a wall (Ishi, et al, 1998). Ambient displays seek to present information in the modality and form that can be interpreted with minimal cognitive effort. Ambient information is processed in the background. The person decides whether or not to move it into the foreground or back again. A person has the option to choose to focus his attention on ambient information displays at will. In the presentation of ambient media, one of the key elements is the modality chosen to present information. The choice of modality for the background media should be considered with the person's foreground task in mind.

Unfortunately, ambient displays are an emerging field and literature is limited. The area of notifications shares some similarities with ambient displays and has been studied extensively. Several studies in this area have shown that the nature of the display of notifications influences performance on the primary computing task. Maglio and Campbell demonstrated that continuously scrolling displays were more distracting than discrete displays to ongoing word editing tasks. They found that all notification styles reduced word-editing performance in comparison to a no-notification condition (Maglio and Campbell, 2000).

Ware, Bonner, Knight and Cater reported an experiment designed to test the use of simple linear motion as an attention-getting device for computer displays. A primary task required the transcription of a document typed into a word processor and a secondary task involved detecting and responding to a moving icon signal. The icon was a rectangular bar that grew and shrank vertically in an oscillatory fashion. Both the amplitude and velocity of the icon's motion were varied and response time recorded. The results showed that there was an inverse relationship between the velocity of the moving icon and time to respond to the icon movement, but no effect was found for amplitude. Observed response speeds appeared to indicate that simple motion was an effective attention-getting device for events in the periphery of the visual field. Their attention-getting device is similar to the device used in this thesis in that both work on the periphery of the user visual field. Their work also shows some of the implications of using ambient displays as interruption devices.

2.6. INTERRUPTIONS

The use of interruptions is a key issue in the design of human-computer interfaces. One observational study of workplace communication, in which two mobile professionals were shadowed with a camera for a full working week, showed that the recipient of an interruption benefits 64% of the time from being interrupted. However in 40% of the cases, the recipient of an interruption did not resume the task they were doing prior to the interruption (O'Conaill and Frohlich, 1995). Other studies investigating the effect of interruptions in highly abstract processes, such as software development, show that interruptions significantly reduce a developers' efficiency (Solingen, et al, 1998). Some researchers have examined interruptions by looking at when to interrupt users in a multitasking environment (McFarlane, 1999). Interruptions can be classified according to the way they are presented:

1. Immediate: user must instantaneously act in response to an interruption.
2. Negotiated: user selects when to attend to an interruption.
3. Mediated: an intelligent agent determines when is the best time to generate an interruption.

4. Scheduled: user prearranges time intervals for an interruption to appear.

McFarlane found that none of these methods was the single best way to interrupt users in tasks across all performance measures. He concluded that giving people the control to negotiate for the onset of interruptions resulted in good performance. However, he cautions that users may postpone attending to interrupting messages in these cases. Also, if forced to acknowledge an interruption immediately, users in his study got the interrupting task done promptly but were less efficient overall.

Other researchers have examined the length of interruptions, the similarity of interruptions to the main task, and the complexity of processing demanded by interruptions. Gillie and Broadbent, conducted a series of experiments investigating why some interruptions are more disruptive than others. The experiments utilized a computer game in which subjects navigated to different locations collecting specified objects along the way. In each experiment, the interruption dimensions of length, similarity, and complexity were manipulated to better understand their disruptive effects. The authors concluded that the length of an interruption (from 30 seconds to 2.74 minutes) does not affect how disruptive an interruption is perceived, that is, the length of an interruption is not a factor in determining whether one interruption is more disruptive than another. They also discovered that interruptions with similar content could be quite disruptive even if they are extremely short, replicating findings in earlier work by Kreifeldt and McCarthy. They found that interrupting a user while performing a series of calculator-based tasks, caused subjects to complete those tasks slower than when performing without interruptions (Gillie and Broadbent, 1989) (Kreifeldt and McCarthy, 1981). On contrast, Zijlstra measured the effects of interruption frequency and complexity on a user's emotional state and task performance. The authors found that interrupting users during a document-editing task caused them to complete the task faster than when performing the same task without interruption. The more often a user was interrupted, the faster that user completed the task (Zijlstra, 1999).

Contrary to the work presented by Gillie and Broadbent, recent work from Czerwinski found that interruptions that were relevant to ongoing tasks were less disruptive than those that were irrelevant. Czerwinski designed an experiment to measure disruption of instant messaging interruptions and used the times required for the user to move from the primary task to the notification, the time to read notifications, and the time to return to the primary task, as measures of disruption. Czerwinski also found that the costs of disruption depended on the nature of the ongoing task or subtask (Czerwinski, 2000). In the experiment presented by Czerwinski, users navigated a list of items searching for a book title. The difficulty of remembering the goal when returning from a notification was manipulated by altering the type of search target, assuming that these tasks were cognitively more demanding, requiring more resources for recall: 1) Verbatim title of the book, which made the task a relatively straightforward visual scan with little cognitive demand. 2) Gist, it provided with a general description about the book to get. The experiment presented in this thesis uses fixed order lists to impose a cognitive load on subjects and a similar search task. Czerwinski used total task time, time to switch to a notification and time spent on a notification when one occurred, as measures of interruption.

Hess and Detweiler found that if an interruption imposes a high memory load on the user, it is harmful to the primary task. They showed that interruptions that were similar to an ongoing computer task are quite disruptive over the first two of three sessions, but are significantly less disruptive by the third session. In addition, they found that, if participants are allowed to train on the primary task without interruptions for two sessions, then presenting a third session with interruptions is significantly harmful to performance, despite the user being highly trained (Hess and Detweiler, 1994). Because experience handling the interrupting tasks reduces their harmful effects over time, the experiment used training session to familiarize subjects with the expected interruptions, but a learning effect is still possible.

More recently, Brian Bailey described an experiment measuring the effects of an interruption on a user's task performance, annoyance, and anxiety in the user interface. Their key findings are that a user performs slower on an interrupted task than a non-interrupted task, the level of annoyance experienced by a user depends on both the category of primary task being performed and the time at which a peripheral task is displayed, a user experiences a greater increase in anxiety when a peripheral task interrupts his primary task than when it does not, and a user perceives an interrupted task to be more difficult to complete than a non-interrupted task (Bailey, et al, 2000). This thesis supports these findings in that users with interrupted tasks have slower performance than non-interrupted tasks. The research proposed in this thesis goes a step further by looking at what is the effect of different modalities of interruption on performance. Since we already know performance decreases for interrupted tasks, this work shows that performance decreases at different degrees depending on the interruption modality used.

2.7. SUMMARY

This chapter presented some of the physiological aspects of vision and thermal perception necessary for the understanding of the possibilities of building ambient displays to present information via the sense of vision and the sense of touch. Ambient displays were introduced as an information medium that uses the entire physical environment and was shown they can be used as interrupting devices. This chapter also discussed on some aspects of and pain because of its close relationship to thermal ambient displays. Interruptions are presented as a key issue in the design of computer interfaces by showing several studies designed to study the effect of interruptions.

CHAPTER 3

EXPERIMENTAL DESIGN

3.1. EXPLORATORY EXPERIMENT

A pilot experiment designed to test the effect of different modalities of interruptions measured the performance of participants in a task interrupted with five modalities of interruptions: heat, light, smell, sound, and vibration. The test without interruptions served as the control condition. The experiment exploited research showing that interrupting people affects their behavior, such as anxiety level, performance level (Van Bergen, 1968).

The task combined reading passages and counting backwards. Participants performed this combined task while being interrupted with five modalities randomly. Performance in the task with "no-interruption" served as the baseline to compare to performance with the "interruption" condition. A comprehension test applied after the end of each section, measured memorability about each section read. After the experiment ended, participants ranked all interruption modalities by their disruptive level from a most to least order.

The goal for the pilot study was to get a lay of the land for modality and interruption. For this pilot study not enough subjects were evaluated as to have enough power for statistical analysis for five modalities. In any case, the study did yield interesting and provocative results. The post-test questionnaire does indicate the modalities ranking according to participants are quite different. Further investigations could rank interruption modalities by their disruptive effect. The question as to which parameters reflect the effect of interruption modalities is not yet answered

3.1.1Results

The experiment showed that the rate of appearance and novelty effects must be taken into consideration when designing a follow-up experiment to appropriately test the effect of interruption modalities. The least used modalities in computer interfaces apparently had bigger disruptive effects, probably because of their novelty, some perhaps because of the appearance rate.

Experiment observations and subjects' comments relating to the experiment also suggest that each interruption modality affects them differently. Indicating there is some potential in testing the effect of different modalities when used as interruptions.

3.1.2 Discussion

Observations from this experiment indicate that it might be best to test all interaction possibilities using a single experiment. It is preferable to narrow the scope of this work by focusing on a reduced number of modalities, performing pair-wise comparison of modalities, and identifying well defined parameters to test the effect of interruption modalities.

This exploratory experiment also showed it was necessary to use accurate devices to generate interruptions. The devices used for this experiment were calibrated manually, adjusting the intensity and rate of appearance according to what was perceived by the evaluators. Manually controlling interrupting devices introduced error when presenting each of the modalities. Therefore, to avoid this effect in future experiments, ambient displays should be entirely computer-controlled to deliver stimulus on time. The use of computer-controlled devices provides precision and the ability to calibrate these devices, necessary to provide reliable and comparable stimulus.

Since the end goal is to build a computer interface, then the type of task used to analyze interruptions for such an interface should be computer-related. This task should be similar to a task in which people have some familiarity and already perform on a regular basis, such as playing computer games. A real task also offers the advantage of providing many more performance indicators and people are have already some familiarity with them. For these reasons, a computer game was designated as the task to use in a follow-up experiment. It also has the advantage that will keep subjects engaged in the game and interested at the same time.

3.2. FOLLOW-UP EXPERIMENT

This experiment was designed for testing the effect of different modalities when used as interruptions. The experiment attempts to answer the question about what are the parameters a computer interface could use for determining the proper interruption modality to use. Tactile and visual are the modalities examined in this research. Tactile displays have recently been explored, but more in the form of vibration (Tan, et al, 1997). Neurophysiological studies have shown that fingers and hands are one of the most sensitive areas of the body and have relatively large areas of representation in the cortex (Penfield, et al, 1950). Thus, heat was used as a novel ambient display to generate interruptions. Since fingers and hands are also well represented in the somatosensory cortex, they provide with an excellent channel for computer interfaces. A preliminary experiment showed that heat was a good interruption modality because of its novelty and its sense of immediacy. This exploratory experiment also proved light was a good interruption modality because of the domination of the visual system over other senses

The experiment is greatly influenced by the methodology proposed by McFarlane, who presented the first empirical comparison to the problem of coordinating user-interruption in HCI (McFarlane, 1999). This experiment is also based on the research presented by Gillie and Broadbent where they explored the effects of length of interruptions, the similarity of interruptions to the main task, and the complexity of processing demanded by interruptions. They conducted a series of experiments investigating why some interruptions are more disruptive than others. The experiments utilized a computer game in which subjects navigated to different locations collecting specified objects along the way (Gillie and Broadbent, 1989).

The interruption of people during human-computer interaction is a high-level interdisciplinary topic. Background literature also shows that interruption is a complex process that involves many subtle low-level mechanisms of human cognition. However, these individual mechanisms are not the focus of this experiment. It was judged that a simplistic and typical task like those used in studies about low-level topics of human cognition, would be inappropriate for this experiment. A reasonably complex experimental task had to be found to elicit people's cognitive load at an appropriate high level. It is possible to investigate the process of interruption at the level of user interface design without fully understanding the many subtle low-level cognitive mechanisms involved (McFarlane, 1999). In this experiment, the smaller effects were ignored and isolated from the high-level effects by looking only into several aspects of the human-computer interaction.

A second pilot experiment with two modalities attempted to use a computer-related primary task, consisting of a 3D graphical maze game. Real time skilled tasks are common in work as well as games. Subjects had to tilt the maze to direct a ball toward its destination in the center of the maze. See figure 3 for a screen shoot of the maze used for this pilot study. Subjects demonstrated some familiarity with the game, but several trials showed this task was mechanically demanding rather than cognitive demanding. Even thought a 3D graphical game was similar to a real-life task and subjects' were familiar with it, a more cognitive demanding task that could provide with more performance and disruptiveness indicators had to be used. This pilot experiment showed that a computer game has the advantage it will keep subjects engaged in the game and interested before subjects' attention starts to decrease at the same time.

