

**AFFECTIVE INTERFACE – TOWARD A MACHINE THAT
EXHIBITS ITS STATE EMOTIONALLY**

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By

HAILI LU

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ABSTRACT

In the field of human-machine interaction, it is generally agreed that emotion may affect the users' response behavior. With this consensus, interfaces of the machine are developed, among which a kind of interface that shows the machine state with human emotions is less studied. This kind of machine interface is called emotional or affective interface. This thesis studied affective interfaces. Two research questions were identified in the study: (1) how an affective interface is built and (2) whether an affective interface of a consumer device (e.g., personal digit assistant, personal computer, cellular phone, etc.) would significantly affect human's emotion, judgment and decision making behavior?

Corresponding to the two research questions, this research consisted of three works along with their respective objectives: (1) developed a general design approach to affective interfaces; (2) constructed an affective interface test-bed with high fidelity, which is a laptop computer with an attention to its internal temperature state, by using the developed approach in (1); (3) conducted experiments to show that the affective interface of the test-bed has a significant effect on human emotion, judgment and decision making.

This research concluded (1) the general interface design approach, as developed, is valid to all interfaces including the affective element in human-machine interactions, (2) the human judgment and decision making behavior will be significantly affected by the affective interface (with the confidence interval being 95%), and (3) affective interfaces significantly change human emotions.

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LIST OF ABBREVIATIONS

HMS	Human-machine Interaction System
HMI	Human-machine Interface
3H	Head, Heart and Hand
ADT	Axiomatic Design Theory
PCP	Proximity Compatibility Principle
FBS	Function-Behavior-Structure
EID	Ecological Interface Design
FCBPSS	Function-Context-Behavior-Principle-States-Structure
FR	Functional Requirement
DP	Design Parameter
CPU	Central Processing Unit
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 Human-Machine System

There are a growing number of studies on human-machine interaction systems. A machine represents a broad technical system which may include humans as part of the system (Zhang and Luttervelt, 2011). Johannsen (2007) defined a human-machine interaction system (**HMS**) as consisting of human users, human-machine interfaces and machines. Human-machine interface (**HMI**) is an essential device in HMS to facilitate interactions between the human and machine. An HMS can be further divided into two types of interactions, human to machine and machine to human. Therefore, there are two types of interface devices for these interactions: the device used by the human to communicate with the machine, e.g., keyboard, mouse, etc., and the device used by the machine to communicate with the human, e.g., display screen, audio system, etc. It is noted that these devices are commonly called interfaces, and more precisely, the first type of devices may be called **human-to-machine interface** and the second type of devices may be called **machine-to-human interface**. Both types of interface devices are responsible for an effective and efficient interaction between the human and the machine.

In the modern era, machines become more intelligent in that they have the abilities of sensing, decision making, adapting and learning. Such a machine may be called **robot**, and therefore, the machine and human interaction becomes the robot and human interaction (**RHI** for short). For the robot, the functional elements such as sensing, learning, adapting, and decision making need to be built. In fact, the robot is a kind of machine with additional devices (both hardware and software) to possess the intelligent behaviors. Further, in the era of automation, machines are controlled by computers, and as such, **human-machine** reduces to **human-computer**. However, in this thesis,

the term human-machine is used instead of human-computer in order to highlight the system behind the computer as well as to make the knowledge developed useful to human-robot interaction systems.

According to the communication theory (MacLennan, 2003), a good communication between two parties (the human and machine in this case) much relies on the matching of the two parties in the areas of action, cognition and emotion or hand (action), head (cognition) and heart (emotion), 3H for short (Gupta, 2016). Figure 1-1 shows a general set-up of such a human-machine interaction system. This figure is self-explanatory. Indeed, the design of interfaces and management of interactions are the essential variables to make the human and machine or the human and robot have a better communication.

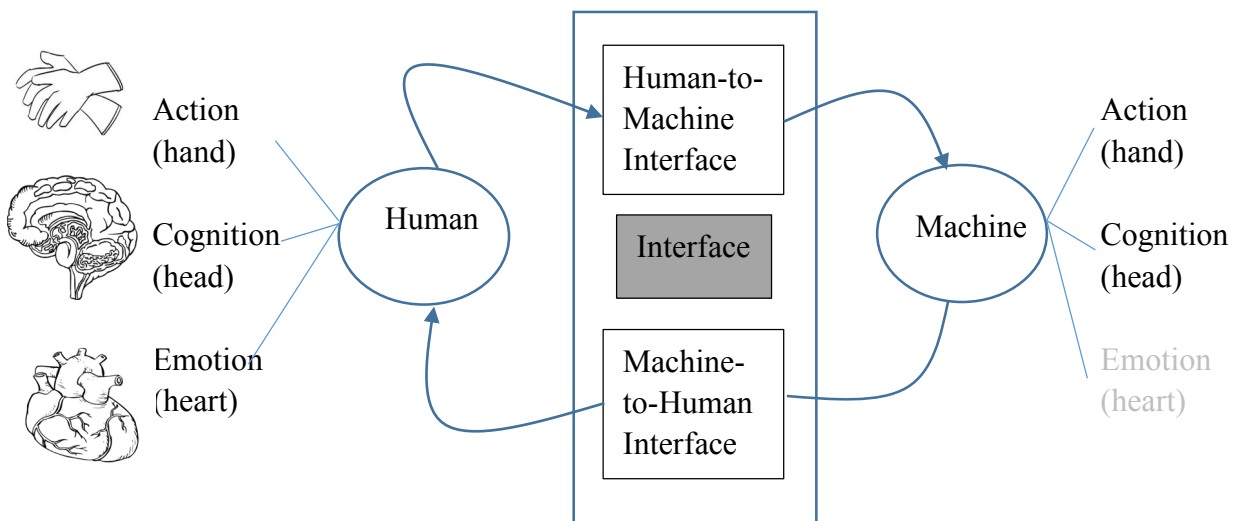


Figure 1-1. A general set-up of the human-machine interaction system

1.2 Motivation

The study in this thesis was focused on the human-machine system instead of the human-robot system. However, the result of the research should also be useful to the human-robot system, as the human-machine system is a generic system of the human-robot system (see the previous

discussion). In the past several decades, there have been many studies on how to develop two types of (interface) devices for the human-machine system, namely the human-to-machine interface and the machine-to-human interface. However, the focus in literature seems to be on the match between the human and machine in the aspect of hand (or action) and head (or cognition) but not heart (or emotion). For instance, in the aspect of hand, the voice or audio interface is developed for both types of interfaces; for the human-to-machine interface, the interface that supports the handwriting by the human user is developed. In the aspect of head, several design theories and methodologies are available, such as proximity compatibility principle and so on.

In the aspect of heart, most of the studies, though only a few, are focused on the development of the machine capability including sensing, learning, decision making, and adapting, all of which are with respect to the human mental state and behavior (including emotion or affect) such as cognitive fatigue or fatigue, mental workload, anger, anxiety and so on. For instance, studies on understanding and modeling of human mental states and behaviors are widely carried out; see the work by Suzuki, Igarashi, Kobayashi, Yasuda and Harashima (2013). Another work is on machine's adapting capability, e.g., the work by Orellana and Madni (2014). According to Picard (1997), all these works fall into one of the three categories of interface: (i) machines that can express humans' emotions, e.g., smiling; (ii) machines that can understand humans' emotions, e.g., happiness; (iii) machines that have human-like emotional appearance. In short, the machines of these categories do not have the so-called human emotional intelligence which will be discussed later in this thesis.

It is known that humans have emotion. For time being, emotion is considered as a human state other than cognition and action, while later in Chapter 2, a definition of emotion will be presented. Emotion (or heart), cognition (or head) and action (hand) are coupled to one another. Emotional intelligence of natural creature refers to the behavior of the creature that can understand its own emotion and identify others' emotion, and further can make use of this emotion to influence

cognition, e.g., judgment and decision making (adapted from Emotional intelligence, n.d.). The coupling among emotion, cognition and action is the most important attribute with the human, which is not quite available to contemporary machine. Therefore, to build a machine or more precisely a machine-to-human interface of the machine, which exhibits emotional intelligence to the machine, a proposition was first proposed in our group in a MS thesis (Modi, 2011) that a machine that has emotional intelligence or emotional machine according to (Norman, 2004) must have its states (both cognitive and physical) link to human emotion labels or emotions. The proposition has been inspired by the work of Norman (2004) in which he wrote: “A robot should be concerned about dangers that might befall them, many of which are common to people and animals, and some of which are unique to robots.” In this narrative, “feel or concerned about dangers” is in the category of emotion or at least not in the category of action and cognition. The work of Potkonjak et al. (2002) also inspired us for this proposition. In Potkonjak et al. (2002), the considered the thermal state in a machine as fatigue state with a human.

Given the above elaboration, it should be interesting to extend the aforementioned categorization of machines into three types, as Picard did in her book (Picard, 1997), to further three types, namely (iv) a machine that can understand human emotion from others, (v) a machine that has an internal linkage between its state and emotion and can express its state emotionally, and (vi) a machine that can perform an emotional dialogue with a human such that both the machine and the human may change their state as well as behavior. A particular case of (vi) refers to the situation that the machine is just a piece of computer software without its sensible state (likely a tireless machine). In such a case, the software can express emotionally to change a human’s state as well as behavior; see the work of Bickmore (2003). Such an interface may also be called persuasive computing or interface (Fogg, Bedichevsky, & Tester, 1998). This thesis focuses on the category (v) of machine (i.e., machine-to-human interface of such a machine or **affective interface** without confusions).

As a first step towards the goal of building an interface for the category (v) of machine (i.e., the machine with its state connected to human emotion), one needs to answer the following question:

*Whether would such an interface of the machine significantly change a human's emotion, judgment and decision making? By significance, it is meant that there must be a structural reason rather than noises behind the change. In short, the study in this thesis was aimed at providing an answer to this question. Therefore, the **general hypothesis** of the study was thus: *the machine that has emotions will significantly change a human's emotion, judgement and decision making behavior in the event that such machines interact with humans.**

During the course of seeking the answer to the foregoing research question in this thesis – particularly seeking a test-bed to conduct the experiment to test the above-mentioned hypothesis, I have also noticed that there seems to be no unified and general design theory and methodology for the machine-to-human interface of the category (v) of machines. For this reason, the study in this thesis was also turned to look into a general design theory and methodology for the human-machine interface including the affective interface.

1.3 Objectives and scope

Based on the above discussion, the study in this thesis defined three specific objectives as follows:

Objective 1: *To develop a general design theory and methodology for generalized human-machine interfaces including the affective interface.*

There are two remarks for this objective. First, by the generalized interface, it is meant that the interface device goes beyond the conventional one such as display. This term first appeared in the paper of Xue et al. (2015). Second, by general design theory and methodology, it is meant that the theory and methodology is applicable to the concept design and layout design of interfaces while

leaving out the detail design of interface devices (gadgets and widgets). Details of the concept regarding the concept design, layout design, and detail design of interfaces refer to the paper of Lin et al. (2006).

Objective 2: *To design and construct a test-bed for the study of the affective interface – in particular enabling to conduct an experiment on it to test the general hypothesis, as described before.*

There are two remarks regarding this objective. First, the specific test-bed is a computer machine with a particular focus on the internal temperature state of the computer as an example (despite some other states). The reason to choose the temperature state is that the temperature state has a practical implication to the computer as well as other machines: when the internal temperature is over a certain degree, the computer often shuts down. It is noted that in the work of Potkonjak et al. (2002), the temperature in the joint of a printer was studied, though not with the same context as this thesis. Second, the design of this test-bed followed the design theory and methodology developed with Objective 1, which also served as a case to illustrate the application of the design theory and methodology for interfaces developed with Objective 1. The test-bed should also be constructed to meet the requirement for conducting an experiment to test the general hypothesis as mentioned before.

Objective 3: *To conduct an experiment to test the general hypothesis.* For the convenience of readers, the general hypothesis is re-visited below.

The **general hypothesis:** *the machine that has emotions will significantly change a human's emotion, judgement and decision making behavior in the event that such machines interact with humans.*

It is noted that this thesis only considers the thermal state (i.e., temperature variable) of a machine. There are other general states in machines, that is stress state, stiffness state, equilibrium state, and field state (depending on a particular field machine, e.g., gravity field, electric field, etc.). It is my belief that these states can all be connected to emotions in particular contexts. Nevertheless, the study on the thermal state should have a generalized implication to the study of other states. Further, in the context, an over-heat thermal state was considered being linked to the cognitive fatigue state and anxiety state, respectively.

1.4 Research methodology

With respect to Objective 1, the general ideas were: (1) Take an interface as a product or device and then apply the general design theory and methodology, e.g., Axiomatic Design Theory (ADT) (Suh, 1990) for products to the interface product (Lin et al., 2006). (2) Combine the ADT with the design theory and methodology for interfaces in literature such as Proximity Compatibility Principle (PCP) (Wickens and Carswell, 1995) and Function-Behavior-Structure (FBS) approach (Lin and Zhang, 2004) to the interface product. It is noted that ADT can be found in Appendix A, and PCP and FBS will be discussed in Chapter 3.

With respect to Objective 2, the design theory and methodology developed in Objective 1 was applied, and then the test-bed (i.e., a computer system with an interface to exhibit the internal temperature information of the computer in different kinds of emotions including no-emotion) concerned was developed by applying the design theory and methodology as a case study. Given a particular thermal state, three interfaces were constructed with the computer: no-emotional state interface, fatigue state interface, anxiety state interface. The latter two interfaces are an affective interface.

With respect to Objective 3, an experiment was first designed using the statistic methodology, in particular the interface is a main factor with three levels (i.e., interfaces as developed with

Objective 2). After that, a sufficient number of human participants were recruited to perform a gaming task on the computer with the aforementioned three interfaces. A set of questions was designed to elicit the participants' view on the task and interface. The participants' task performance and response to the questions were obtained and analyzed.

1.5 Organization of the thesis

The remainder of the thesis is organized as follows. Chapter 2 is a comprehensive review of the literature pertinent to the three objectives as defined in Section 1.4. This includes: (1) the general design theory and methodology for interfaces, (2) the basic concept such as emotion, (3) affective interface. This chapter also serves as a further justification of the need of the proposed research. Chapter 3 presents a novel design theory and methodology for interfaces including affective attributes. Chapter 4 presents the development of the test-bed (i.e., an affective interface for the computer machine with its internal temperature state) by applying the design theory and methodology as presented in Chapter 3. Chapter 5 presents the statistical design of the experiment and the experimental result with analysis. Chapter 6 is a conclusion including the discussion of the contribution and limitation of the study along with the discussion of some future work.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

In this chapter, the background and literature pertinent to the proposed research objectives are discussed in details. The purpose of the discussion is to give a further justification of the need of this study. Section 2.2 gives definitions for various terms and concepts related to emotion or affect. Section 2.3 gives a background about the emotion theory. Section 2.4 discusses the literature on the general design theory and methodology for interfaces including affective interfaces. Section 2.5 discusses design of interfaces in particular the affective machine-to-human interface. Finally, Section 2.6 is a conclusion with discussion on the need of the proposed research.

2.2 Definition

There are some basic concepts underlying this thesis study. It is helpful to clarify them first in order to facilitate discussions later in this thesis.

Definition 2.1. Emotion. “Emotion is any relatively brief conscious experience characterized by an intense mental activity and a high degree of pleasure or displeasure” (Emotion, n. d.).

Definition 2.2. Affect. “It is the experience of feeling or emotion” (Affect, n. d.). The difference of affect from emotion is thus that emotion is an instantaneous experience while affect is a long term experience. In this thesis, the two are used interchangeable unless otherwise stated explicitly.

Definition 2.3. Feeling. “In psychology, feeling is usually reserved for the conscious subjective experience of emotion” (Feeling, n. d.).

Definition 2.4. Mood. “A mood is an emotional state. Moods differ from emotions, feelings, or affects in that they are less specific, less intense, and less likely to be triggered by a particular stimulus or event. Moods are typically described as having either a positive or negative valence” (Mood, n. d.).

Definition 2.5. Generalized interface. A generalized interface is a separate system from the machine and human, serving as a third-party system sitting between the human and the machine to facilitate the communication between the human and the machine, adapted from (Xue et al., 2015). The generalized interface is as opposed to some specialized interface systems (e.g., visual display, keyboard, mouse, etc.). The generalized interface may include any widget that is sensitive to human sensory organs such as visual, audio, touching, and smelling. The concept of the generalized interface makes the interface design into two levels: logical level and physical level. The logical level interface design concerns what and where the information needs to be communicated between the human and machine, while the physical level interface design concerns how the information is presented to the human (through the machine-to-human interface) and the machine (through the human-to-machine interface). It is noted that the design theory and methodology concerned in this thesis is for the logical level design of an interface. Another note is that the generalized interface in this thesis refers to the machine-to-human interface. The human-to-machine interface actually refers to the machine that can understand human emotion – see the previous discussion in Chapter 1 – particularly the category (iv) of machines. Though the human-to-machine interface of the category (iv) of machines is part of emotional intelligence (emotional intelligence, n.d.), it is out of the scope of this thesis.

Definition 2.6. Affective generalized interface. It is a generalized interface that exhibits human-like emotions that are further connected to machine states.

Definition 2.7. Interaction. “Interaction is a kind of action that occurs as two or more objects have an effect upon one another” (Interaction, n. d.).

Definition 2.8. Interaction management. Interaction management refers to activities such as planning, scheduling, coordinating and controlling of interactions among members. In the context of the human and machine interaction system, interactions occur between the human and machine through the interface devices, and the human and machine interaction management thus refers to managing utilizations of the interface devices.

2.3 Emotion theory

While the previous definition of emotion (Definition 2.1) appears to be very general. Hockenbury & Hockenbury (2007) stated in a relatively specific way: “An emotion is a complex psychological state that involves three distinct components: a subjective experience, a physiological response, and a behavioral or expressive response”. The mechanism of the emotion regulation may be classified into three main categories of theories: physiological, neurological, and socio-cognitive. Physiological theories suggest that responses within the body are responsible for emotions; Neurological theories propose that each emotion emerges from independent neurobiological systems; Cognitive theories argue that thoughts and other mental activities play an essential role in forming emotions (White et al., 2014).

In order to measure emotions, the concept of dimension emerges to emotion. Among many others, Schacter (2011) presented a two-dimensional model for emotions (Figure 2-1a). The two dimensions are: dimension 1: valence (negative or positive feeling); dimension 2: arousal (energized or enervated feeling). Then, a set of core affects can be placed on the two dimensional map (Figure 2-1a). In Figure 2-1a, **fatigued** is labelled as an emotion. There is no agreement of the set of core affects, meaning others may label emotions differently (Figure 2-1b) (Russel, 1980), where **tired** is labelled as an emotion. Further, in both figures, **tense** is labelled as an emotion,

which is considered as **anxiety** in this thesis. Indeed, in the Plutchik's wheel of emotions model, anxiety is labelled as an emotion as well (Pluchik, 1980).

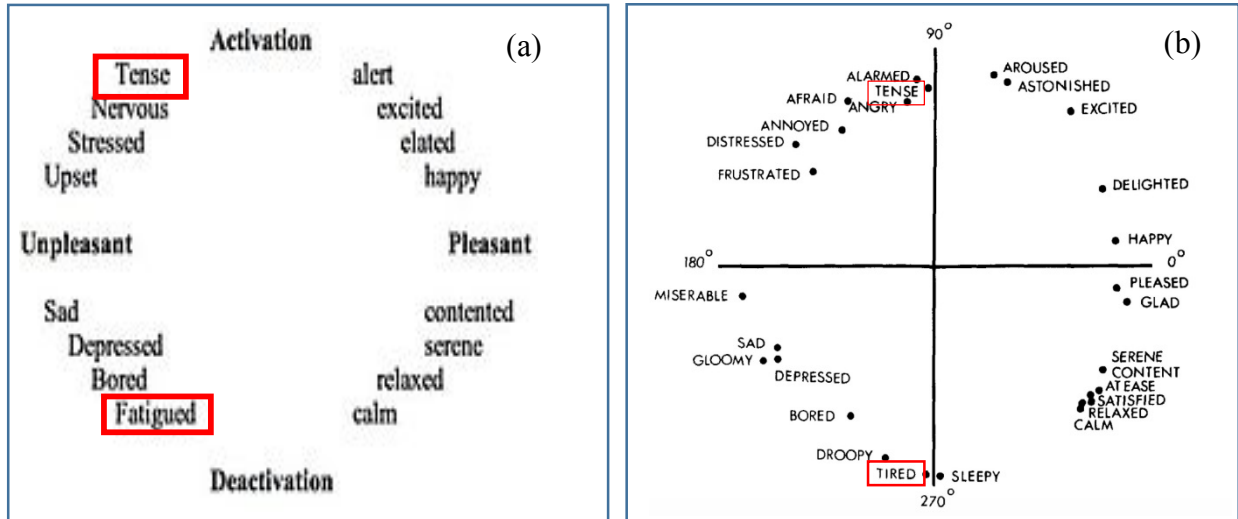


Figure 2-1. Direct circular scaling coordinates for 28 affect words or emotion labels

It is widely agreed in literature that human emotion can influence cognition, which is called **emotion intelligence** (see also the previous discussion in Chapter 1). Wang, Nicol, Skoe, Sams and Kraus (2008) indicated that the emotional state influences the listener's physiological response to speech by comparing three different conditions: neutral, positive and negative. Yang et al. (2013) suggested that human brains are equipped with increased sensitivity to the valence strength of positive compared to negative words. Pessoa (2015) summarized supports from the literature that emotion and cognition are coupled. These studies are very encouraging to the study in this thesis.