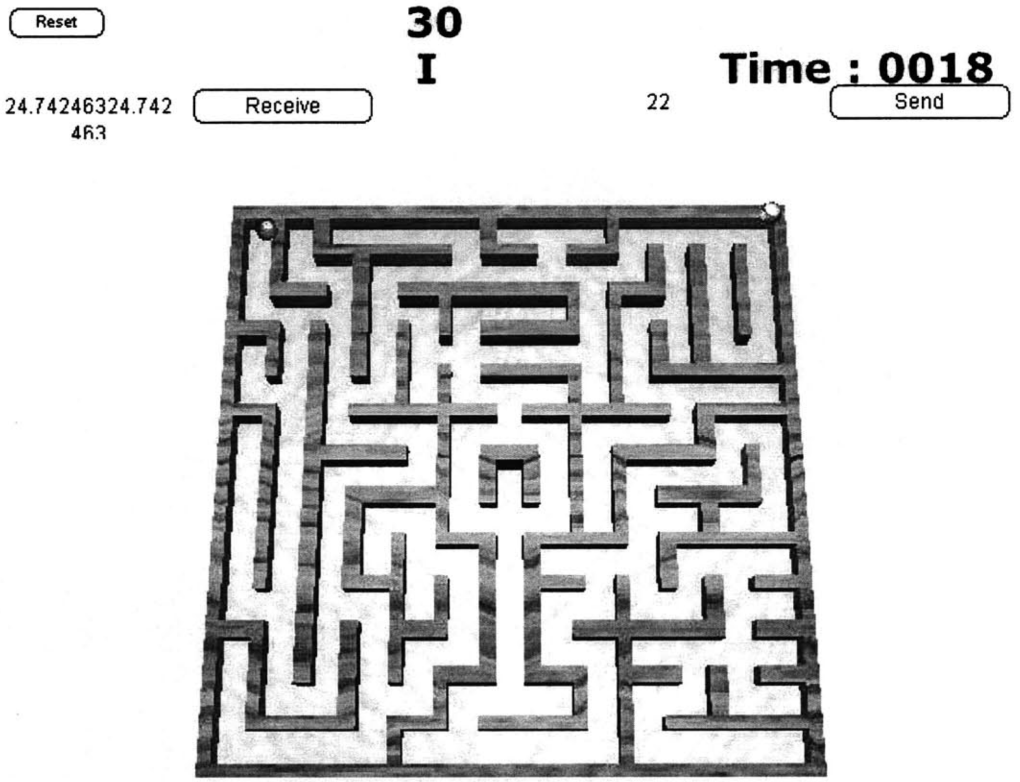
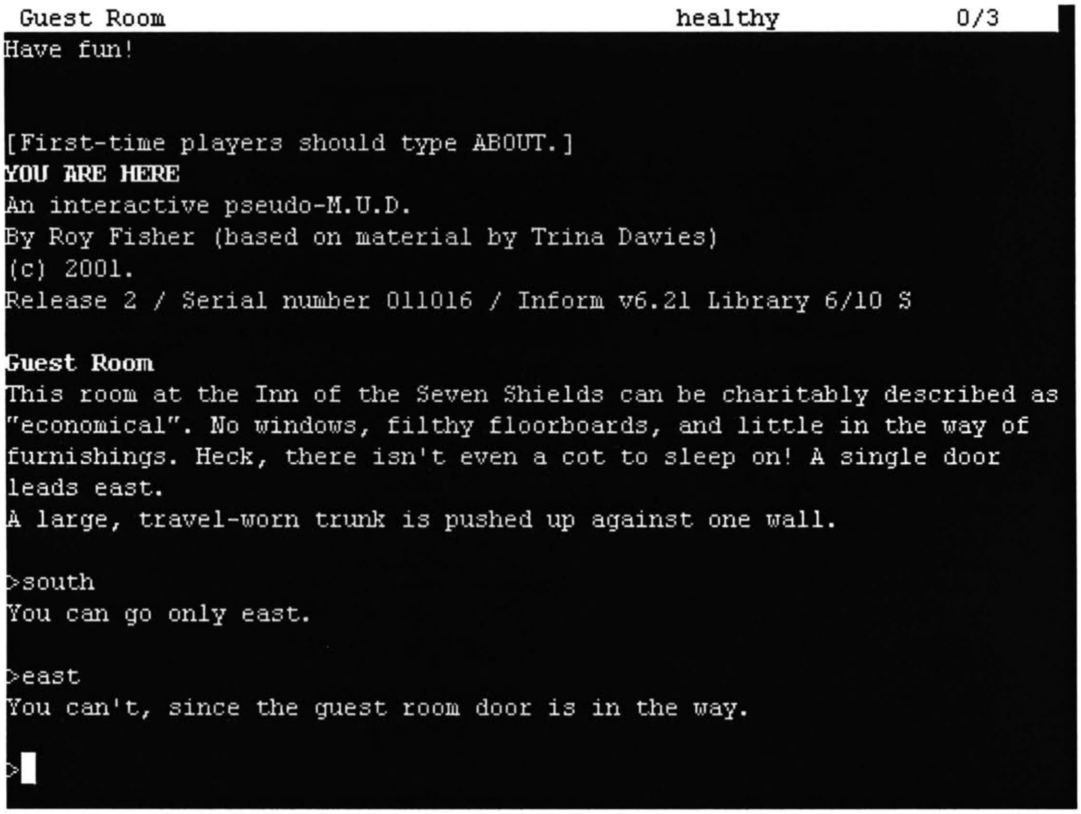


Figure 3 Graphical maze task was mechanically demanding rather than cognitive demanding [http://www.havok.com]

An abstract task was chosen. It is a simplified model of common real world tasks. Examples of people performing this type of tasks are software developers. A debugging task, for example, requires a software engineer to identify and maintain track of variable values as they change over the execution of the software. A software engineer has to create a mental grid and memorize several values while looking for the next line of code to execute. These identification and tracking tasks impose a high cognitive load and interruptions during this process causes errors, allowing for observations of subjects' responses to be easily broken down into discrete units. This task relates to tasks involving navigation and memory, such as installing software where the user has to keep track of several configuration setting while performing this activity.

For the reasons presented before, the experiment is set in the context of a computer-based adventure game, similar to online Multi user Dungeon (MUD) games, where the player has to issue commands to the computer in order to achieve certain goals. Gillie, et al and Lewis used this approach in 1985 and 1989 respectively. They used a program to model a small geographic area with a number of locations that could be reached by issuing directional commands available from a list of options.

A MUD (Multi-User Dungeon or, sometimes, Multi-User Dimension) is a network-accessible, multi-participant, user-extensible virtual reality whose user interface is entirely textual. Participants have to type commands on the keyboard and the computer displays text corresponding to the action taken. Figure 4 shows an example of this type of interaction in a MUD game. Participants have the appearance of being situated in an artificially constructed place.



```
 Guest Room                                    healthy             0/3
Have fun!


[First-time players should type ABOUT.]
YOU ARE HERE
An interactive pseudo-M.U.D.
By Roy Fisher (based on material by Trina Davies)
(c) 2001.
Release 2 / Serial number 011016 / Inform v6.21 Library 6/10 S

Guest Room
This room at the Inn of the Seven Shields can be charitably described as
"economical". No windows, filthy floorboards, and little in the way of
furnishings. Heck, there isn't even a cot to sleep on! A single door
leads east.
A large, travel-worn trunk is pushed up against one wall.

>south
You can go only east.

>east
You can't, since the guest room door is in the way.

>
```

Figure 4 Text-based MUD screenshot

3.2.1. Hypothesis

The experiment was designed to test three hypotheses regarding the effect of different modalities when used as interruptions, and an alternative hypothesis regarding the effect of subject's preferred interruption modality:

1. Disruptiveness of interruptions when playing a text-based adventure game will vary with the interruption modality. That is, Disruptiveness before and after an interruption is different.
2. The interruption modality will affect users' performance when playing a text-based adventure game. That is, Performance before and after an interruption is different.
3. Light is more effective than heat as an interruption in a text-based adventure game.
4. If subjects are interrupted by their preferred modality, then their performance won't be affected as much as if they were interrupted by another modality. A post-test questionnaire was expected to provide with the necessary information to test this hypothesis.

3.2.2. Method

The experiment asks subjects to perform a high level cognitive task; consisting of a text-graphic hybrid adventure game. The task is a computer game that presents a challenge to subjects and keeps them engaged playing the game. The subject's task is to read directions, memorize a list of items presented to them, explore several locations around a small geographical area, create a mental map about the location and its contents, take objects in the specified order, and decide the next location to go to. The task generates a high cognitive load and it is similar to a real life scenario. In fact, playing a game is an event that people often do when using their computers, and that is how MUDs where born in the first place. This task provides with enough performance and disruptiveness indicators, such as score, speed, error rate and overall time.

This primary task is similar to other task used by other researchers when examining interruptions. Czerwinski presented an experiment where subjects navigated a list of items searching for a book title. He used a memory task to look for effect of disruption; the difficulty of remembering the goal when returning from a notification was manipulated by altering the type of search target, assuming that these tasks were cognitively more demanding, requiring more resources for recall. The task selected for the experiment in this thesis uses fixed order lists to impose a cognitive load on subjects and can be seen as a search task, similarly to the task used by Czerwinski.

Other researchers have used computer-based adventure games to investigate the effects of interruptions. Gillie and Broadbent utilized a computer game in which subjects navigated to different locations collecting specified objects along the way (Gillie and Broadbent, 1989). McFarlane created and used an interruption-laden computer-based multi-task composed of a contiguous video game and an intermittent graphical matching task. The game task consisted of a video game by Nintendo Corporation called "Fire". The graphical matching task is modeled after the matching tasks used in experiments of the Stroop effect; it required subjects to make matching decisions either based on color or shape (McFarlane, 1999).

While subjects are performing the primary task, an ambient display device attracts the participant's attention by changing temperature or by changing light intensity. Users have then to acknowledge the interruption and perform a secondary task. For this task subjects have to read a list of words related to the same topic, similar to a free recall test. Interrupting messages are organized into networks of associated ideas, so that information that fits a schema may be easier remembered. Every message was developed to contain several highly associated words based on the work carried out by Roediger. They used pre-established association strength norms to create lists for experiments involving creating false memories and cognition (Roediger and McDermott, 1995). The lists of words presented throughout the entire experiment are categorized into four groups: rough, sleep, rain, and chair. See appendix D for a list of interrupting words used. This dual-task of the experiment is conceptually simple, but difficult to perform because of the high cognitive load.

The experiment has twelve randomly presented trails; each of them contains a fixed-ordered list with six items with in the same category norm (Battig, 1969). Those items are distributed randomly in a geographical area contained in a 5x5 matrix where subjects navigate. Once subjects have taken all six objects, the next trial is presented. Interrupted trials, as well as the time to interrupt (between the third and fourth item) are also randomly selected.

In this experiment, disruptiveness is defined as the error rate produced by the interruption modality in the primary task (playing an adventure game). Performance is defined as the time spent and velocity of movement when taking objects. Effectiveness is defined as the time taken by the user to acknowledge an interruption.

3.2.3. Dependent Measures

There are several measures from the game that describe the effect of interruption modalities. These measures were grouped into three main categories: disruptiveness, performance, and effectiveness.

Each of these categories supports the first three hypotheses in the experiment. The combination of other measures (a fourth category) and these categories support the fourth hypothesis related to the effect of the preferred modality on performance and disruptiveness.

The program monitored subject's performance during the duration of the entire experiment by recording commands issued, errors committed, reaction times, modality used, and other measures. This section describes the four categories where all these measures are grouped.

3.2.3.1. Disruptiveness group

Disruptiveness is the most interesting group because it reflects a direct effect from interruption modalities. Measures for this group include the number of reminders before and after an interruption, the number of requests for inventory before and after an interruption, the number of errors taking the wrong object before and after an interruption, the number of errors going in the wrong direction before and after an interruption and the time taken to recover from an interruption.

3.2.3.2. Performance

Measurements of performance include the time spent to take each object before and after an interruption, and the time spent deciding before selecting any option; this term could also be defined as speed.

3.2.3.3. Effectiveness

There is a single measurement for effectiveness and it is related to how fast each of the modalities is noticed. This measurement is the time taken to acknowledge an interruption message; this term could also be defined as reaction time for each modality.

3.2.3.4. Other measurements

Other measurements taken for descriptive purposes and for user input include a subjective evaluation to preferred modality, and an open questionnaire about subject's experiences with the two modalities used.

3.2.4. Material

3.2.4.1. Light/ Visual Ambient Display

A lamp, as a traditional ambient display presents information according to its level of intensity. This information is constantly present and in the background. Traditionally, on of the user's task is to focus their attention on an ambient display and bring it to the foreground. This experiment; on the contrary, explores the transition in an ambient display from the background to the foreground. For this experiment, an ambient display light behaves as an interruption moving from the background to the foreground by itself when necessary. A light controller controls the power going to a bed lamp located at the periphery of subject's field of view, approximately at a 45-degree right to the screen. The game application sends a desired brightness level ranging from 5% to 95% through a serial connection with the controller. A detailed explanation can be found in the implementation section of this thesis.

3.2.4.2 Thermal Ambient Display

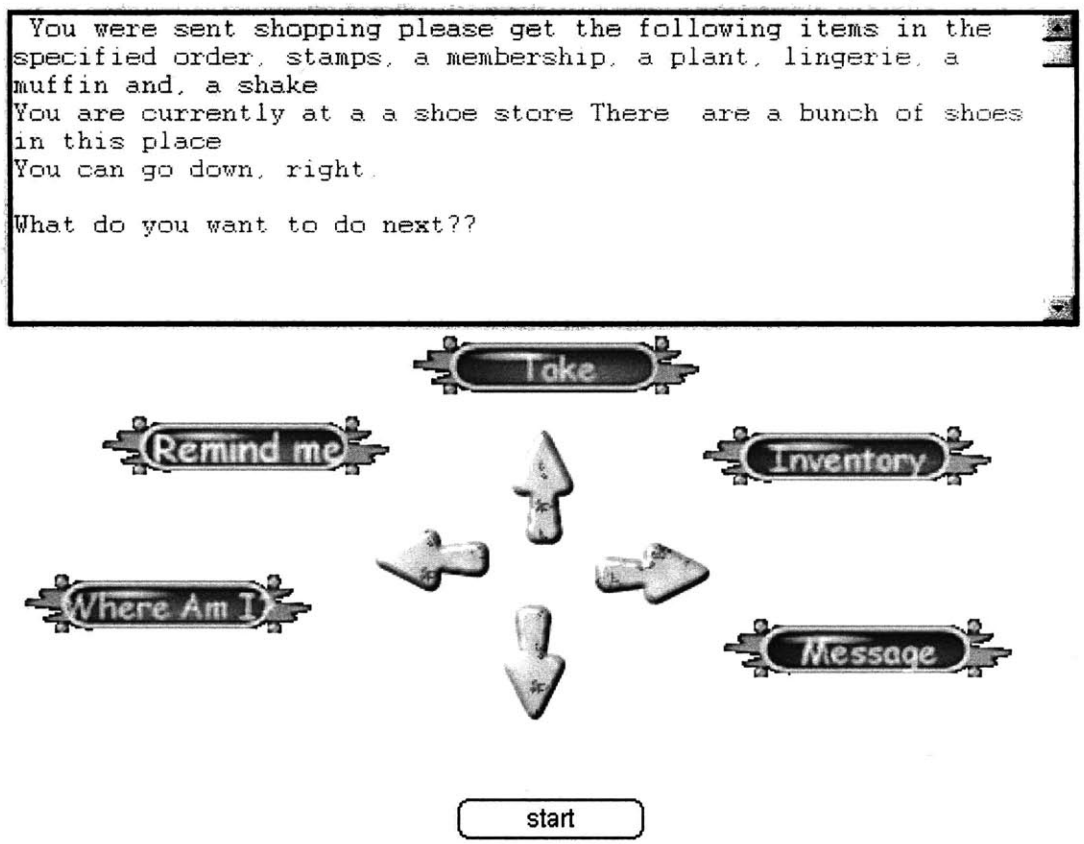
Three peltier devices connected in series fixed into a copper mouse pad compose a heating device. This Thermo-mouse pad has the ability to warm a wide area that is in contact with the user's hand. Temperature moves from ambient temperature to a warmer temperature at a rate of about 1 °C per second. The temperature range goes from 22°C to 40°C.

A temperature controller uses closed loop feedback and PWM modulation to control the amount of power going to the device. This controller receives the desired temperature the trough a RS-232 serial link from the game interface whenever an interruption is required. A detailed explanation of the functioning of the thermo-mouse pad can be found in the implementation section of this thesis.

See appendix A for a detailed explanation of the implementation and functioning of ambient displays used in this thesis. This appendix also includes a description of the required technical information to replicate these devices.

3.2.4.3. Adventure-based Graphical Game

This experiment simulates a hybrid version of a MUD game. The game application was designed and implemented using Macromedia Director, a multimedia design tool. The application developed combines a text-based game and a graphical game. Figure 5 shows an implementation of the application interface developed. All information pertaining the game is presented using a text window and the user interacts with the game using mouse clicks. Using a mouse to interact with the computer rather than a text only interface is a requirement of the heat interface so that subjects could support their hands on top of the thermo-mouse pad. The experiment used a MUD hybrid windows application running on a IBM Thinkpad laptop. The application shoe five options (buttons) available.



```
 You were sent shopping please get the following items in the
specified order, stamps, a membership, a plant, lingerie, a
muffin and, a shake
You are currently at a a shoe store There  are a bunch of shoes
in this place
You can go down, right.

What do you want to do next??
```

Figure 5 Hybrid MUD window application developed.

3.2.4.3.1. Options

Pressing this button presents a description of the user current location and objects available at that location. The application shows subject's current location by default, subjects need to use this button only after another option has been selected and the information is no longer available on the screen. The option is available at all times. The following is an example of the information provided by this option when the user enters a restaurant:

`"You are currently at a fast food restaurant. There are hamburgers and fries at this place. You can go right and down"`

Remind Me

Pressing this button reminds the user of the task at hand. Conceivably subjects are expected to press this button after coming from an interruption and whenever they need to be reminded of the list of items to take. This option is available at all times. The following is an example of the information provided by this option when the user needs to go grocery shopping:

`"You need to do some shopping; get these items in order: a home video, a music CD, a magazine, some stamps, holiday brochures, and some books"`

Take

Pressing this button takes the object present at the current location. When subjects enter a location, the application displays the item present at such location. Subjects can then take it if necessary. The application warns if subjects attempt to take the wrong item, or in the wrong order, it also warns if there are no items at all. The following are examples of the described interaction using stamps at the item to take:

`"Stamps taken successfully"`

`"You are not allowed to take stamps at this time, try a different order. Click on 'Remind me' for a reminder of the things to get"`

`"There is nothing to take"`

`"There is nothing to take anymore. Object already taken"`

Inventory

Pressing this button displays a list of items that were already taken. The application also shows when no objects have been taken yet. Subjects are expected to use this button after coming from an interruption. This option is available at all times. The following is an example of the type of interactions this option provides:

`"Nothing taken yet"`

`"Inventory: a home video, a music CD, and a magazine"`

Message

Pressing this button displays a message when an interruption is present. Subjects acknowledge an interruption whenever any of the ambient displays move from the background to the foreground.

Pressing this button for a second time closes the interruption message. This option is only available when the application decides it is time for an interruption. The following is an example of the type of messages available. See appendix D for a list of all messages used.

`"Please read this words CAREFULLY aloud: pillow, awaken, comfort, peace, slumber.`

3.2.5. Calibration Pilot Study

A total of 5 subjects assisted to test and calibrate the devices used. During the first trials, light appeared to be significantly faster than heat, as a matter of fact, they were completely dissimilar. Light revealed itself suddenly, whereas heat did it slowly at intensity that couldn't be perceived by some subjects. It was necessary to use an alternative power supply that would deliver more power to the thermo-mouse pad to increase the thermal stimulus. This study was designed to calibrate the thermal and visual stimuli as to make them of equal salience. This was crucial in order to be able to compare the effect of each of the modalities when used as an interruption. Ambient displays were calibrated to have a similar rate of appearance. A rate of appearance of 4jnds/sec was determined by comparing the rate of appearance for heat and light Vs. Reaction time. This rate is also based on the physical limitations from both ambient devices. Light increased 40% luminosity every second. Temperature increased 0.82°C every second.

3.2.6. Procedure

The computer game presents subjects with a series of problems; each problem contains a list of six items that need to be taken in a fixed order. Miller considered that fixed plans would use more working memory than flexible plans, and that fixed plans would tend to be recalled more often after interruptions (Miller, 1960). Also, Gillie compared the effect of flexible plans with arbitrarily fixed order plans and with logical fixed order plans, and reported that people performed similarly across the three types of problems (Gillie, et al, 1989). Miller's study motivated the use of fixed order lists in this experiment because it suggests that fixed lists will tend to be recalled more often. This would reduce the effect from the interruption itself and increase the possibility to detect the effect coming from the interruption modalities. Also, choosing a single fixed order reduces the number of factors involved in the experiment.

Twelve plausible stories embed the fixed-ordered list of items. The following is an example of the type of stories presented (See appendix B for a complete list of stories and items used):

`"You are planning to go on vacation to a foreign country and you need the following items in the specified order: brochures,` `some traveler's checks, a passport, a pair of sandals, a guidebook, and lotion"`

When subjects start navigating, the computer shows their current location and a description of objects present at that location. The computer then shows a list of possible directions in which users are allowed to go. Available options are Up, Down, Left, and Right. The computer presents available directions in randomized order to keep users from visiting each direction in a mechanical order and to force them to read information carefully. Also, since pilot studies showed that subjects were only looking at the change of words relevant to the contents of a location and were not reading entire descriptions and available directions. Every site contains "slightly" different descriptions to force subjects to read carefully.

The computer game presents a prompt after all interactions. This prompt is the same throughout the entire session and signals that the computer is waiting for user input. The following is an example of a subject entering a shoe store, which contains shoes:

```
"You are currently at a shoe store There is a big variety of
shoes in this place"
"What do you want to do next??"
```

The computer game presents the next problem after all objects from a trial have been taken. The order at which the computer presents each problem, as well as the choice of problems to interrupt is randomized. Non-interrupted problems serve as a baseline for comparison. The computer game also randomizes the interruption modality to use and presents it between the fourth and fifth item. This is done with the intention to keep subjects from expecting to be interrupted at each trial and at a specific item. Randomizing the order of presentation of the modalities also reduces any novelty effects that they might have caused.

Every subject performed a total of fifteen trials, three of them for practice and the rest of them as formal trials. At the end of each session, every subject produced four data sets per interruption modality: light interruption, heat interruption, and no interruption. See Appendix C for a list of all trials

The evaluator instructed subjects to acknowledge an interruption by clicking on the message button whenever he/she saw/felt a change in temperature/lighting conditions. After a subject acknowledges an interruption, the computer game displays a long and engaging message unrelated to the task at hand. This message is intended to disrupt subjects from their previous activity and serves as a secondary task. The following is an example of such message:

"Please read these words CAREFULLY aloud: pillow, awaken, comfort, peace, slumber.
Press Message button to continue…."

This message is closed by pressing the message button for a second time and cannot be read again. In order to force subjects to read interruption messages carefully, the evaluator instructed subjects to read the interruption message aloud and warned them that they would be presented with a free recall test at the end of the experiment. But no test was actually used. Subjects familiarized themselves with the game during three practice sessions and asked questions when necessary only at this time.

3.2.7. Results

For ease of readability, the results after evaluating the dependent variables are presented in four categories: performance, disruptiveness, effectiveness, and other measure. All of which support the hypotheses stated previously in section 3.2.1

3.2.7.1. Performance

In order to verify the data from an effect inherent to the trials, a One-way repeated measures analysis of variance ANOVA applied to the time to take each object before an interruption revealed that there is no difference in the time used to take each object before an interruption, F(2,44) = .352, p>0.705. This indicates, that subjects' performance is similar for all trials before any stimulus or interruption is present, as it should be because no interruption has happened yet. This also confirms that if there is an effect in performance before and after an interruption, it is caused by interruption and not by mere practice on the game.

3.2.7.1.1. Time to take object

A One-way repeated measures ANOVA applied to the time to take each object after an interruption revealed that there is significant difference in performance caused by interruptions. The Huynh-Feldt epsilon was applied to the degrees of freedom to account for violation of the sphericity assumption, F(1.6, 36) = 819.47 p<0.0005. Pair-wise post hoc comparison revealed that there is a significant difference in performance after an interruption for non-interrupted tasks (20.32secs. per objects) Vs. interrupted tasks with heat (32.25secs. per object) and light

(25.32secs.pero object), F(1,22)= 30.89, p<0.0005, F(1, 22) = 6.47, p<0.19. This comparison also revealed no significant difference between heat and light modalities F(1, 22)= 3.895, p>0.061.

The data was entered into a one-way repeated measures ANOVA with two levels (before interruption, and after interruption). There is a significant effect of modality of interruption, F(1,68)= 19.145, p<.0005. Pair-wise repeated measures showed statistical significance for light, F(1,22) = 8.79, p<0.007, and no-interruption, F(1,22) = 30.61, p<0.0005, but no significance for heat F(1,22) = .083, p>0.766. See figure 6.