It is also widely agreed that emotion can affect action. West, Al-Aidroos, Susskind and Pratt (2011) raised some considerable evidence to show that emotive processing has widespread effects on human perceptual and attentional functioning, and also conducted an experiment to show that the emotional displays do have the ability to affect the temporal oculomotor action. Ma, Pei and Wang (2015) studied the influence of negative emotion on the framing effect and conducted an experiment to indicate that negative emotion increases the decision makers' risk preference.

Knickerbocker, Johnson, and Altarriba (2015) conducted an experiment to compare the eye-movement record while participants reading sentences that contained a neutral target word or an emotion word, and proved that readers were able to process both positive (e.g., happy) and negative emotion words (e.g., distressed) faster than neutral words.

2.4 Design theory and methodology for interfaces

There are various theories and methodologies proposed for the design of interface in particular the machine-to-human interface in literature. In this section, several important ones are reviewed.

2.4.1 The Proximity Compatibility Principle

The proximity compatibility principle (PCP) was proposed by Christopher Wickens in 1987, which has two axioms: (1) perceptual proximity called PCP-1 and (2) processing proximity called PCP-2. Perceptual proximity (display proximity) defines how close together two display channels convey task-related information lie in the user's multidimensional perceptual space, and processing proximity (mental proximity) defines the extent to which the two or more sources are used as part of the same task (Wickens and Carswell, 1995). The PCP principle is always used as a guideline to determine where a display should be located and where the widgets that carry information should be located on an interface media (Wickens and Carswell, 1995).

2.4.2 Ecological Interface Design

Vicente and Rasmussen (1992) proposed a theoretical framework for designing interfaces for complex human-machine systems called ecological interface design (EID). Ecological Interface Design can help designers develop displays which allow users to cope with novelty and change (St-Cyr, Jamieson & Vicente, 2013). Rasmussen also proposed that EID is a framework using abstraction hierarchy model to identify variables and constraints in a domain and represents this information externally in a way that supports multiple levels of cognitive control: skill-based; rule-based; and knowledge-based (as cited in Mazaeva & Bisantz, 2013). It is widely used in interface

design. Alvarado Mendoza et al. (2011) developed an integrated advisory interface for several advanced driver assistance systems by combining EID with a user-centered design approach.

2.4.3 Function–behavior–structure

The original version of the function-behavior-structure (FBS) model was proposed by John S. Gero in 1990, which is applied in the process of design. There are three basic concepts in FBS: Function (F), Behavior (B), and Structure (S). The function is defined as “the results of the artefact's behavior”; the behavior defined as “the artefact's actions or processes in given circumstances of the natural environment”; the structure defined as “For a homogeneous artefact: its material arrangement; for an artefact composed of components: the components of the artefact, the components material arrangements and their connectivity” (Rosenman and Gero, 1998). While the FBS ontology has been discussed in terms of its completeness, our research group has extended it to fit the needs of their specific domains. Lin and Zhang (2004) extended it into FCBPSS (F: function, C: context, B: behavior, P: principle, S: structure, S: state) and applied it to designing interfaces. The context is defined as the environment where a structure is placed; the principle is the fundamental law with which one can develop a quantitative relation for the state variable; and the states of the entities are thus quantities or attributes of either physical or chemical domains (Zhang et al., 2011). Lin et al. (2003) and Lin and Zhang (2004) compared the FBS approach and the EID approach to designing interfaces and showed that the FBS approach is better than the EID approach.

2.4.4 Lin-Zhang three design phase model

It must be noted that both EID and FBS are for the concept design phase, while PCP can guide the interface design at the embodiment or layout design phase (Liu et al., 2015). Lin et al. (2006) further proposed a total interface design approach by dividing interface design into three design phrases: (1) conceptual design or concept design, (2) basic design or layout design, and (3) detailed design or detail design. Xue et al. (2015) proposed a new type of interface called redundant

interface based on the total interface design approach of Lin et al. (2006). Redundant interfaces refer to an interface that has more than one way for the user and machine to communicate on the same information and knowledge. The design steps in the approach of Xue et al. (2015) are briefly summarized as follows:

- Step 1: Work domain analysis based on the FCBPSS approach.
- Step 2: User domain analysis.
- Step 3: Identification of the functional requirement (FR) and design parameter (DP) of an interface system under design at the conceptual design phase, derived from the result of Step 1 and Step 2.
- Step 4: Layout of the DP based on the PCP.
- Step 5: Design of the DP at the detail design phase, such as color and shape of widgets.

There are also other methodologies developed for particular applications. For instance, Nuzzo et al. (2012) built a compositional synthesis framework on top of Analog Platform-based Design for design of an analog integrated interface. Anuar and Kim (2014) introduced a systematic method to identify the design requirement for human-system interfaces. Lo, Ko and Hsiao (2015) built a relationship matrix for the components on real car panels by using fuzzy graph theory to design a high-performance operating interface.

Overall, design theories and methodologies for affective interfaces are not satisfactory. PCP needs to be extended to include the affective attributes. The approach of Xue et al. (2015) needs to be extended to include the design for affective attributes in particular to design of affective machine-to-human interfaces.

2.5 Affective interface design

Unfortunately, these interfaces differ from the interface which is named “machines that have emotion” or machines that have emotional intelligence. Picard (2003) further characterized the

machine-to-human interface that has emotion with the four attributes, namely (1) emotional appearance, (2) multi-level emotion generation, (3) emotional experience (e.g., physiological changes, cognitive or semantic label, subjective feeling, etc.), (4) emotion-cognition-action [mind-body] interaction (e.g., conscious and non-conscious event, regulatory and signaling mechanisms, physiological and biochemical changes, etc.). In fact, according to the previous discussion in Chapter 1 regarding the category (vi) of machines and the category (v) of machines, the category (vi) of machines meet the first three attributes of Picard (2003), while the category (v) meets the all the four attributes. Indeed, actually the attribute (4) of Picard (2003) well supports my proposition described in Chapter 1; revisiting herein for the convenience of readers: my proposition: a machine that has emotional intelligence or emotional machine according to (Norman, 2004) must have its states (both cognitive and physical) link to human emotion labels or emotions. In the following, the literature for Affective Interface (i) (or the category (i) of machines), for Affective Interface (iii) (or the category (iii) of machines), and Affective (v) (or the category (v) of machines) is reviewed, as they are more related to the proposed research objective of this thesis study (discussed in Chapter 1).

Regarding Affective Interface (i), color of widgets has been studied widely (Arbeláez-Estrada & Osorio-Gómez, 2015). Shubin, Falck and Johansen (1996) introduced several examples of colors in interface design and pointed out that colors should be applied properly. Tylor and Murch indicated that “color can be a powerful tool to improve the usefulness of an information display in a wide variety of areas if color is used properly. Conversely, the inappropriate use of color can seriously reduce the functionality of a display system” (cited by Wright et al., 1997). The combination of text, color and graphic is powerful than each of them alone. Colored images provided higher levels of emotional activation than gray-scale images. In general, it can be said that the more affective signals are given, the more clearly the message can be understood (Schütte, 2005).

In Affective Interface (iii), Portet et al. (2013) designed a voice interface smart home system for elderly, which shows are more easy to use than general smart home system. Another famous example is the voice control system called “Siri” in iPhone. Schmitt and Minker (2013) pointed out some limitations of the current technology and the great complexity of natural language interaction between the human and machine. The US navy designed a fire fight robot called “Octavia”, which has human-like facial expression (Otto, 2012). Shayganfar, Rich and Sidner (2012) designed a methodology for expressing emotion and conducted an experiment with a robot called “Mavin” who has six different facial expressions. Hu et al. (2013) proved that an emotional expression robot which is designed by emotional expression model can improve the human-computer interaction. Kumar et al. (2014) demonstrated an intelligent and interactive interface to help reducing car accident by assisting the driver in various aspects of driving. Nakadai, Mizumoto and Nakamura (2015) designed a Robot-Audition based Car Machine Interface to improve the driving performance.

In Affective Interface (v), Potkonjak, Radojicic and Tzafestas (2002) was a pioneer to study Affective Interface (v) with a particular development that a robot state (temperature in joint) forms a human emotion (fatigue in this case). They defined a critical temperature for the joint, and then deemed that the machine has a feeling of fatigue when the actual temperature in the joint is greater than the critical temperature. Unfortunately, they have not gone on to look into how the fatigue feeling of a robot is expressed and to perhaps change the behavior of the human user who interacts with the robot. In our research group, a previous student Modi (2012) studied the effect of the emotion which is composed of the machine state on a simulated test-bed. In this thesis, a real test-bed will be built to replicate the work of Modi (2012), so in a sense, this thesis is a continuing effort on the study of the machine that has emotion (Picard, 2003).

2.6 Conclusion

Literature review and discussion above shows that emotions play a very important role in the human and machine interaction system, in particular influencing cognition and action (Megill, 2014). However, there sounds no unified approach to designing an affective interface in particular Affective Interface (v) which is least studied. This means that Objective 1 in this thesis (see Chapter 1), in short, developing a general design approach to designing the general interface incorporating the affective attribute, is in need of research. It may also be clear that there is no effective physical test-bed available for studying affective interfaces and Affective Interface (v) in particular. Therefore, to build a physical test-bed that may be useful to study Affective Interface (v) is meaningful, which refers to Objective 2 of this thesis (see Chapter 1). Finally, the experiment to study how an affective interface, Affective Interface (v), may change the behavior of the human user who interacts with the machine is important to fuel the future research on Affective Interface (v), which refers to Objective 3 of this thesis (see Chapter 1). As a final note in this chapter, a care must be taken that not all the characteristics of Affective Interface (v), as summarized by Picard (2003), were in the scope of research in this thesis, and certainly a special type of human-computer interface of Affective Interface (vi) (discussed in Chapter 1), which may also be called persuasive interface (Bickmore, 2003) was not in the scope of this thesis.