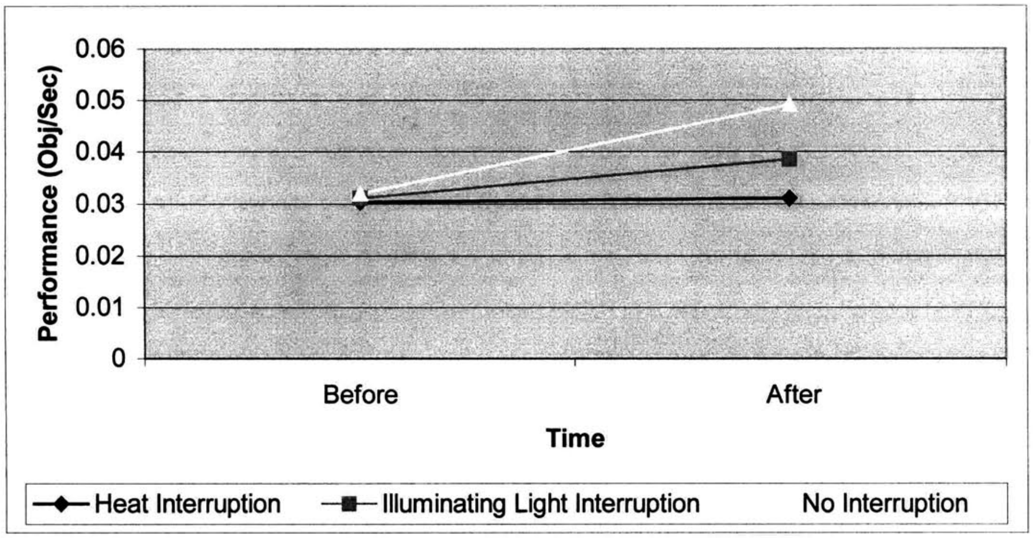


Figure 6 Effect of interruption modality on time to take each object

3.2.7.1.2. Performance difference

A one-way repeated measures analysis of variance ANOVA with modality used as the repeated variable (no interruption, heat interruption, and light interruption) and performance difference as the dependent variable. The ANOVA showed statistical significance in the effect of modality in performance change, F(2, 46) = 9.06 p<.0005. There is an increase in performance after being interrupted of about 0 .74secs for heat, 6.24secs for light and 11.03secs for no interruption. See figure 7.

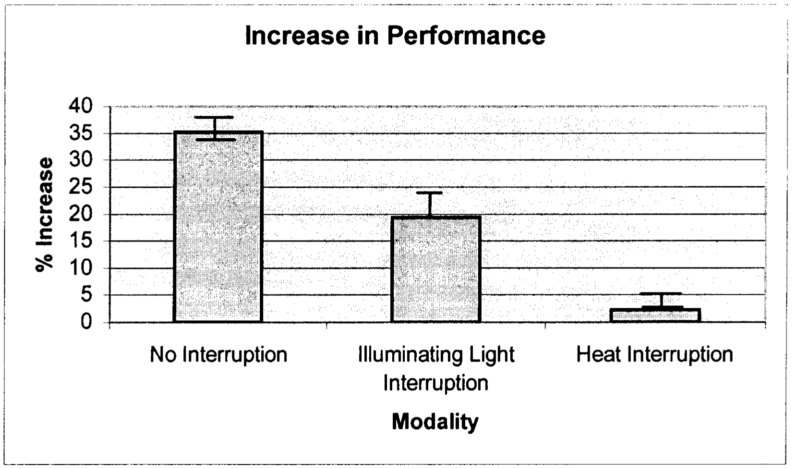


Figure 7 (%) Increase in performance after interruption

3.2.7.1.3. Overall Speed

A one-way repeated measures ANOVA showed that there was a significant effect of modality in overall speed, F(2,44) = 5.246 p<.004. Post hoc analyses indicate significant difference for non-interrupted tasks Vs. interrupted tasks, F=(1, 22) = 5.027 p<.035, F(1, 22) = 8.38 p<.008. But no significant difference between interrupted tasks heat and light, F(1, 22) = .916, p >0.349. Numerically, non-interrupted task were performed slightly faster (2.62secs.) than interrupted tasks with heat (2.76) and light (2.82). See figure 8.

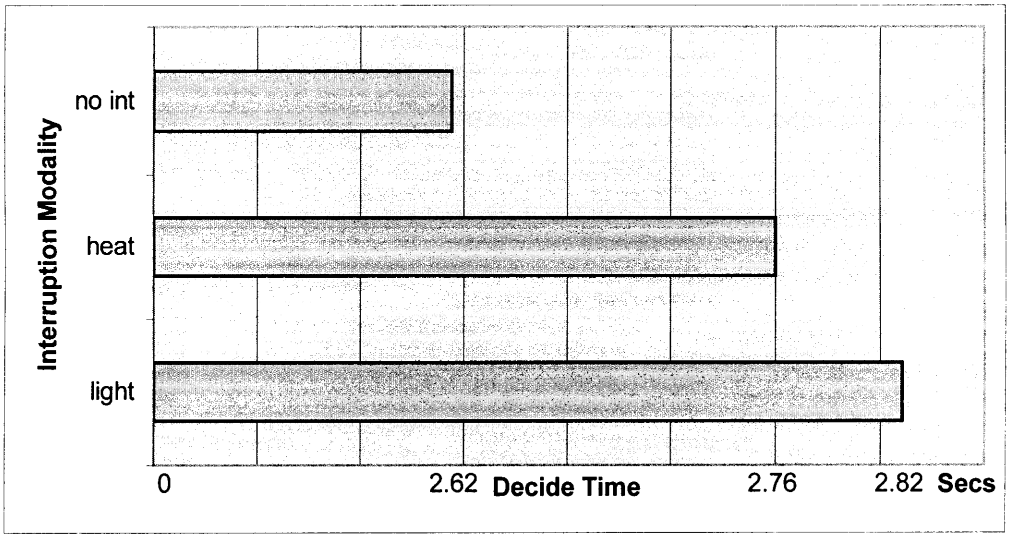


Figure 8 Average decide time per interruption modality.

3.2.7.2 Disruptiveness

Examining the variance on error direction before an interruption using a one-way repeated measures ANOVA revealed, contrary to what was expected, that there is a significant difference in the number of errors before an interruption for each of the modalities (10.42 errors for heat, 14.43 for light, and 9.7 for no interruption), F(2,44) = 3.636, p>.035. This significant difference on this measure casts doubt in conclusions made using error direction.

Some subjects surfed the game, some subjects moved onto the corners until an error was reached, some thought carefully about their next move, and some other committed multiple errors at the same location because were not paying attention to the information presented.

3.2.7.2.1. Error direction

One-way repeated measures ANOVA applied to the number of errors in direction after an interruption for heat and light revealed that there is a main effect from interruption modality on error, F(1, 22) = 5.478. p<0.029. Error rate for heat was 0.45 errors per trial and 0.21 for light. A one-way repeated measures ANOVA compared the number of errors before an interruption vs. number of errors after an interruption and found there was a significant effect of interruption F(1,45) = 19.855 p<0.0005. Pair-wise repeated measures applied to light (-4.84 error difference) and heat (-2.88 error difference) modalities before and after an interruption showed statistical significance. F(1,22) = 12.757, p<0.002 and F(1,22) = 7.23, p<0.013 respectively. See figure 9.

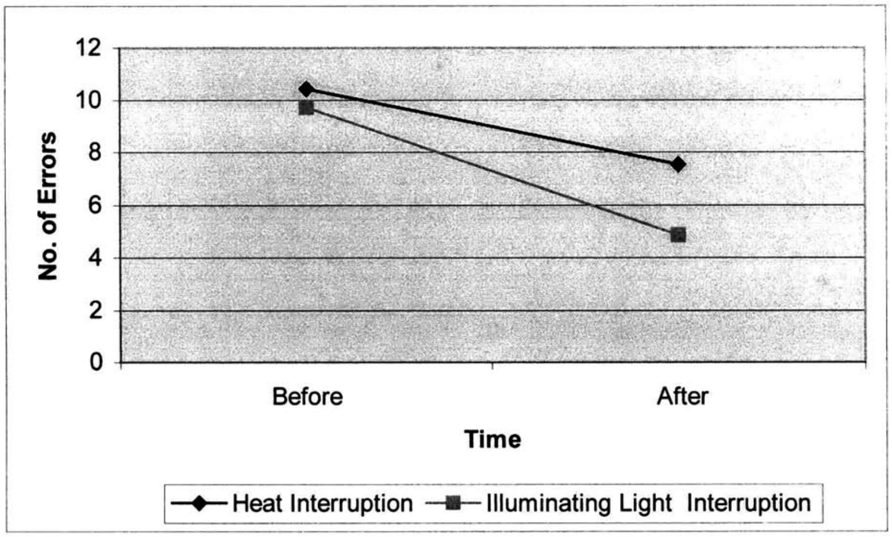


Figure 9 Effect of modality on number of errors

This measure shows there is a decrease of the number of error after an interruption. This reduction is more noticeable when using light as the interruption modality than heat.

3.2.7.2.2.Error object

As a preventive measure, a One-way repeated measures ANOVA applied to the number of error taking wrong objects before an interruption revealed, as expected that there is no difference in error taking wrong objects before the interruption F(2, 44) = 1.32 p>0.277. A one-way anova after the interruption indicated there is not a significant difference in the number of errors committed after an interruption. F(1,22) = .196, p>0.40. Also, there is no significant effect from interruptions in the number of errors before and after, F(1,45) = 3.052 p>0.087. No further analysis was necessary for this factor.

3.2.7.2.3. Help requested

As a preventive measure, a one-way repeated measures ANOVA applied to help requested before an interruption revealed, as expected that there is no difference in help requests before an interruption. The Huynh-Feldt epsilon was applied to the degrees of freedom to account for violation of the sphericity assumption, F(1.09, 25) = 2.171 p<.152. There was no significant difference in the number of requests for help after the interruption F(1,23) = 0.275, p>0.605. There is also no significant effect from interruptions in the number of requests for help before and after an interruption, F(1,25)=3.222, p>0.079. Since there was no effect no further analysis were necessary to compare heat and light.

3.2.7.2.4. Reminders

As a preventive measure, a One-way repeated measures ANOVA applied to the number of reminders before an interruption revealed, as expected, that there was no difference in requests for reminders before an interruption F(2, 44) = 1.438 p>0.248. A one-way repeated measures ANOVA after the interruption indicated there is not significant difference in modality in the number of requests for help after an interruption. F(1,22) = 0.081, p>0.778. There is also no significant differences between modalities for the number of requests for help after the interruption F(1,23) = 0.275, p>0.605. With 0.89 reminders requested for heat and with 0.84 reminders requested for light. There is a significant effect of interruption in the number of reminders requested before and after an interruption, F(1,45) = 21.454, p<.0005. Pair-wise repeated measures applied to heat and light modalities before and after an interruption showed statistical significance, F(1,22) = 6.98, p<.015 and F(1,22) = 16.38, p<.001 respectively. See figure 10.

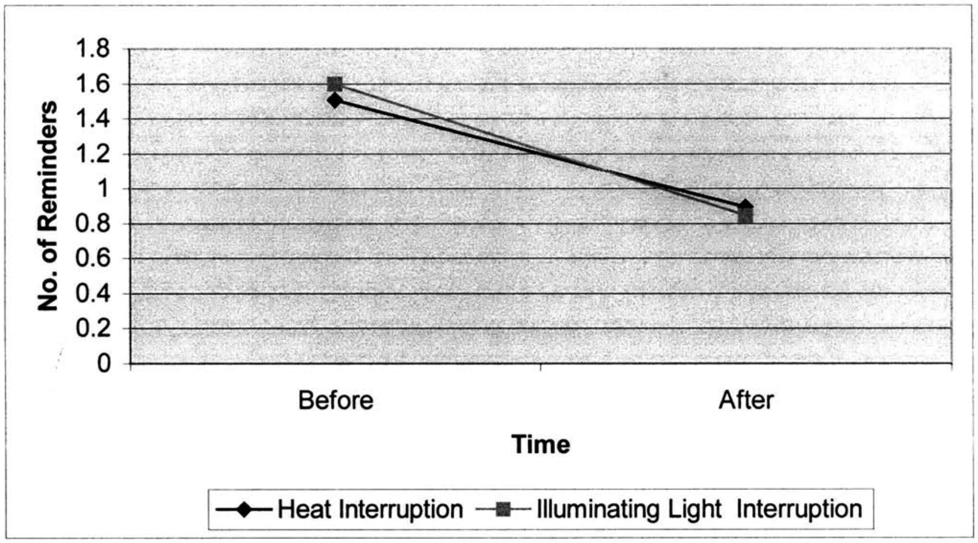


Figure 10 Effect of Interruption on number of reminders requested

3.2.7.2.5. Recover time

A one-way repeated measures ANOVA showed that there was no main effect of interruption modality in recover time, F(1, 22) = 1.132 p<.299. Numerically recover time for heat (4.4secs.) was longer than for light (3.1secs.). This numerical difference agrees with the effect of heat on performance. Heat has detrimental effect in performance, and it also appears to also have a detrimental effect on recover time, although with no statistical significance.

3.2.7.3. Effectiveness

3.2.7.3.1.Reaction time

Measures of reaction time associated with the time to acknowledge an interruption were tested for differences with one-way repeated measures analysis of variance. The analysis indicated that there was a significant difference in reaction timed for heat (9.60secs.) and light (5.50secs.), F(1, 22) = 7.76, p<.011.

3.2.7.4 Other measurements

Subjects' ability to remember the list of words presented to them when interrupted had no comparison. The task was mentally demanding that kept subjects from remembering any of the groups of the lists presented to them during each interruption. Very few subjects were able to remember two out of the four general topics in which the interrupting words were divided.

3.2.7.4.1.Preferred modality

Subjects were asked to choose their preferred modality subjectively based on their experience with it. 40% of the subjects selected heat as their preferred modality, and the remaining 60% of the subjects selected light. One-way repeated measures ANOVA showed that there was no main effect of preferred modality in performance difference, F(1,22) = 1.374, p>.254, neither in speed, F(1,22)= .006, p>.94.

3.2.7.4.2. Open questionnaire

One surprising comment about heat was that it made subjects worry about being hurt. In general heat was perceived as a dangerous threat. It was also generally mentioned that heat is slower than light, and thus harder to detect. Interestingly, although heat was harder to detect, it was also harder to ignore once it was present. This is probably to the fact that subjects associated heat with danger, and as a consequence, did not dared to ignore heat, anticipating that it could burn them. Whereas a light could be postponed until the task at hand had finished. Light, as opposed to heat, which had an affective component, has no physical interaction with subjects that could be perceived as an invasion their own personal space.

39% of subjects agreed that light is easier to identify than heat. There were mixed comments about how disruptive light is, some mentioned light is more disruptive and some others mentioned light is less disruptive. There were only 8% of subjects classifying light is pleasant. There were mixed comments about how disruptive heat was, 50% of subjects classified heat as more distracting or disruptive, whereas the other 50% classified heat as less distracting and less obtrusive. Some Subjects even mentioned heat as pleasant, especially in cold environment or as an aid for carpal tunnel syndrome treatment.

3.2.8. Summary of results and Discussion

The hypothesis stating the type of modality used to interrupt has a different effect on performance was verified. Performance, measured by the time to take objects, indicates that there is a 24% increase in performance when interrupting with light and only a 2% increase in performance when interrupting with heat. Performance, measured by speed, indicates that there is a significant effect caused by an interruption, but not a significant difference between modalities. There is a 5.3% decrease in performance when interrupting with heat and a 7.6% decrease when interrupting with light. From these results it is clear that using heat as an interruption modality has a larger detrimental effect on the performance; determined by both measures of the task being interrupted than light. It is possible that heat was perceived as a threat, since being hurt could have stressed subjects. As a consequence, this could be an external factor that causes differences in performance in heat and light.

The hypothesis that disruptiveness changes with the type of modality used to interrupt was partially verified. There is no significant effect from interruptions in error in objects taken, help requested, or recover time as measures of disruption. Disruptiveness, measured by the number of reminders requested before an after an interruption, shows that there is no difference between heat or light modalities. Nevertheless, there is a main effect of the interruption itself, resulting in a reduced number of reminders after an interruption. Regarding errors in direction as a measure of disruptiveness, light seems to reduce the number of errors in direction by 50%, whereas heat reduces them by only 37%. According to this result, heat has a greater disruptive effect than light. Measures of disruptiveness should be interpreted with caution because there was an unexpected significant difference in the number of errors before an interruption. However, taking into account that there was a significant effect on interruption and the fact that this result agrees with the previous hypothesis in that heat has a greater effect on performance than light suggests that these findings are valid.

The hypothesis stating light is more effective as an interruption modality than heat was verified. Based on the time necessary for acknowledging, light was about 42% faster than heat. Thus, it is more effective for getting the user's attention promptly. Theory indicates that reaction times for heat and light should have been faster. There are three possible explanations for this result, 1) subjects were highly engaged in performing the task and took longer to notice the visual and thermal stimuli, 2) Subjects postponed acknowledgement of an interruption until they were done with a specific section of their current task. 3) A combination of the two. Observations on trial sessions indicate that in some cases subjects were really engaged in the task and did not notice the stimuli for some while after it had appeared, in other cases subjects specifically mentioned that they finished their current activity before acknowledging the interruption. The same type of subjects mentioned that the thermal stimulus prevented them from doing so, which could also explain for the decrease on performance when interrupting with heat (subjects had to immediately stop their activity to acknowledge a heat interruption and forgot the details of their current task, whereas light was easier to postpone).

The alternative hypothesis could not be verified It stated that if subjects are interrupted by their preferred modality, then their performance won't be affected as much as when they are interrupted by another modality. There was no main effect of subject's preferred modality in performance, neither was an effect in speed. 60% of subjects selected light as their preferred modality, and the other 40% chose heat as their preferred modality.

This experiment verifies previous research about interruptions, in that subjects perform slower on an interrupted task than on a non-interrupted task. The general effect of interruptions was demonstrated. Furthermore, this experiment also shows that there is an effect caused by interruption modality on performance. The thermal display produced a larger decrease in performance than the visual display. This thermal display also has a greater disruptive effect on the interrupted task than light. Disruptiveness and performance measures agree that heat causes more of a detrimental effect than light when used as an interruption.

From these results there are many things we learn about the use of two modalities of interruption. This work also shows that light is more efficient in getting user's attention (42% faster than heat). Light has a disruptive side effect on speed (24% slower than uninterrupted); this effect is slightly larger than the effect from heat. In contrast, heat takes longer to be noticed. Heat could be used more reliably in environments where other channels are already saturated or overwhelmed with information; i.e., when there are many visual distractions. One of the advantages of using heat is that users can attend to an interruption without having to take their attention off the screen. Whereas with light, users tend to focus their attention to the light source. Heat acts as an interruption to a single person, without disrupting everyone around them. Whereas ambient lights alert all people present at the location where light changes occur. Heat can be used to signal messages subtly to a single person, that is, heat is a personalized attention-getting device. Light can also be used to signal messages when there is only one person present at certain location, or when multiple recipients are intended.

The factors that had a statistical effect on performance are speed and time to take an object (success rate). The factors that had a statistical effect on disruptiveness are the number of errors in direction and reminders. The factor that had a statistical effect on effectiveness is reaction time; the time necessary to acknowledge an interruption. These factors could be used by an adaptive interface to compare the effect of different modalities in every user. By taking these results and applying them to user interface design, a system could maximize the effectiveness of interruptions through proper modality selection.

CHAPTER 4

CONCLUSION

Traditional human computer interfaces found in desktop computers focus only on a small number of modalities to interact with users. Finger and hand actions with the keyboard and mouse are commonly used to communicate to the computer. Visual and acoustic modalities are the most often used for conveying/presenting information to the user. Current human computer interfaces generally ignore important modalities such as ambient and peripheral visual cues, heat, vibration, smell and the sense of touch. This work demonstrated that HCI could be greatly improved by using multimodal interfaces that involve the use of all human senses.

This work explored the use of ambient displays in the context of interruption in order to illustrate the use of other perceptual channels in current computer interfaces. A multimodal interface was created to communicate with users through multiple channels by using several ambient displays. These ambient displays also acted as external interruption generators designed to get users' attention away from their current task; playing a game on a desktop computer. Interruptions were presented in the form of heat and light. Ambient displays can help orient and situate a person to serve a purpose other than the mere presentation of information—they can serve as a media for creating and changing context about interruptions.

Advances in computer technologies have enabled the creation of systems that allow people to perform multiple activities at the same time. People have cognitive limitations that make them susceptible to errors when interrupted. Unfortunately, interruptions are common to today's multitasking computing user interface experience. Computer interfaces must be designed to accommodate people's limitations relative focus, concentration and interruptions.

Human senses differ in their ability to be ignored, precision and speed. The common and unique characteristics of the human senses allow for the design of an interface that uses multiple modalities and, furthermore, of an interface that selects the modality to use based on contextual information. Even though more recent work has explored the area of adaptive user interfaces, they do not consider adapting the output modality itself. This thesis has shown that it is possible to differentiate between modalities and build multimodal interfaces by selecting the interruption modality to use, based on its effectiveness, user's performance, and disruptive effects. Armed with data we can now work to improve the effectiveness of an interruption through proper modality selection and configuration.

This thesis presented two exploratory experiments designed to test the effect of different modalities when used as interruptions. The purpose of these experiments was to identify the key factors that influence the perceived effect of each of the modalities. The experiments were designed to test fourth hypotheses.

The first two hypotheses held that disruptiveness and effectiveness of interruptions when performing a task would vary with the interruption modality used. Light was expected to be more effective. A third hypothesis suggested that the type of modality used as an interruption would affect users' performance differently when performing a task. And finally, an alternative hypothesis suggested the idea that if subjects are interrupted by their preferred modality, then their performance won't be affected as much as if they were interrupted by another modality.

The principal experiment presented here used a combination of two ambient display devices. The first device was a thermo-mouse pad that works as a heating apparatus capable of heating at rate of 1°C/sec. The thermo-mouse pad serves as a thermal ambient display, increasing temperature up to 42°Cto indicate an interruption. The second device is a computer-controlled dimmable night lamp. The light from this lamp can change intensity from 0%-100% at different rates of appearance or instantly if desired. The dimmable lamp serves as a visual ambient display, changing its intensity to signal an interruption.

The hypothesis that performance changes with the type of modality used to interrupt was verified. It is clear that using heat as an interruption modality has a larger detrimental effect on the performance of the task being interrupted than light. The hypothesis that disruptiveness changes with the type of modality used to interrupt was partially verified. Heat appeared to have a greater disruptive effect than light. This result agrees with the previous hypothesis in that heat has a greater effect on performance and disruptiveness than light. The hypothesis stating light is more effective than heat as an interruption modality was verified. Light is more effective for getting users' attention promptly than heat. The alternative hypothesis could not be verified. This hypothesis stated that subjects' performance would be less affected by their preferred modality

4.1. CONTRIBUTION

This works contributes to previous research by showing there is an effect on performance caused by interruption modalities. Thermal modality produced a larger decrease in performance than visual modality. This modality has a greater disruptive effect on interrupted tasks than light. Disruptiveness and performance measures agree that heat causes more of a detrimental effect than light when used as an interruption. The results of the experiments presented in this thesis are in agreement with previous research about interruptions. Subjects perform slower on an interrupted task than on a non-interrupted task. The general effect of interruptions was demonstrated.

This work also shows that light is more efficient (42% faster than heat) in getting users' attention, but has a disruptive side effect on speed slightly larger than heat. Heat takes longer to be noticed. Heat could be used more reliably in environments where other channels are already saturated or overwhelmed with information, such as when there are many visual distractions. One of the advantages of using heat is that users can attend to an interruption without having to take their attention off the screen. Whereas with light interruptions, users tend to focus their attention to the light source. Heat acts as an interruption to a single person, without disrupting everybody around them. Ambient lights, however, alert all people present at the location where light changes occur. Heat can be used to signal messages subtly to a single person, that is, heat is a personalized attention-getting device. Light can be used to signal messages when there is only one person present at certain location, or when multiple recipients are intended.

The factors that had a statistical effect on performance; effectiveness and disruptiveness, could be used by interfaces to compare the effect of different modalities in applications involving similar tasks to the one examined in this thesis. By taking these results and applying them to user interface design, a system could maximize the effectiveness of interruptions through proper modality selection.

This thesis proposed the use of users' physiological responses as feedback to a computer interface; so that the interface could modify the way it communicates with every user by selecting and configuring an adequate modality. Experiments in this thesis set the initial point for understanding how to build an interface of this type by looking at the effect of different modalities when used as interruptions.

4.2. FUTURE WORK

This thesis proposes to utilize users' physiological responses as feedback to a computer interface, so that the interface could modify the way it communicates with every user by selecting and configuring an adequate modality. Experiments in this thesis set the initial point for understanding how to build an interface of this type by looking at the effect of different modalities when used as interruptions.

The work presented in this thesis compared two interruption modalities, future work could compare interruption modalities covering the five humans senses. It is interesting to rank these interruption modalities according to their disruptive effects on performance and their effectiveness.

Some human sense can be triggered using different type of devices. We could explore new possibilities for such type of devices and expand the options of ambient displays. The sense of such as touch, for example, can be triggered using temperature changes, vibro-tactile wind flow, shape changes, etc.

Another area for future work is the interaction between modalities and how can the be used jointly to convey information. Further experimentation could show new possibilities of interaction; especially concerning the use of more than one modality at the same time and the interaction between modalities.

Mainstream computer-controlled appliances, desktop computers, and handheld electronic devices are poised to become truly multimodal. They can use this work to generate interfaces, receiving physiological feedback about the disruptive effects of an interruption modality. These interfaces will be designed based on how users react to each modality. These Interfaces could also be self-adaptive configuring themselves to the appropriated modality to a specific environment and users.

APPENDIX A

APPARATUS

A.1. INTRODUCTION

This appendix describes the design and implementation of the devices used for the evaluation of ambient displays as interruptions. The ambient displays described here refer only to those devices used in the final experiment. The following sections describe all components needed for the construction of such ambient displays.

A preliminary experiment showed that heat was a good interruption modality because of its novelty and its sense of immediacy. The experiment also proved light was a good interruption modality because of the domination of the visual system over the other senses. The first device is a thermo-mouse pad, which works as a heating apparatus using Peltier devices. The thermo-mouse pad serves as thermal ambient display, increasing temperature indicates an interruption. The second device is a dimmable night lamp, the light from this lamp can go from 0%-100% intensity at different rates of appearance or instantly if desired. The dimmable lamp serves as a visual ambient display, changing its intensity to signal an interruption.

The design of these devices includes a generic RS-232 serial interface so that any program capable of handling serial communications can calibrate, specify the desired settings or control them.