CHAPTER 3
DESIGN OF AN INTERFACE WITH AFFECTIVE ATTRIBUTES

3.1 Introduction

This chapter extends the existing design theory and methodology for interfaces, particularly the approach developed by Xue et al. (2015), described in Section 2.4, to Affective Interface (v). It is to be noted that the persuasive interface (Freeney, 2014) or a special type of the human-computer interface of the category (vi) of machines is out of reach by the design theory and methodology discussed in this thesis. Section 3.2 proposes the labels of human emotions to some common machine states, some of which are drawn from the literature, while others are inspired from Norman (2004). The connection between emotions and machine states, as proposed, is preliminary, and needs more elaboration in future work. Section 3.3 extends the PCP to the inclusion of the affective response. Section 3.4 extends the approach of Xue et al. (2015) to the design of affective interface (v) by noting that the approach is by no means to persuasive interface. Section 3.5 gives a summary with a discussion of the developed approach.

3.2 Machine state versus human emotion

The common states of a machine are: stress, strain, temperature, energy/power, material resource, information/signal/data resource, and pH-value. The association of the machine states to emotion states may be possible with respect to particular contexts. A preliminary and incomplete association of part of the machine state to emotion was developed in this thesis and is shown in Table 3-1. In Table 3-1, the first column is the machine state. The second column gives possible scenarios for the machine state. The third column is the emotion (label) that might be associated with the machine state in possible human-human scenarios. The fourth column gives symptom in terms of the output or response of consequence of the machine as well as human, such as fracture,

unbalance, and so forth. For instance, the stress in a machine is a state that describes the force on the machine over an area or simply say pressure. When a person is under stress or pressure, that person may be unhappy (or angry) in a usual situation¹. Therefore, an emotion label ‘angry’ is associated to a stressed state in a machine. When a person is in an elevated temperature environment, that person may tend to be tired not to do anything (i.e., fatigued). Therefore, over-heat in a machine is considered being associated with the fatigued state of human².

It is noted that the list in Table 3.1 is not exhaustive but it suffices to the purpose of this thesis (e.g., a machine’s thermal state is associated with a human’s fatigued state). A more exhaustive list warrants a future work. Further, it is my belief that the association of machine states and emotion states may be many-to-many and depend on particular applications or contexts in a general sense (Zhang, 1994).

Table 3-1. Human emotions representing machine states

Machine state	Context	Human emotion	Symptom
Temperature	Over or under	Fatigued	Performance slow down; burning
Short of material resource	A*	Mood down	Performance slow down
Run of material resource	B*	Heart-broken	Stop functioning
Stressed/strained	C*	Angry	Performance slow down; deformation; broken
Short of energy/power	D	Scared	Performance slow down; noise and vibration
Short of information	E	Scared	Performance slow down

* not considered in this thesis but tailored to a particular application.

¹ A usual situation refers to a situation that the majority of people in a community will take.

² See the discussion around Figure 2-1.

3.3 Extension of PCP to the affective compatibility

As reviewed in Chapter 2, one of the most powerful approaches to design a machine-to-human interface is the PCP (proximate compatibility principle) (Wickens and Carswell, 1995). The PCP with the two general principles (see the previous discussion in Chapter 2) is not proposed for designing an affective machine-to-human interface. A new PCP is proposed herein for designing an affective machine-to-human interface, as stated below.

***PCP-3:** proximate compatibility principle for emotion or affect. That says, a machine-to-human interface must be designed to make the emotion of the machine be compatible with the emotion of human. Several remarks regarding PCP-3 are further discussed below.*

Remark 3-1: In Chapter 2, particularly in Definition 2.1, emotions were described. However, one must be aware that the science of emotions or why and how emotions occur to human beings is not well understood, leaving many debates in literature. This thesis assumes the emotion theory as illustrated in Figure 2-1, and further considers the attributes of cultures³, values, life philosophies, and life styles, and geographies as the five most fundamental ones to account for the emotional behavior of human beings⁴.

Remark 3-2: The effect of PCP-3 will be taken on in all the interface design phases, i.e., the concept design, embodiment design, and detail design. The definition of the design phases for interface can be found from Lin et al., (2006). Figure 3-1 gives an example of the architecture of building of four countries or regions to illustrate how PCP-3 may work. A building is viewed as a machine or technical system, and its architectural elements that put together are viewed as an interface device or product of the building. Buildings are designed, in addition to their functions and comforts, to meet the emotional need of people in a particular society and a particular

³ Collective behavior of people on life.

⁴ Adapted from the definition from (<https://en.oxforddictionaries.com/definition/culture>).

geographical situation. For instance, the geographical condition of The Netherlands (Delft in particular) is such that the whole land is enclosed by sea and below the sea level, and there are a lot of canals in the land to control the water level in the land. People in The Netherlands like the blue color, as it is the sea color, and people like the green and brown colors, as these two colors belong to the same family of blue. This is with reference to the detail design of interfaces according to Lin et al. (2006). At the concept design phase, the building in Figure 3-1b is with a shape of tower. The tower shape gives an imagination of the light tower in the sea to give some navigation to ship. The building in Figure 3-1c resides in Italy (Pontedera), which meets the geographical and climate condition in there (Mediterranean climate), that is hot, humid, dry summers and mild, rainy winters. The shape is flat with the material of soil-based cement and wood with reference to the concept design and embodiment design. The yellow color dominates the building color in that part of Italy with reference to the detail design. Figure 3-1a is the indoor decoration of a building in Canada (Saskatchewan). The weather in Saskatchewan is extremely cold and the land is plain (prairie). The building architecture is gracious, made of the steel material and stone, and with the dark color. Finally, Figure 3-1d is the landscape of a part of the town in France (Troyes). The climate in France is between Italy and The Netherlands, and one may be able to see that the architecture is between that of Italy (Pontedera) and Netherlands (Delft).

Remark 3-3: By generalizing the previous discussion in Section 3.2 – particularly Table 3-1, one can view the association of machine states to emotion states as a generalized match between the human and machine in terms of emotion. Therefore, the concept as illustrated in Table 3-1 can be viewed as part of PCP-3.



Figure 3-1. Buildings at different countries: (a) Canada (Saskatoon), (b) The Netherlands (Delft), (c) Italy (Pontedera), (d) France (Troyes)

3.4 A general design procedure to affective machine-to-human interfaces

The following design steps are adapted from the novel procedure proposed by Xue et al. (2015) by including the affective attributes – particularly by incorporating PCP-3.

Step 1: work domain analysis for the machine-to-human interface. The result of this analysis is a collection of information that needs to be communicated to the user. It is important to note the difference of the approach here other than the approach in Xue et al. (2015) in that the result of work domain analysis in this thesis is the information that needs to interact with the user (e.g., the temperature in the processor of a computer machine), which is not a complete collection of information for the work domain in consideration.

Step 2: user domain analysis. The result of this analysis is a collection of assumptions about the user in the aspects of both the user's cognition and emotion⁵. These assumptions are about the user's knowledge of the underlying work domain or system and about the user's affective experience of the underlying work domain or system. For instance, if a work domain is a laptop computer, there may be assumptions that the user should have the knowledge that when the temperature is too high the computer will die (in the aspect of cognition) and that the user would express a frustrating feeling or mood⁶ (in the aspect of emotion) if the computer dies (while the user is working on some important stuff on the computer).

Step 3: identification of the Function Requirement (FR) and Design Parameter (DP) of a machine-to-human interface device under design. It is noted that at this step, the DP may not be any kind of entity that describes materials and geometry but the entity that explains why and how an object or a system that is composed of material and has geometry can fulfill the FR. In general, the FR has three categories: action or hand, cognition or head and emotion or heart. Therefore, the DP also has three categories. Particularly, for the emotion category of FR, Table 3.1 could be applied; as well PCP-3 could be applied.

It is further noted that specific FRs are derived from the work domain analysis. For instance, for the web interface of a university, one specific FR may be: to allow the user to find professors who have research in the area of robotics. Specific DPs are derived from specific FRs and the user model analysis. For example, continue the foregoing example, the university web interface – finding a professor whose area is robotics, there may be two specific DPs or routes of search to achieve this specific FR.

- DP1: (1a) go to the college and then department of mechanical engineering and electric engineering, (1b) then open the list of faculty members to view the research area, (1c) find

⁵ Not only those temporary but also persistent attributes (see also the discussion in Remark 3-2).

⁶ The definitions of feeling and mood can be found in Chapter 2.

all faculty members who have their area of research in robotics.

- DP2: (2a) find the research area of the department of mechanical engineering, and then (2b) find the area of research “robotics”, and (2c) find the faculty members in the area of robotics.

The fact that there could be two DPs in this case demonstrates the notion of redundant interface developed by Xue et al. (2015), which increases the user-satisfaction and the resilience of interfaces (particularly machine-to-human interfaces) according to Xue et al. (2015).

It is further noted that the interface product differs from the machine product in that for a machine product, finding DPs is not a straightforward task. For instance, for the FR that is to convert the rotation to the translation, the DP can be a crank-slider mechanism or rack-and-pinion mechanism (Figure 3-2). The design knowledge of this kind is built upon kinematics, which is further built upon physics and geometry. In the case of designing a machine-to-human interface, the DP simply serves to exhibit the information, while “exhibiting information is exactly the FR of interface”. Therefore, one can simply say: DP is nearly FR in most of cases. At most, DP refers to the navigation to search information, as discussed above (the example of searching a professor whose research area is robotics).

Last, FR and DP still need to meet the Axiom 1 of ADT (Axiomatic Design Theory), as the interface is after all a kind of product. Axiom 1 states: For a product which has several FRs at the same level in the hierarchy of product, they must be independent to each other, and further, DPs that fulfil FRs must maintain this independency. For details about Axiom 1 and ADT, interested readers are directed to Appendix B.