A.2. LIGHT DIMMER

A dimmable lamp device has five components that allow it to function properly, a phase controller used to control the amount of power going to the lamp, a zero crossing detector in charge of synchronizing with the AC power line, control logic circuitry responsible for the proper interaction of all components, and an optocoupler used to isolate the control circuitry from the AC power line, the optocoupler also serves as an interface to the AC power line.

A.2.1. Phase controller

Phase control is an effective and widely used method for controlling the average power through a load. It is commonly used to control lights, heaters, and high power motors. Phase control uses a bi-directional triode thyristor (TRIAC) to apply AC supply to the load for a controlled fraction of each cycle. The triac is a three terminal semiconductor used to control current flow in either direction and is activated by a gate signal. This gate is held in an off or open condition for a small period of time during an AC Cycle (60 Hz). The amount of time the triac is off is determined by the control circuitry; explained later in this appendix.

During the first portion of each half cycle of the AC sine wave, an electronic switch is opened to prevent current flow. The switch is closed at a specified Alpha angle to allow the full line voltage to be applied to the controlled element for the remainder of the half cycle. Varying Alpha will control the portion of the total sine wave that is applied to the lamp (shaded area in Figure 11), and thereby regulate the light intensity produced by the lamp.

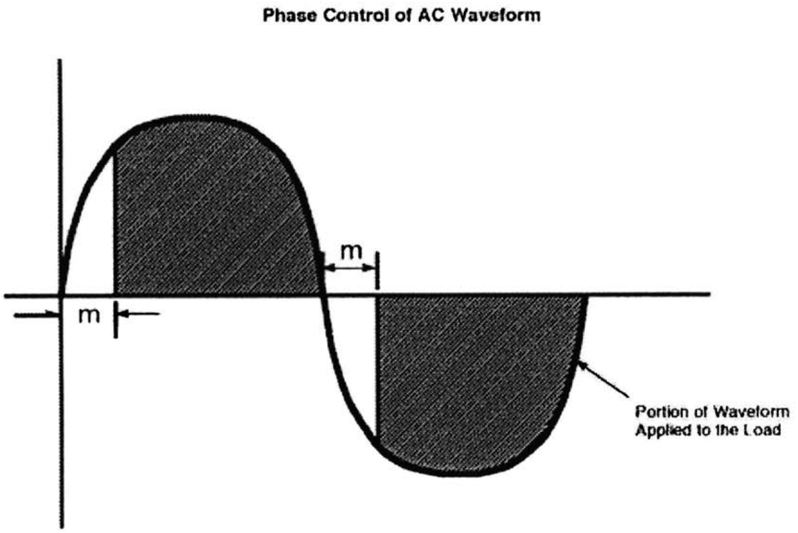


Figure 11 Phase control of an AC Waveform
[http://onsemi.com]

A.2.2. Zero Crossing detector

In order to be able to build a phase controller, the circuitry needs to be in sync to the AC line going to the lamp. This was implemented using a zero crossing detector. A zero crossing detector detects the moments when the main AC voltage crosses a zero level to change polarity and its output polarity changes whenever this happens.

An accurate detection allows for good synchronization; so firing pulses driving the phase controller can be generated at the right moment.

The circuit shown in figure 12 operates as a zero-crossing detector, producing a True or logic 1 output whenever the input voltage goes negative. The circuit consists of a high precision voltage comparator operating from a single power supply, which allows sensing near GND for an optimal zero cross detection. A transformer first converts the 120V AC input into 12V AC before feeding it into Vin of the zero-crossing detector.

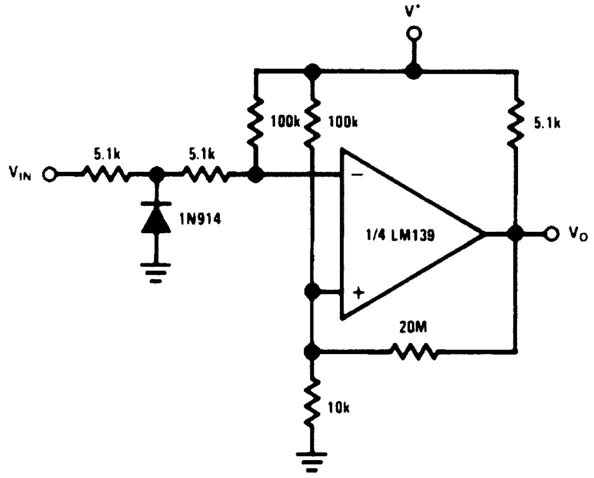


Figure 12 Zero crossing detector circuit with single power supply [LM139 Data sheet http://national.com]

A.2.3. Optocoupler or power interface

An optoisolator provides a layer of protection to the circuit between the delicate control logic explained in the next section and the high-voltage potentials that may be present at the power output stage. An optocoupler is an optically coupled isolator consisting of a Gallium Arsenide infrared emitting diode and a light activated Silicon bilateral switch.

In an electrical circuit, the use of optical isolation devices (optocouplers) ensures total electric isolation. In practice, this means that the control circuit is located on one side of the optocoupler, i.e., the emitter side, while the load circuit is located on the other side, i.e., the receiver side. Both circuits are electrically isolated by the optocoupler. Signals from the control circuit are transmitted optically to the load circuit, and are therefore free of retroactive effects. Figure 13 shows an optoisolator connected to a load. The optoisolator used is a MOC3022, which can handle up to 8 Amps, enough bandwidth for the thermal system built.

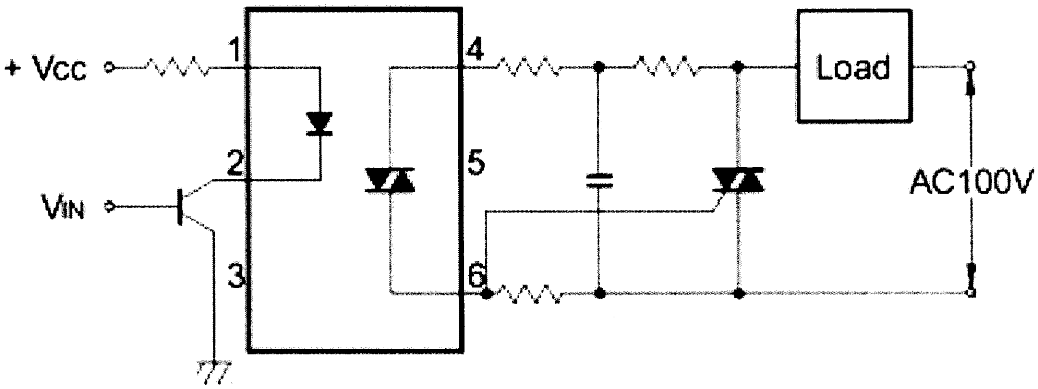


Figure 13 Optically isolated Circuit

A.2.4. Control Circuitry/Logic

An 8-bit CMOS FLASH microcontroller is responsible of implementing a phase controller, handling signals from the zero crossing detector, and triggering the TRIAC trough the optoisolator interface. It consists of a PIC16f87 microcontroller operating at 10Mhz. with 256 bytes of EEPROM for data memory and a serial communications module. Some of its function are to detect a zero-cross in the AC signal, read the temperature sensor and translate mV values to the appropriate units, communicate with a computer using a RS-232 link and receive the desired temperature, and perform as a proportional controller, generating pulses proportional to the error for controlling the power going to the lamp.

The microcontroller receives a system interruption from the zero crossing detector every time the AC signal changes polarity, which triggers a timer for a fraction of the AC signal period over two plus a delay for the corresponding time for the desired dim level (see Table 2). After delaying, the microcontroller activates an optoisolator, which then triggers a TRIAC gate, allowing current to flow for the remaining time of the AC cycle to the lamp. Thereby regulating the light intensity produced by the lamp. Figure 14 illustrates dimming near full bright where the microcontroller triggers the TRIAC gate every 833.33 μsecs. This circuit produces a reliable phase control or dimming control (approximately from 10% to 95% of the AC sine wave). See a functional diagram for every component used for the dimmable lamp controller in figure 22.

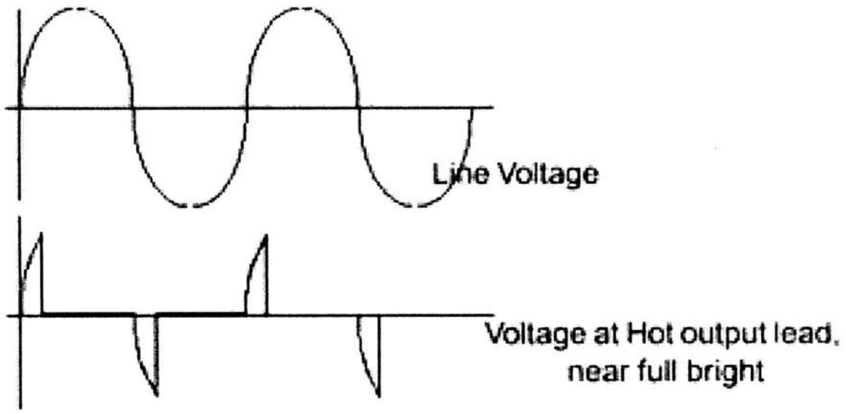


Figure 14 Light dimming near full bright compared to AC voltage

Timer - Delay (seconds)	Dim Level - Average Power
T / 2	100 %
T / 4	50 %
T / 6	33 %
T / 8	25 %
0	0 %

T = AC signal period ~ 1/60

Table 2 Corresponding Delay for desired Dim level

A.3. THERMO-MOUSE PAD

A thermo-mouse pad device has three components, Peltier modules that act as the heating/cooling elements, an H-bridge that allows temperature to flow in reverse directions (warm up and cool down), a PWM modulation module that regulates the amount of power going to the Peltier devices; and therefore regulates the speed at which temperature increases or decreases, a closed-loop feedback controller to boost performance and precision.

A.3.1. Peltier Device

Peltier devices, also known as thermoelectric modules TEM, are small solid-state devices that function as heat pumps. The basic concept behind TEM technology is the Peltier effect—a phenomenon first discovered in 1834 by a French physicist by the name of Jean Charles Athanase Peltier. The Peltier effect occurs whenever DC current is applied and electrical current flows through two dissimilar materials that have been connected to one another at two junctions, creating a temperature difference as a result. Depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. Contrary to infrared lamps, with a TEM it is possible to reverse the direction of the temperature flow by just reversing the direction of current flow. Thus, a perfect fit for a thermal device designed to be in contact with the human skin in which over heating is not allowed.

A typical thermoelectric cooler consists of an array of p- and n-type semiconductor elements that act as the two dissimilar conductors. The array of elements is soldered between two ceramic plates. Heat is carried through the cooler transported by electrons from n- to p elements and released on the opposite side, heating and cooling happens as the electrons move from a high to low energy state. Figure 15 shows how the direction of the flow of electrons affects which side of the TEM absorbs or releases heat. The heat pumping capacity of a cooler is proportional to the current and the number of pairs of n- and p- type elements in it.

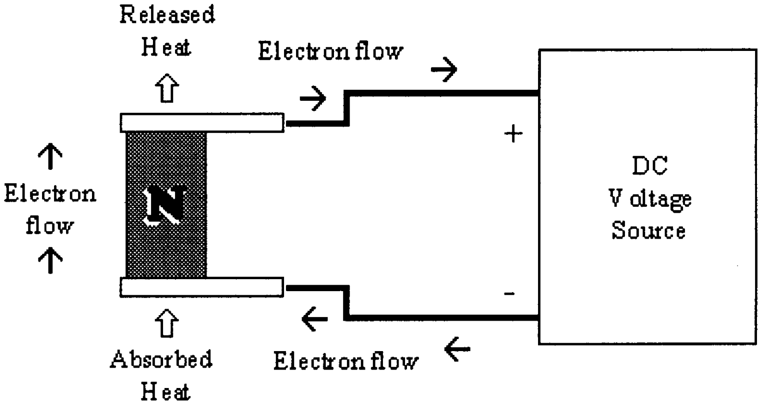


Figure 15 Electron flow through the connections to the power supply

A typical unit is a few millimeters thick by a few millimeters to a few centimeters square. It is a sandwich formed by two ceramic plates with an array of small Bismuth Telluride cubes in between. Figure 16 shows components from a typical TEM.

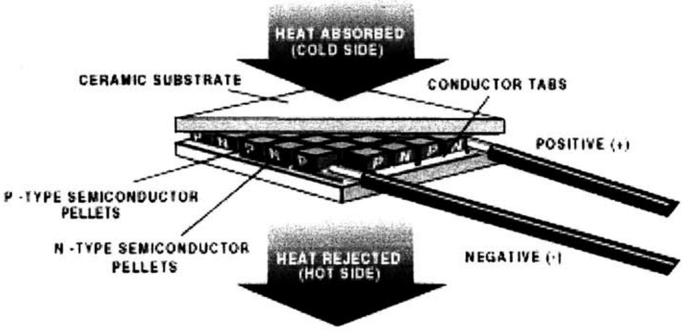


Figure 16 Peltier device components

One of the benefits of TEM technology is that the direction of heat pumping can be switched by simply reversing the polarity of the applied voltage. Thermoelectric modules make efficient heaters, which is a perfect characteristic for our application. The thermal system developed for this thesis uses three Peltier devices connected in series with a total of 254 junctions, allowing a wider area to come into contact with the user's hand. Three TEM were used for this thesis with their array of elements connected electrically in series and thermally in parallel.