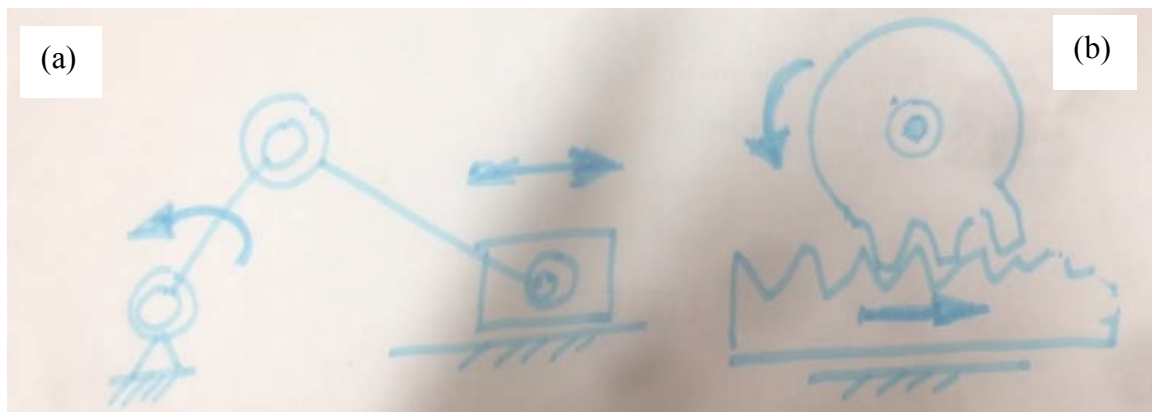


Figure 3-2. The design parameters (DPs) for the function of converting a rotation to translation:
 (a) crank-slider; (b) rack-and-pinion

Step 4: layout of the DP, based on PCP-1, PCP-2 and PCP-3. It is noted that at this step, PCP-3 is at play, which differs from the procedure of Xue et al. (2015). For instance, in Figure 3-1b, c, d, one can see the difference of layout of buildings with respect to the cultural element of people, in Canada, France, Netherlands, and Italy.

Step 5: design of the DP at the detail design level, where essentially details of the widgets are specified. For instance, details of a voice widget are specified if an audio sensory system is talked about. At this level, the physical redundancy may also be designed according to Xue et al. (2015). An example of the physical redundancy is that both the text display and voice exhibition are used for the same piece of information. It is also noted that at this step, PCP-3 will be considered, which differs from the procedure of Xue et al. (2015). For instance, in Figure 3-1, one can see the difference in the color of building, which matches the different cultural elements of Canadian, French, Italian, and Dutch.

3.5 Summary with discussions

In this chapter, a general design approach was proposed for machine-to-human interfaces with the affective attribute or the category (v) of machines, as proposed before in this thesis, particularly

Section 1.2. Special care needs to be taken that the interface discussed in this thesis is not the so-called persuasive interface but refers to the notion that a machine that has human emotion – particularly that the machine state is connected with the emotion. However, the proposed general design approach can be further extended to persuasive interfaces by adding a persuasive module that is tailored to individual users. The example of such a module is the so-called Relational Agent pioneered by Bickmore (2003).

Several salient points with the proposed approach can be summarized. First, the PCP in the literature (Wickens and Carswell 1995) has been extended to the inclusion of emotions (i.e., PCP-3). In the interface design literature, aesthetic interfaces were studied, see the work of Lund (2015) and Pajusalu (2012) and the work in our group (Wang, 2010; Mokarian, 2007), but the focus of the aesthetic interface is only on beauty which is a narrow sense of emotion. Certainly, there is no generalization of the theories in these works to PCP-3 presented in this thesis. Second, the association of machine states to emotion states has been more comprehensively developed than what was developed in literature. Potkonjak et al. (2002) only did a specialized study on the thermal state but never generalized their work to the category (v) of machines, as elaborated in this thesis. Norman's work (2004) is inspiring, but he stayed at elaboration of the concept of emotional machine.

CHAPTER 4

CONSTRUCT A TEST-BED OF AFFECTIVE INTERFACE

4.1 Introduction

This chapter has two purposes. The first purpose is to build a test-bed for affective interfaces for the experiment to test the general hypothesis (see Chapter 1 for detail). The second purpose is to illustrate the application of the proposed design approach to affective interfaces, as described in Chapter 3. The test-bed is a laptop computer with a particular attention to its thermal state ‘temperature’ or over-heat in its microprocessor or CPU (central processing unit). The organization of this chapter is as follows. In Section 4.2, an affective interface for the laptop computer is designed by following the steps of the approach in Chapter 3. Section 4.3 presents a discussion of the development process.

4.2 Design of an affective interface for the laptop computer

4.2.1 The scope and assumption

Laptop computer can be viewed as a machine, data processing machine in this case. There are two conditions or constraints for the computer machine to perform its function: temperature and memory. This means that a computer machine may fail due to too high temperature in its processor and may fail due to its memory overflow. This thesis only considered the temperature condition. It is known that the critical temperature in a computer depends on the nature of data processing task as well as the length of data processing. The notion called **critical temperature** arises. That is to say, given a particular data processing task along with its length of time, there is a particular critical temperature, over which the machine may die. In order to avoid a sudden collapse of the computer machine, a monitor of the temperature in the computer is thus very important especially for some very important data processing task.

The study of this thesis was not to design a completely new interface for laptop but to add on top of the existing interface for laptop, which is widely available (Figure 4-1), an affective interface for the temperature monitoring. The monitor works as such: when the actual temperature in the computer is greater than the critical temperature, the user will get a warning signal and may take action accordingly, such as backing up the process including the data and pausing the task performing.



Figure 4-1. Two existing laptop interfaces: (a) Apple computer, (b) Microsoft computer.

It is noted that this warning interface may sound like playing some role in persuading the user to take action to prevent a collapse of the computer. However, this is certainly not the main purpose of this thesis. In fact, the interface, though with different affective influences to the user, does not have a target or object to persuade the user to reach a target, e.g., purchasing a property as the software real estate agent does in the work of Bickmore (2003).

4.2.2 Step-by-step design process

Step 1. Work domain analysis.

The main function of the computer machine is to process data. The computer machine can be viewed as having two tier architecture: infrastructure system and substance system (Zhang and van Luttervelt, 2011). The infrastructure system is meant for the hardware system such as processor,

memory, and so on. The substance system is meant for the software system, which includes the data and process management software and application-oriented data. It is noted that the application-oriented data is associated with a particular task that the human user is interested and performs tasks with the computer. Since this thesis was focused on the temperature monitoring, the temperature in the computer hardware system or infrastructure system is concerned, in particular the temperature in CPU (central processing unit). The temperature in CPU is obtained through a sensor built in the computer and can be read by a program function called “C#” (Appendix C).

Step 2. User domain analysis.

It is assumed that the human user knows that (1) the temperature is a condition for the machine to function, (2) when the actual temperature is greater than the critical temperature, there is a period of time that the machine can operate but after that the computer will shut down, and (3) the high temperature (i.e., greater than the critical temperature) may cause the crash of the computer.

Step 3: Identification of the Function Requirement (FR) and Design Parameter (DP) of the machine-to-human interface (i.e., the temperature warning interface) device under design.

From the results of the first two steps, one can obtain:

- FR 1: allowing the user to specify a critical temperature to the computer.
- FR 2: showing the temperature in the processor of the computer machine.
- DP 1: a human-to-machine interface device to allow the computer designer to specify the critical information to the machine.
- DP 2: a machine-to-human interface device exhibits the temperature information to the human user. There could be several ways to do so, which follows the concept of redundant interface, namely DP 2-1: display the actual temperature with a real number value; DP 2-2: display a temperature bar; DP 2-3: exhibit in voice. In this design, DP 2-3 has three

versions of voices that are supposed to significantly⁷ change a user's emotion and thus task performance including the response to the warning signal, and the three version of voices will be discussed later.

Step 4: Layout of DP, based on PCP-1, PCP-2 and PCP-3

DPs are further physically rendered to widgets and gadgets which are a collection of widgets (Zhang, 1994). Figure 4-2 shows the layout of the DPs on the interface media. There are four gadgets or areas in the interface, denoted as A, B, C, and D. It is noted that this particular temperature interface is just a part of the total interface of the computer (Figure 4-1, where on the lower right corner (denoted by TM), there is supposed to be a temperature monitoring interface). This thesis was focused on the development of the interface for the temperature monitoring.

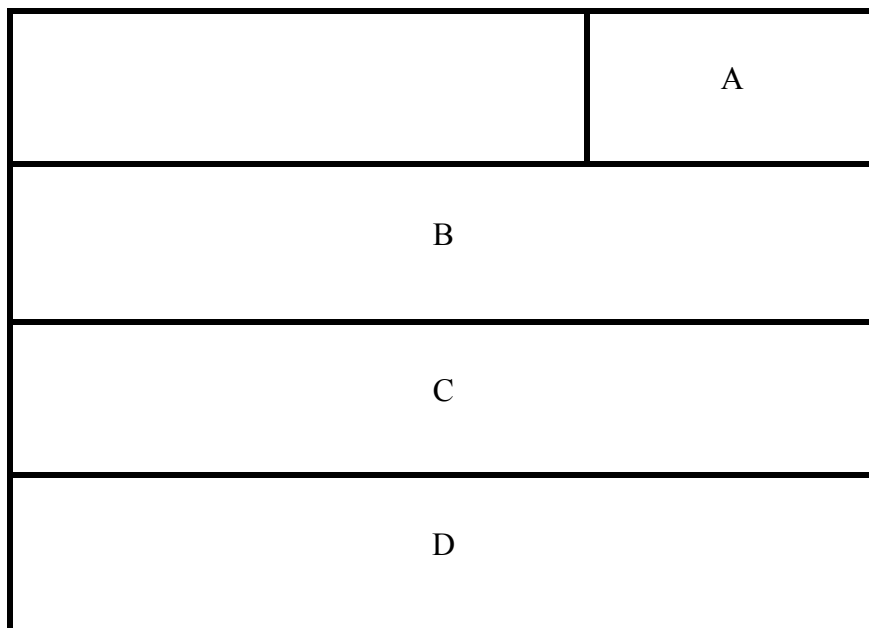


Figure 4-2. Layout of DPs on the interface media

⁷ By significantly, it is meant for the statistical significance.

Gadget A:

This gadget/area is designed to realize the DP 1 – that is to allow the computer machine designer to enter the critical temperature (e.g., 70⁰ C). It is noted that the critical temperature is also called warning temperature; that is to say, if the actual temperature in the computer machine is greater than the critical temperature, the machine will warn the user, as otherwise after a while the computer will shut down. Figure 4-3 shows this gadget.



Figure 4-3. Display of Gadget A

Gadget B:

This gadget/area is designed to display the real-time temperature in the computer, obtained by a temperature sensor in the CPU of a computer machine (Figure 4-4).