A.3.2. H Bridge

An ideal H-bridge merely consists of 4 switches connected in topology of an H, where the motor terminals form the crossbar of an H shape. Its name is derived from the obvious appearance of the four switches and the motor. Figure 17 shows an ideal H-bridge circuit. For the construction of the thermo-mouse pad, Peltier devices in series replaces the motor, and they are controlled in a similar manner in which a motor would be controlled.

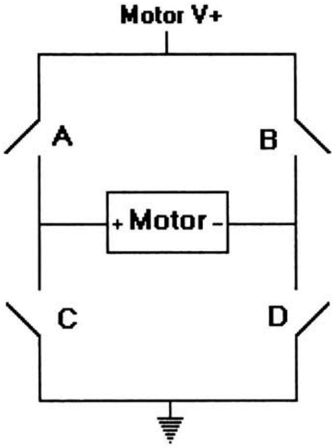


Figure 17 H Bridge Conceptual diagram

In an H-bridge, the switches are opened and closed in a manner so as to put a voltage of one polarity across the TEM for current to flow through it in one direction or to put a voltage of the opposite polarity, causing current to flow through the TEM in the opposite direction. In the circuit shown on figure 17, if switches A and D are closed while switches C and B are open, current will flow from left to right (positive voltage across the terminals) in the TEM, pumping heat on the TEM from one side to the other. When switches C and B are closed and switches A and D are open, current will flow from right to left, reversing the voltage polarity and pumping heat in the opposite direction. If we had a motor with open terminals, the motor would freewheel and if the terminals are short circuited, the motor will brake. A "shoot-thru" occurs when two switches on the same side of the H are turned on, the top right and the bottom right for example. Unless the transistors, traces, connectors, etc. can handle the excessive current developed in a "shoot-thru", the circuit could be damaged. Control logic for this (Peltier) application ensures that TEMs terminals are never open or closed and that a "shoot-thru" condition never occurs.

A.3.3. PWM Control

Pulse width modulation is a method of modifying the width or duty cycle of a periodic signal based on some characteristic of another signal. PWM is sometimes used as a method of regulating power. For example, shorter duration pulses that are each at a fixed power level produce less net power overall. A PWM circuit works by making a square wave with a variable on-to-off ratio; the average on time may be varied from 0 to 100 percent, see figure 18. In this manner, a variable amount of power is transferred to the load. The on-time is the time during which the DC supply is applied to the load, and the off-time is the period during which that supply is switched off.

By switching quickly, we can create an average voltage across the Peltier device. The speed of the temperature change can be adjusted by changing the pulse-width ratio:
Pulse-Width Ratio = t(on) / t(period) of the voltage applied across its terminals.

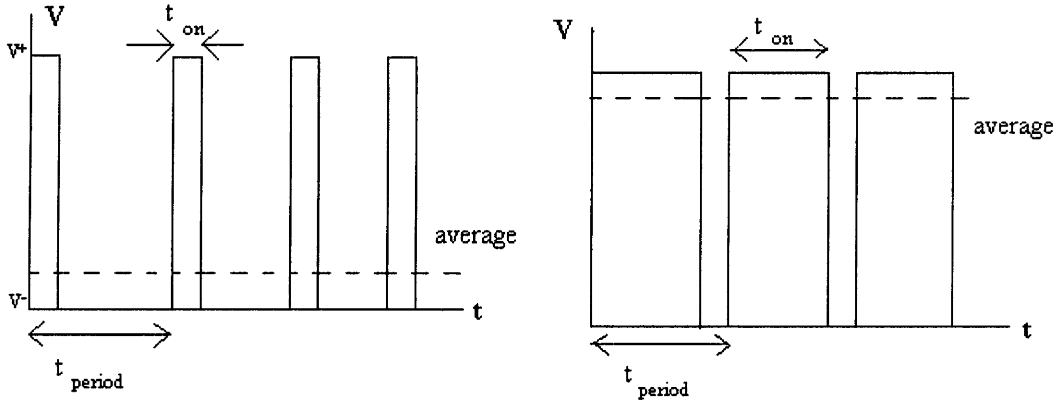


Figure 18 Average voltages across a TEM over time for 10% and 90% duty cylce [http://mechatronics.mech.nwu.edu]

According to TEM specifications, if PWM is to be used to control TEM, the modulating frequency must be above 1-2 KHz. For this reason a frequency of 100 kHz was chosen as a compromise to limit switching losses in the H-bridge while minimizing the size of the filter components, required to convert the PWM output from the bridge back to a DC voltage. This filter is necessary because a ripple is detrimental to the TEC; causing it to drop off efficiency rapidly and also because it reduces electromagnetic interference EMI produced by switching on and off the TEM.

A.3.4. Thermal system characterization

The transfer function for a TEM used in the thermo-mouse pad is a 1st order system. The maximum temperature generated by this TEM at 100% power is 48.53 ° C. and its raise time is 43.677° C. Raise time is the time taken by a system to reach 90% of its maximum value when a full (100%) load is applied.

The thermal system transfer function was obtained by characterizing the TEM after several trials by analyzing the system response in the following conditions: 10%-40%, 10%-60%, 10%-80%, and 10%-90% step increments of power delivered to the system. Temperature examined ranged from a minimum of 26.15 to 46.37 maximum. Figure 19 shows the thermal system step response for a step change of 10 to 80% power. It is important to notice that the time to reach a steady state is about 282 seconds. It is extremely slow and is due to the inherent response of Peltier devices to a steady current.

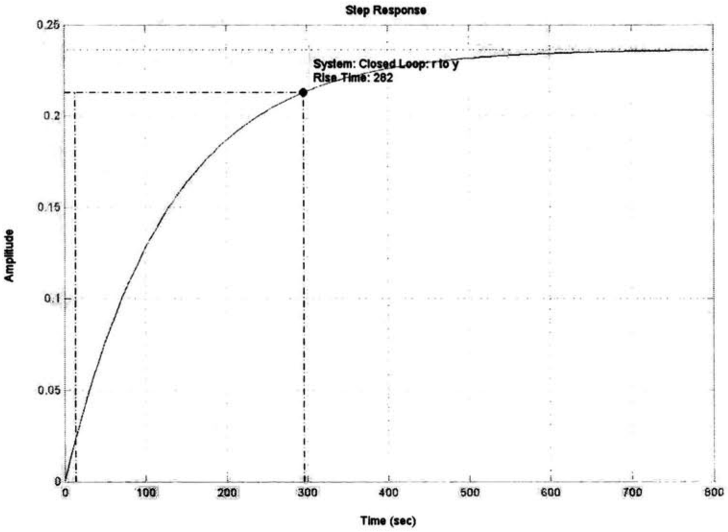


Figure 19 Thermal system step response

The transfer function of 1st order for the thermal system is of the form:

$$\frac{A}{\tau S+1}, \quad \tau = \frac{T_{raise}}{2.2} \quad \text{where A = 50 and } \tau = 168.26.$$

A.3.5. Temperature Feedback controller

There are several types of feedback controllers commonly used to control temperature systems: On-Off, Proportional, Proportional-Derivative, Proportional-Derivative-Integral, Proportional-Integral and Third Order controllers

On-Off is the simplest form of control, used by almost all domestic thermostats, but is not recommended to use with Peltier devices. A proportional controller performs better than a On-Off type by applying power in proportion to the difference in temperature between the controlled element and the desired set-point, As its gain is increased the system responds faster to changes in set-point, but eventually becomes unstable. Proportional-Derivative control solves stability problems by adding a damping constant, but introduces a steady-state error: final temperature lies below the desired set-point. And finally, Proportional-Integral-Derivative control deals with overshoot and stability problems associated with previous controllers, but needs a low gain to solve steady-state error problems.

On one hand a Proportional-Derivative (PD) controller introduces a percent overshoot PO of about 25%, and as the thermal system is intended to use with humans, its temperature cannot go beyond human thresholds. Thus, the controller was designed to have a small PO or no overshoot at all. On the other hand, the use of a PID controller requires extra circuitry and can only be used with small gain values. For such reasons, the system was implemented using a proportional controller, even though there is a tradeoff between speed response and error.

According to feedback control theory, $Lim_{s\to 0}\frac{E}{R}=\frac{1}{1+kA}$

the bigger the gain in a proportional controller, the smaller the error the system will have, thus the system was designed to use a high gain.

A temperature sensor placed on the contact surface (where a hand would be placed) closes the loop, serving as feedback for the temperature controller. This sensor is a LM35 precision temperature sensor, which gives an output of 1omV per degree Centigrade. It works in a broad temperature range; from -40°C to 100°C. Figure 20 shows a diagram of the closed loop proportional temperature controller.

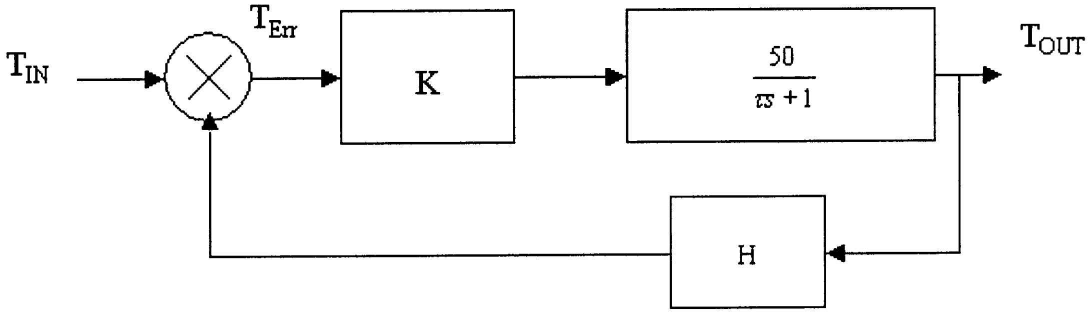


Figure 20 Proportional closed loop controller

The controller was designed to provide the fastest response allowable given that the maximum power permitted by the system, which is the limit impose by the TEM. It was determined theoretically that a gain of 10 would give the system sufficient speed Figures 21 a) and b) compare the impulse response for a proportional controller using gains of 2 and 10 respectively. Even with a gain of 2, the steady response state is reached in 14.6 seconds, at rate of temperature change of 1.2 C/sec, which is still much faster than 0.06C/sec in the original thermal response. With a gain of 10, the steady response is reached in 4 seconds only, at this gain, the rate of temperature change would be extremely fast 4.5 C/sec. Unfortunately a gain of 10 couldn't be obtained; the system saturates at a gain of 6, for this reason a soft start was used to keep the system from saturating while warming up. That is, the controller increases the baseline temperature to a value close to the temperature range that the system will work in, at ambient temperature in this case. Once the system is taken to the initial temperature, the system becomes stable.

In order to keep the temperature controller from saturating, a gain of 3 was selected as a conservative approach to keep the system stable at all times. Using a gain of 3, the rate of temperature change for the thermo-mouse pad would be 1.4 °C/sec and about 1 °C/sec in reality for the system built. As can be seen in figure 21, an error is introduced, but taking the error into account when setting the desired temperature compensates for it. See a functional diagram for every component used for the dimmable lamp controller in figure 22.