Figure 4-4. Display of Gadget B

Gadget C:

This gadget/area is designed to give the temperature in CPU of the computer machine using an image bar, as shown in Figure 4-5 (the red line indicates the critical temperature), both the bar length and bar color will change with the change of the temperature in CPU of the computer.

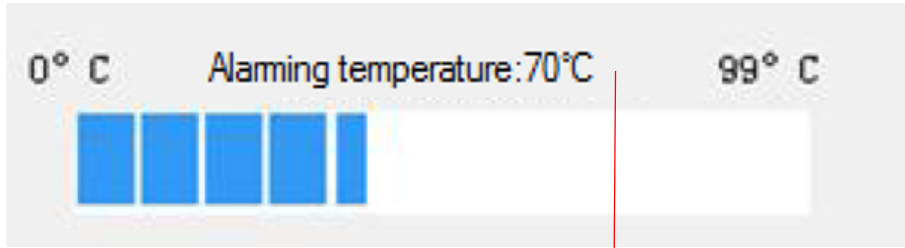


Figure 4-5. Display of Gadget C

Gadget D:

This gadget/area is designed to exhibit the warning using the voice modality, as shown in Figure 4-6. In this case, three different voices for warning message are designed. The first voice is with no emotion (“Bi --- Bi --- Bi” sound), the second voice is with a fatigued sound, and the third one is with an anxious emotion. The design of the fatigued sound is based on Table 3-1 in Chapter 3, that is, the high temperature emulates the cognitive fatigued or tired emotional state. The design of the anxious state was intended to understand what a different effect would be to the user if an emotional state does not emulate a machine state (i.e., the anxious state of the human does not emulate the over-heat state of the computer machine). The contents of the voices are shown in Table 4-1.

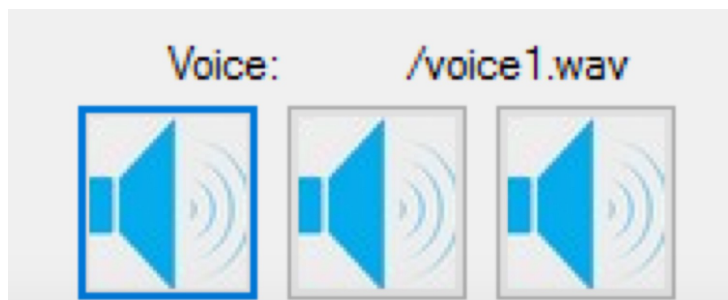


Figure 4-6. Display of Gadget D

Table 4-1. Contents of the three voices for the warning message - Gadget D

Interface	Voice type	Warning content
Voice 1 (V1)	Beep message	“BI——BI——BI——”
Voice 2 (V2)	Fatigue voice	“Hi, I am so tired. Could you please pause the game for a second? I want to have a rest.”
Voice 3 (V3)	Anxious voice	“Stop! Stop! It is so hot! I am going to die if you continue playing!”

Step 5: Design of the DP at the detail design level, where essential details of the widgets are specified. Figure 4-7 shows the detailed design of the temperature monitoring interface. In this thesis, no much attention has been put on the shape, size, and color of the widgets. The entire computer code for the interface of Figure 4-7 can be seen in Appendix C.

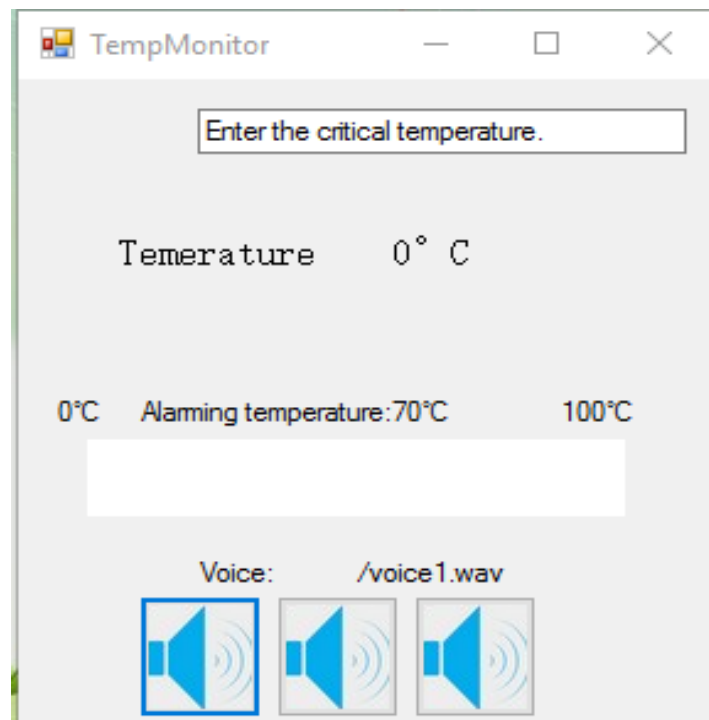


Figure 4-7. Detailed design of the temperature monitoring interface as a test-bed

4.3 Conclusion with discussion

In this chapter, a general test-bed was designed for an experiment to be presented in the next chapter (Chapter 5). The test-bed was designed by following the proposed interface design approach in Chapter 3, which was intended to show the effectiveness of the proposed design approach. The proposed design approach to affective interfaces appears to be systematic (step-by-step) and rational (association of machine states to emotion states and PCP-3). On a side note, the design of the two affective interfaces to the particular problem in this chapter (i.e., over-heat warning for the computer machine) may give some implication to persuasive interfaces (Bickmore, 2003) in that one with a more correct emulating to an emotional state (i.e., the fatigued state to an over-heat state of the machine) may have a better collaboration with the user than the one with a less correct emulating to an emotion state (i.e., the anxious state to an over-heat state of the machine). More work needs to be done in future on this speculation.

CHAPTER 5 EXPERIMENT

5.1 Introduction

This chapter describes the experimental study of the general hypothesis as proposed in Chapter 1, which is revised here for the convenience of discussions. The general hypothesis of this thesis is: *the machine that has emotions will significantly change humans' judgement and decision making in the event that such machines interact with humans*. In this chapter, this general hypothesis is studied experimentally.

5.2 Materials and Methods

5.2.1 Experimental design

The interface is obviously a factor and it has three levels corresponding to the three voice widgets to deliver the warning message (see Table 4-1), namely 'regular', 'fatigue', 'anxiety'. All of the research participant performed called 'GoBang' (Figure 5-1). This task was selected as it had the feature of competition and rewarding, and it was further assumed that the participants do not like to interrupt the task unless some urgent need arises. The urgent need in this experiment was an over-heat in the CPU of the computer machine that may further unexpectedly terminate the computer, and when the unexpected termination of the computer system occurs, the player was considered as a loser of the game (i.e., no any reward is offered). It is noted that there was a time tolerance for the over-heat for the computer to terminate or not, that is, when the over-heat occurs, the computer does not immediately terminate the task performing but instead, waits for a while (i.e., time tolerance) until the subject does not respond to the warning (i.e., to pause the task performing). The task performance by the subject was scored (see Figure 5-1, "score") and this score was continuously displayed to the subject. The score was calculated by the task performing

time, and the shorter the time, the higher the score. In the experiment, the task performing was not actually terminated; instead the penalty of the zero score was given to the participant for failure to respond to the warning message in a pre-defined period of time (10s).

The subject was given a duration of time (10 minutes in this case) to perform the task. While performing the task, the subject can see the score. When the over-heat in the computer occurred, a warning message was delivered to the subject with three voice interfaces separately or one at each time. The subject may or may not respond to the warning message, and the subject was performing the task to the end of the required duration.



Figure 5-1. The Game interface of “Gobang”

After task performing, the top three winners of the subjects were offered a gift. For each task performing with one interface (i.e., the three voice interfaces), the subject repeated three times. The average score was calculated over the three repeats of task performing, which was regarded as the score of the subject with one interface. So there were three scores for a participant corresponding to the three voice interfaces, respectively.

To avoid the carry-over factor that may be caused by the familiarity of the interface and subsequently the subject’s developing a strategy for the response to the warning message (i.e., the subject’s response behavior may not be solely due to the interface but the foregoing strategy as well), a randomized block design of the task performing was taken in the experiment. Three blocks were designed in this case to conform to the three levels of the interface (i.e., three voice interfaces). Participants were randomly assigned to one of the three groups. Each group performed the task with the three interfaces by following the order as shown in Table 5-1. The order is given by the Latin Square (Latin Square, n. d.). Latin square design is a type of partially balanced incomplete block design (PBIBD). The Latin square design is for a situation in which there are two extraneous sources of variation. The advantages to choose Latin Square design are: (1) Greater power than the general randomized block design when there are two external sources of variation; (2) Easy to analyze.

Table 5-1. Blocks with various treatments

Block	Interface		
Block 1	V1	V2	V3
Block 2	V2	V3	V1
Block 3	V3	V1	V2

5.2.2 Participants

There were 12 participants or subjects recruited from the University of Saskatchewan for this experimental study. All subjects recruited for this study were healthy, free of anxiety/depression symptoms, and reported no history of neurological or affective disorder. The subjects were all right-handed, with normal or corrected to normal vision. Each subject signed an informed consent form for the experiment. The experimental procedure was in accordance with the University of Saskatchewan Behavioral Research Ethics Board as described in Appendix A of this thesis. The sample size (i.e., 12) was determined based on the empirical knowledge of Cohen (1998) who pointed out that the statistical power of the experiment in human behavior should be higher than 80%. In this experiment, the confidence interval is 95%, effect size = medium (0.75), the number of levels of effect “interface” =3; the number of levels of effect “block” =3. Based on all this information, the statistical power of the sample size can be found from the program in the following website: “<http://www.math.yorku.ca/SCS/Online/power/>”, and the result is as follows: the sample size is 12, the statistical power is 0.808 (greater than 0.8), so the sample size (12) is adequate.

5.2.3 Measurement

Measurement of the subject’s state and behavior was taken by the task performance and self-reporting approaches. The task performance measure was discussed before, the task performance score in this case (see the previous discussion in Section 5.2.1). The self-reporting measure was taken by a questionnaire with the 7-point Likert scale (Cai et al., 2016). The questionnaire is shown in Figure 5-2). Several remarks on the questions are discussed below. First, Question 1 was designed to understand whether the participants enjoyed performing this game; it was desired that the participants liked to play this game. Second, Question 2 was designed to understand whether the affective interface may affect the user’s task performance; it was desired that the affective interface should not interfere with the task performance. Third, Question 3 and Question 5 were designed to understand the participants’ emotions, particularly one negative emotion by Question

3 and one positive emotion by Question 5. It is noted that according to the model of Plutchik's Wheel of Emotion (Wodehouse & Sheridan, 2014) (see Figure 5-3), both the annoying and interesting states appear on the model. Fourth, Question 4 was designed to understand whether the participants view the affective interface in terms of its potential improvement of human-machine cooperation. Finally, from the foregoing discussion, these questions are independent to each other.

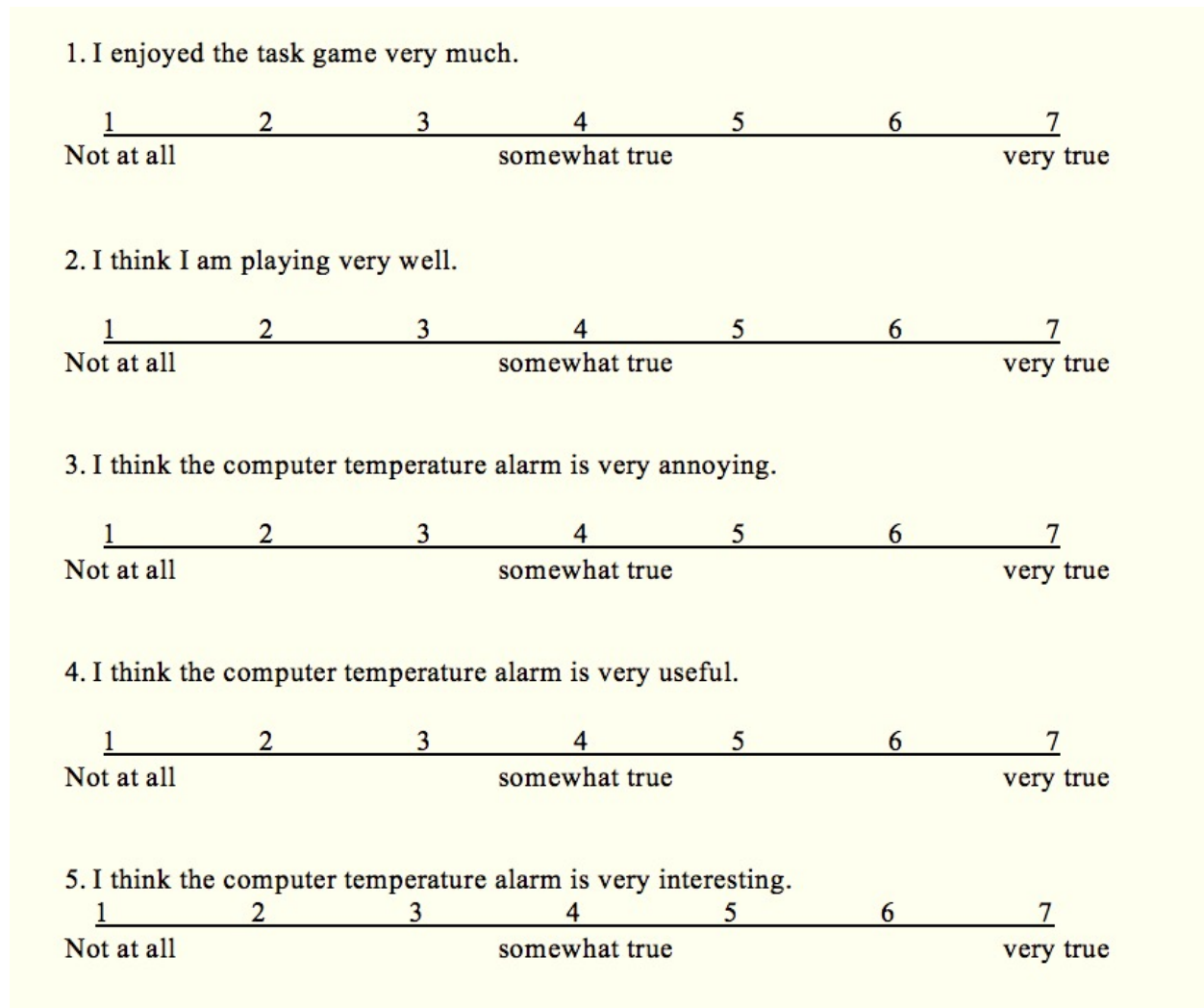


Figure 5-2. Questionnaire for the satisfaction of the subjects with respect to the interfaces

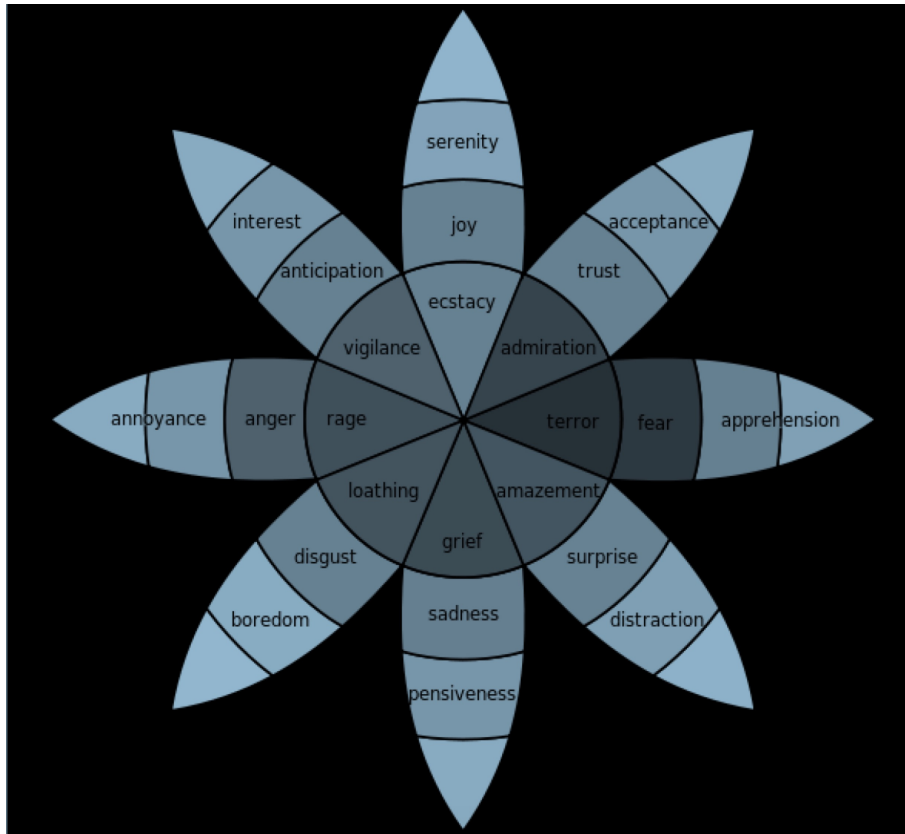


Figure 5-3. Plutchik's Wheel of Emotion

5.2.4 Data analysis and software

The experiment as designed has two factors, namely the interface factor and block factor. For the interface factor, the design followed the within-subject design and it has three levels (regular, fatigue, anxiety), and for the block factor, the design followed the between-subject design – that is each block contains four subjects, and it has three blocks. The statistical analysis method called ANOVA (analysis of variance) was employed for data analysis for this experiment, as the factor has multiple levels (>two levels). The software called SPSS was employed for data analysis.

5.3 Results and discussions

5.3.1 Results

5.3.1.1 Reaction time of the subject

The subject reaction time refers to the task performance score was collected, as shown in Table 5-2 to Table 5-4. It is noted in these tables that if a participant did not respond to the warning message, his or her reaction time was assigned a default time 10s which is a penalty (see Section 5.1.2 for the discussion of how the score was calculated). Table 5-5 shows the result of each participant's reaction time with respect to all the three interfaces. To giving a more vivid impression of the result shown in Table 5-5, the same information of Table 5-5 is plotted and is shown in Figure 5-4.

Table 5-2. Result on Block 1

Block1	V1	V2	V3
Participant 1	5.00s	4.2s	4.4s
Participant 2	10.00s	6.5s	3s
Participant 3	10.00s	7s	5.6s
Participant 4	8.30s	5.2s	5.3s

Table 5-3. Result on Block 2

Block2	V2	V3	V1
Participant 5	4.2s	4.2s	10.00s
Participant 6	10s	8s	4.80s
Participant 7	4s	4.1s	5.50s
Participant 8	9s	10s	6.00s

Table 5-4. Result on Block 3

Block3	V3	V1	V2
Participant 9	6s	8.60s	5.3s
Participant 10	6.2s	10.00s	6s
Participant 11	2s	7.00s	3s
Participant 12	3.8s	6.40s	5.4s

Table 5-5. The reaction time on the three interfaces

Participant	V1	V2	V3
1	5.00s	4.20s	4.40s
2	10.00s	6.50s	3.00s
3	10.00s	7.00s	5.60s
4	8.30s	5.20s	5.30s
5	10.00s	4.20s	4.20s
6	4.80s	6.00s	8.00s
7	5.50s	4.00s	4.10s
8	6.00s	9.00s	10.00s
9	8.60s	5.30s	6.00s
10	10.00s	6.00s	6.20s
11	7.00s	3.00s	2.00s
12	6.40s	5.40s	3.80s

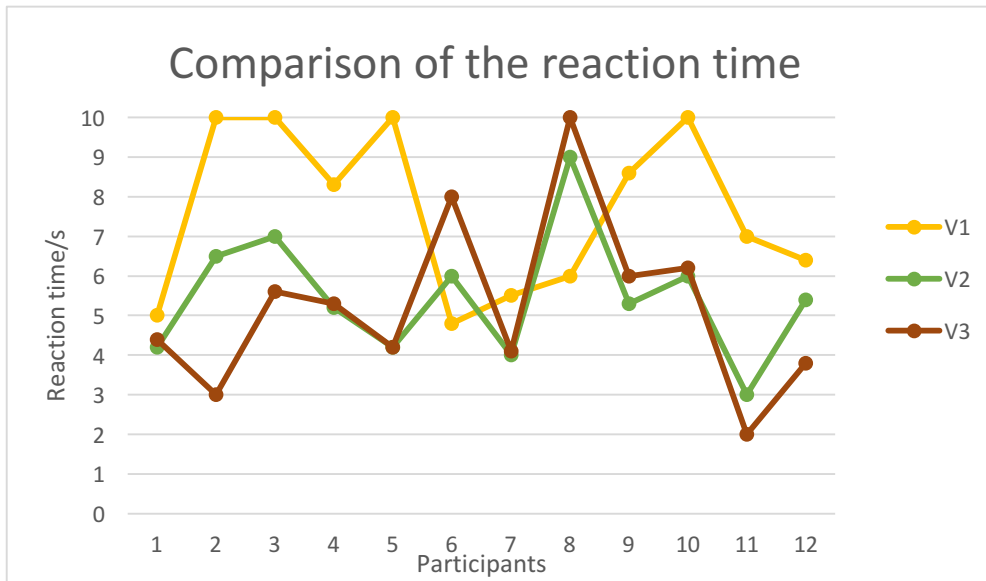


Figure 5-4. Comparison of the reaction time profile

5.3.1.2 Questionnaire of the participants

The score of the participants in responding to the questionnaires is shown in Table 5-6 to Table 5-8.