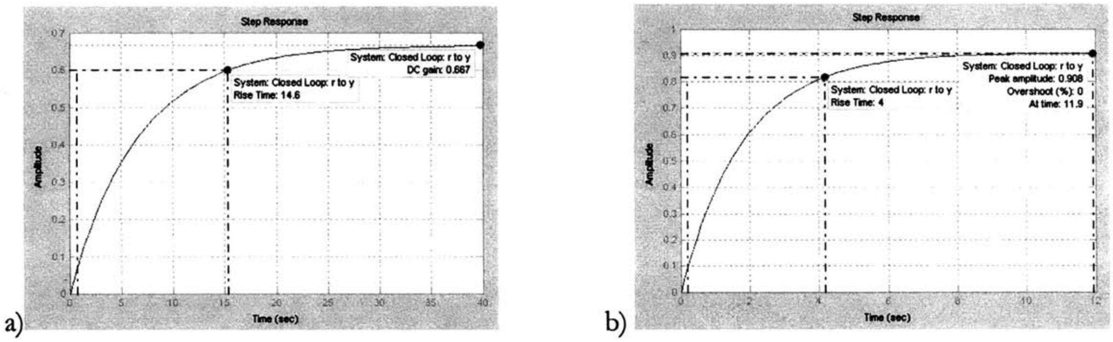


Figure 21 Modeled proportional controller
a)Controller with a gain of 2. b)Controller with a gain of 10

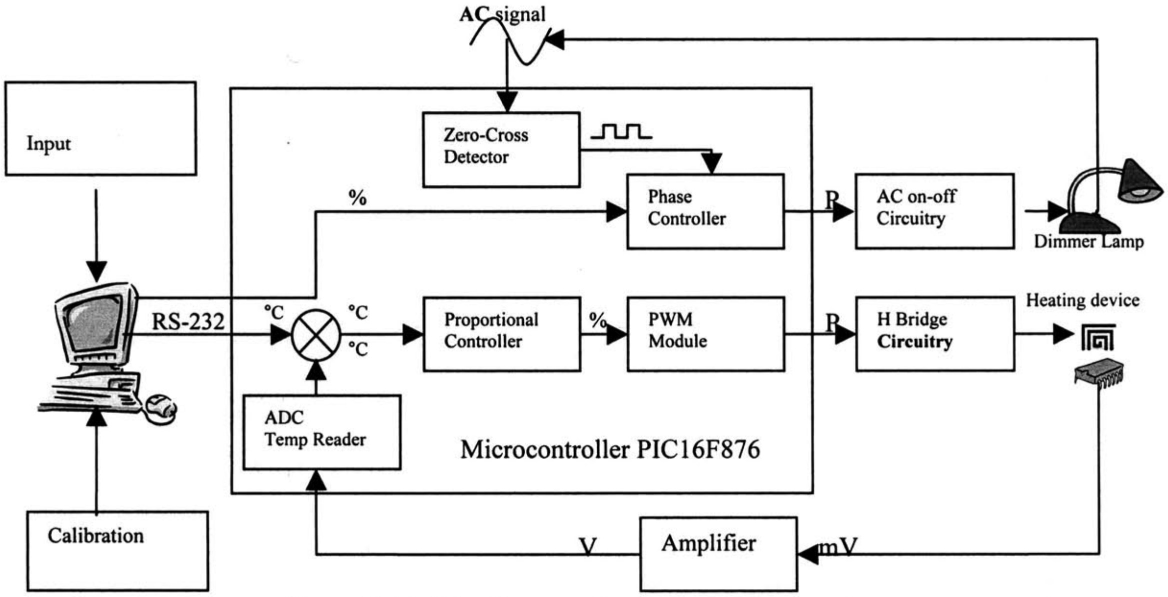


Figure 22 Modular diagram of controller implementation.

A.4. PHYSICAL IMPLEMENTATION

Peltier devices shown were fixed to a foamy plastic material to provide for a soft and comfortable feeling when using the thermo-mouse pad. The three TEM were then placed on top of a square copper plate of 7.5" by 8.5" and secured in place by a thermal interface material TIM. TIMs are materials such as greases, epoxies, and pads with high levels of thermal and electrical conductivity. A second copper plate was sealed with TIM and placed on top of the first layer. The two copper plates allow heat to dissipate. One side dissipates heat to the user's hand, and the other side dissipates heat when cooling the TEM. See Figure 23 for pictures of a working thermo-mouse pad, the system uses a track-ball mouse to keep user's hands in contact with the heating area. This mouse was too uncomfortable to use and was later replaced by a standard two-button mouse.

Figure 23 Working prototype pictures.

A.5. SUMMARY

This appendix described the design and implementation of the devices used for the evaluation of ambient displays as interruptions. A thermo-mouse pad serves as thermal ambient display, it capable of heating at rate of 1°C/sec and is able to increase its temperature up to 42°C to indicate an interruption. A computer-controlled dimmable whose light can go from 0%-100% intensity at different rates of appearance or instantly if desired. The dimmable lamp serves as a visual ambient display, changing its intensity to signal an interruption. This appendix also presented the necessary principles to build and understand these ambient devices built

APPENDIX B

LIST OF STORIES AND ITEMS USED IN EACH TRIAL

1	You were sent shopping please get the following list in the specified order:	a pair of shoes	a newspaper	some stamps	a video	some batteries	a novel
2	You are planning to go on vacations to a foreign country and you need the following items in the specified order:	brochures	some traveler checks	a passport	a pair of sandals	a guidebook	lotion
3	You have a child who is going back to school; get the following items in the specified order for him:	some shirts	some shoes	a geometry set	one backpack	some paintbrushes	some text books
4	You need to do some shopping; get these items in order	a home video	a music CD	a magazine	some stamps	holiday brochures	some books
5	You are going to buy a house; get the following list in the specified order:	detail of houses	a mortage	a loan	a legal contract	a moving van	an insurance policy
6	You are going to buy a car and learn how to drive; the following is an ordered list of the things you will need:	a driver's license aplication	a car	insurance for your car	driving lessons	a practice driving test	a loan
7	You need to start shopping for Christmas; get the following items in order:	a live Christmas tree	some Christmas lights	some Christmas cards	some stamps	wine and liquor	a turkey
8	You are going to organize a party. Get the following items in order :	wine and liquor	fruit	Some cheese	some invitations	some postage stamps	pate

9	You are about to move into a new house and need to buy some things for it. Get the following items in the specified order	some curtains	some paint	A bathroom suite	some kitchen utensils	some food	a plant
10	You need to stock up for the weekend; get this list in order:	fruit	some bread	a video	some fish	wine	some cookies
11	You need to build a house; This is a list of things you will need. Get the list in the specified order	a loan	An architect	planning permission	a design for the house	wood	paint
12	You have to arrange a wedding; you need to get the following items in the specified order:	invitations	a cake	bride maid dresses	champagne	a limousine	a minister

APPENDIX C
MAPS AND ITEMS AVAILABLE AT EACH LOCATION

1

						TAKE		FOILS	
X	x	x	x	x	x	Brochures	B	Camera	C
X	**G**	**L**	**T**		x	Traveler's Checks	T	Swimwear	W
X	**W**				x	Passport	P		
X	**S**	**P**	**C**	**B**	x	Some Sandals	S		
X					x	a Guidebook	G		
X	x	x	x	x	x	Lotion	L		

2

X	x	x	x	x	x	Some Shoes	S	a Picture Frame	A
X	**N**	**T**	**R**		x	a Newspaper	N	Record (CD)	R
X		**V**			x	some Stamps	T		
X		**K**	**S**		x	a Video (tape)	V		
X			**B**	**A**	x	some Batteries	B		
X	x	x	x	x	x	a Book (novel)	K		

3

X	x	x	x	x	x	Some Shirts	S	Crayons	C
X		**H**			x	Some Shoes	H	Sports Kit (Active Wear)	T
X	**P**		**T**	**B**	x	a Geometry Set	G		
X					x	a Briefcase (Backpack)	B		
X	**G**	**S**	**K**	**C**	x	some Paintbrushes	P		
X	x	x	x	x	x	Textbooks	K		

4

x	x	x	x	x	x	a Video	V	Pens	P
x					x	a Record (CD)	R	Envelopes	W
x	**W**	**B**			x	a Magazine	M		
x	**P**	**R**		**M**	x	some Stamps	S		
x	**S**	**V**	**H**		x	Holiday Brochures	H		
x	x	x	x	x	x	a Book	B		

5

X	x	x	x	x	x	Details of Houses	D	a Decorating Catalog	A
X					x	a Mortgage	M	Surveyor's Report	S
X	**D**		**A**		x	a Loan	L		
X	**R**		**L**	**S**	x	a Legal Contract	C		
X	**C**	**M**		**I**	x	a Moving Van	R		
X	x	x	x	x	x	an Insurance Policy	I		

						TAKE		FOILS	
6									
x	x	x	x	x	x	a Driving License Application	D	a Roadside Assistance plan	A
x			**C**	**A**	x	a Car	C	Road Maps	K
x		**I**		**T**	x	some Insurance	I		
x	**L**		**D**		x	Driving Lessons	L		
x		**B**	**K**		x	a Driving Test	T		
x	x	x	x	x	x	a Bank Loan	B		
7									
x	x	x	x	x	x	a Tree	T	Fruit (Christmas) Cake	H
x			**S**	**F**	x	some Christmas Lights	F	some Vegetables	Y
x	**T**		**W**		x	Cards	C		
x				**K**	x	Stamps	S		
x		**C**	**Y**	**H**	x	Wine	W		
x	x	x	x	x	x	a Turkey	K		
8									
x	x	x	x	x	x	Wine	W	Serving Plates	S
x				**T**	x	Fruit	F	Some Bread	B
x	**F**	**B**		**I**	x	Cheese	C		
x			**P**	**C**	x	Invitations	I		
x	**S**		**W**		x	Postage Stamps	P		
x	x	x	x	x	x	Pate	T		
9									
x	x	x	x	x	x	C(o)curtains	C	Furniture	T
x		**K**		**D**	x	Paint	P	Bedding (linens)	D
x	**C**		**L**	**F**	x	a Bathroom Suite	B		
x			**T**		x	Kitchen Utensils	K		
x	**B**			**P**	x	Food	F		
x	x	x	x	x	x	Plants	L		
10									
x	x	x	x	x	x	some Fruit	F	Cheese	H
x	**C**		**W**		x	Bread	B	Steak	K
x	**K**	**B**		**D**	x	a Video	V		
x			**F**	**H**	x	some Fish	S		
x	**V**			**S**	x	Wine	W		
x	x	x	x	x	x	Cookies	C		

11

							TAKE		FOILS	
x	x	x	x	x	x	a Bank Loan	B	Bathtub	H
x	**B**	**W**		**F**	x	an Architect	A		
x	**P**	**T**			x	Planning Permission	P		
x	**A**				x	a Design for the house (catalog)	D		
x	**H**			**D**	x	Wood	W		
x	x	x	x	x	x	Paint (color selection)	T		
						some Furniture	F		

12

x	x	x	x	x	x	Invitations	I	Wedding Rings	R
x		**G**	**I**	**R**	x	a Cake	C	Flowers	S
x		**T**	**C**		x	Bridesmaid Dresses	D		
x			**D**	**P**	x	Champagne	G		
x				**S**	x	Taxis (Limousine)	T		
x	x	x	x	x	x	a Priest (Minister)	P		

APPENDIX D

ASSOCIATED INTERRUPTING WORDS

"rough"

gravel	road	sand	smooth	edge
bumpy	jagged	rugged	uneven	pebbles
callous	sandpaper	harsh	tough	gentle

"sleep"

dream	drowse	rest	snore	doze
wake	yawn	nap	insomnia	bed
pillow	awaken	comfort	peace	slumber

"rain"

downpour	clouds	hail	drought	tornado
fog	monsoon	storm	flood	thunder
drench	lightning	wind	wet	drops
hurricane				"rain"

"chair"

stool	upholstery	cushion	seat	bench
rocker	wicker	relax	sit	table
sofa	couch	swivel	cozy	desk

APPENDIX E

STUDY OF INTERRUPTION MODALITIES CONSENT FORM

Participation in this activity is voluntary and you are free to withdraw your consent, and discontinue participation in this activity at any time without prejudice.

Traditional computer interfaces focus only on a small number of modalities to interact with users. These interfaces are not taking advantage of the fact that humans have extraordinary sensing capabilities, which are in use all the time (five human senses). At the same time we think that the use of interruptions is a key issue in the design of human-computer interfaces, such interruptions are designed to get users' attention away from their current task, such as writing e-mail on a desktop computer.

The purpose of this experiment is to test the effect of different modalities when used as an interruption while using a desktop computer. The experiment will attempt to identify the key factors that influence the perceived effect of each of the modalities. The output modalities to test are tactile (thermal stimuli) and visual (light changes).

You will sit comfortably and relaxed in front of a computer playing a text-based game using the computer mouse. While you are performing this task, the computer/system will interrupt you using a visual or thermal stimulus in a random order. Once you detect the stimulus presented, you will then have to acknowledge the interruption by pressing the "Message Button"; colored in red (this will stop the stimulus). Then you will have to follow instructions provided by each message.

The experiment will collect data such as response time and tracking time. No personal data will be collected and your identity will be protected. By signing this form you become a participant of this experiment.

Any inquiries concerning the procedures should be directed to:

Ernesto Arroyo -- earroyo@media.mit.edu -- 617.253.0170

In the unlikely event of physical injury resulting from participation in this research, I understand that medical treatment will be available from the M.I.T. Medical Department, including first aid emergency treatment and follow-up care as needed, and that my insurance carrier may be billed for the cost of such treatment. However, no compensation can be provided for medical care apart from the foregoing. I further understand that making such medical treatment available; or providing it does not imply that such injury is the Investigator's fault. I also understand that by my participation in this study I am not waiving any of my legal rights*. I understand that I may also contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T. 253-6787, if I feel I have been treated unfairly as a subject.

*Further information may be obtained by calling the Institute's Insurance and Legal Affairs Office at 253-2822.

I agree to the procedures of this activity __________________ Date: ____________

Principle Investigator ________________________________ Date: ____________

APPENDIX F

STUDY OF INTERRUPTION MODALITIES QUESTIONNAIRE

Please answer the following questions to the best of your knowledge:

1. Name at least four topics words you remember from interruption messages make you think of:

2. List any of the words you remember from interruption messages

3. According to your experience in this game, please circle your preferred interruption modality. Explain Why.

   Heat Light

4. Write down any comments, suggestions or experiences regarding the use of heat and light as interruption modalities.

Thank you for your participation in this study. Please return this pages to your evaluator.

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