Table 5-6. Scores on Block 1

Block1	V1	V2	V3
Participant 1	19	23	21
Participant 2	21	29	23
Participant 3	18	27	24
Participant 4	21	23	27

Table 5-7. Scores on Block 2

Block2	V1	V2	V3
Participant 5	20	24	23
Participant 6	23	22	24
Participant 7	20	25	20
Participant 8	21	23	22

Table 5-8. Scores on Block 3

Block3	V1	V2	V3
Participant 9	21	24	21
Participant 10	21	30	24
Participant 11	22	24	23
Participant 12	22	23	25

5.3.2 Discussion

5.3.2.1 Analysis of the reaction time data

The analysis of data with respect to the two assumptions of the ANOVA was first performed. ANOVA has two basic assumptions: Normality of residuals and Homogeneity of variance.

(1) Normality of residuals

A normal probability test was applied to determine whether the data fit a normal distribution ($p > 0.05$). The result is shown in Table 5-9. It is noted that the dependent variable here is the reaction time and the independent variable is the interface which three levels (or interfaces). The results of the normal probability tests indicated that the data of all dependent variables did fit a normal distribution ($p = 0.659 > 0.05$).

Table 5-9. Kolmogorov-Smirnov test

		Reaction Time
N		36
Normal Parameters ^{a,b}	Mean	6.1111
	Std. Deviation	2.20788
	Absolute	.131
Most Extreme Differences	Positive	.131
	Negative	-.100
Kolmogorov-Smirnov Z		.787
Asymp. Sig. (2-tailed)		.565

a. Test distribution is Normal. b. Calculated from data.

(2) Homogeneity of variances

A homogeneity test determines whether the data of population variances are equal. In this experiment, Levene's test was applied, as it is suitable to the problem with more than two variables or levels. The result of Levene's test is shown in Table 5-10. The result ($p=0.365>0.050$) indicated that each variance of the dependent variable was equal and therefore the data meets the Homogeneity of variances assumption of ANOVA.

Table 5-10. Test of Homogeneity of Variances

F	df1	df2	Sig.
1.149	8	27	.365

a. Dependent Variable: Reaction Time

(3) Two-way ANOVA test

To understand whether there is a significant difference in the reaction time with respect to the three interfaces, a two-way ANOVA test was conducted on the data of Table 5-5, and the result is shown in Table 5-11.

Table 5-11. Tests of the Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	62.031 ^a	8	7.754	1.928	.097
Intercept	1344.444	1	1344.444	334.300	.000
Block	1.721	2	.860	.214	.809
Interface	42.136	2	21.068	5.239	.012
Block * Interface	18.174	4	4.544	1.130	.363
Error	108.585	27	4.022		
Total	1515.060	36			
Corrected Total	170.616	35			

a. Dependent Variable: Reaction Time

b. R Squared = .364 (Adjusted R Squared = .175)

Table 5-12. Comparison of the mean between the different blocks

Block	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00	6.208	.579	5.021	7.396
2.00	6.317	.579	5.129	7.504
3.00	5.808	.579	4.621	6.996

a. Dependent Variable: Reaction Time

Table 5-13. Comparison of the mean between the different interfaces

Interface	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.00	7.633	.579	6.446	8.821
2.00	5.483	.579	4.296	6.671
3.00	5.217	.579	4.029	6.404

a. Dependent Variable: Reaction Time

There is no any outlier found in the reaction time data. It can be seen from Table 5-11 that there is a significant difference in the reaction time among three interfaces, interface ($p=0.012<0.05$), but there is no significant difference between different blocks, block ($p=0.809>0.05$). The non-significant difference among the blocks means that the difference among participants is not a factor at all. The p-value of joint fact (block \times interface) is $0.363>0.05$, which means the two factors are independent and the designed experiment is in a correct shape. Table 5-12 and Table 5-13 show the means of reaction time to the three blocks and three interfaces, respectively. From Table 5-13, the mean reaction time of the interface V1 is much higher than those of the other two interfaces (V2, V3). This means that the affective interface may improve the user's task performance.

For a further look into the difference among the interfaces, Post hoc test (Tukey HSD) was taken, and the result is shown in Table 5-14. From Table 5-14 it can be seen that there is significant

difference between interface V1 and V2 ($p=0.036$) and between V1 and V3 ($p=0.017$), respectively. But there is no significant difference between V2 and V3 ($p= 0.943$), which means that the affective interfaces ('fatigue', 'anxiety') do not have a significant difference in terms of changing a user's cognition and action (i.e., playing the game and receiving the warning of over-heat) but they two significantly improve a user's cognition and action as opposed to the interface with no-emotion expression (V1).

Table 5-14. Multiple comparisons between the different interfaces

(I) Interface	(J) Interface	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	2.1500*	.81870	.036	.1201	4.1799
	3.00	2.4167*	.81870	.017	.3868	4.4466
2.00	1.00	-2.1500*	.81870	.036	-4.1799	-.1201
	3.00	.2667	.81870	.943	-1.7632	2.2966
3.00	1.00	-2.4167*	.81870	.017	-4.4466	-.3868
	2.00	-.2667	.81870	.943	-2.2966	1.7632

a. Dependent Variable: Reaction Time

b. The error term is Mean Square (Error) = 4.022.

5.3.2.2 Analysis of the questionnaire data on Question 3

There is no any outlier found in the data of the participants' response or score to Question 3. Figure 5-5 shows the profile of the responses of the participants on Question 3. In the following, first, the two assumptions of ANOVA are verified, and then the result on Question 3 is presented.

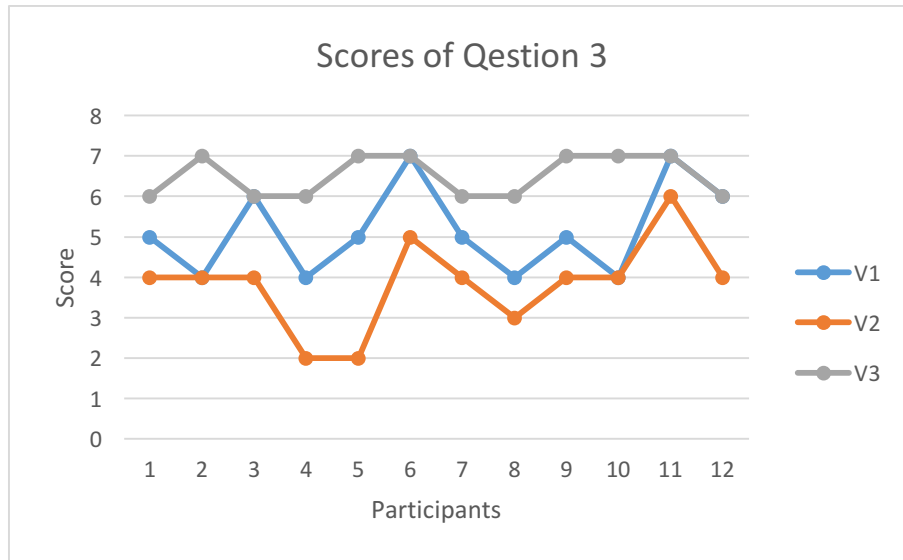


Figure 5-5. Scores of Q3

(1) Normality of residuals

The approach for the testing the Normality of residuals here follows the approach as presented before in Section 5.3.2.1. Table 5-15 shows the result of the testing. The results of the normal probability tests indicated that the data of all the dependent variables did fit a normal distribution ($p= 0.148 > 0.05$), which meets the assumption of ANOVA.

Table 5-15. One-Sample Kolmogorov-Smirnov Test

		scores
N		36
Normal Parameters ^{a,b}	Mean	5.17
	Std. Deviation	1.444
	Absolute	.190
Most Extreme Differences	Positive	.179
	Negative	-.190
Kolmogorov-Smirnov Z		1.142
Asymp. Sig. (2-tailed)		.148

a. Test distribution is Normal.

b. Calculated from data.

(2) Homogeneity of variances

The approach for the testing the Normality of residuals here follows the approach as presented before in Section 5.3.2.1. Table 5-16 shows the result of the testing. The result in Table 5-16 ($p=0.429>0.050$) indicated that each variance of dependent variable was equal and therefore the data meets the Homogeneity of variances assumption of ANOVA.

Table 5-16. Test of Homogeneity of Variances for Q3

F	df1	df2	Sig.
1.044	8	27	.429

a. Dependent Variable: scores

b. Design: Intercept + interface + block + interface * block

(3) Two-way ANOVA test

Table 5-17 shows the result of the two-way ANOVA test, and the result shows that there is a significant difference among the three interfaces (interface, $p=0.00<0.05$), but there is no significant difference between the different blocks (block, $p=0.182>0.05$). To address where the difference of the three interfaces exists, a Tukey HSD test was further conducted and the result is shown in Table 5-18. It can be seen from Table 5-18 that there is a significant difference between V1 and V2 ($p=0.007<0.05$), V1 and V3 ($p=0.007>0.05$), and V2 and V3 ($p=0.000<0.05$). This result means that there is a significant influence over the user's emotion with the affective interfaces.

Table 5-17. Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	47.000 ^a	8	5.875	6.101	.000
Intercept	961.000	1	961.000	997.962	.000
Block	3.500	2	1.750	1.817	.182
Interface	42.667	2	21.333	22.154	.000
block * interface	.833	4	.208	.216	.927
Error	26.000	27	.963		
Total	1034.000	36			
Corrected Total	73.000	35			

a. Dependent Variable: scores

b. R Squared = .644 (Adjusted R Squared = .538)

Table 5-18. Difference among the three interfaces on Q3

(I) interface	(J) interface	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.33 [*]	.401	.007	.34	2.33
	3	-1.33 [*]	.401	.007	-2.33	-.34
2	1	-1.33 [*]	.401	.007	-2.33	-.34
	3	-2.67 [*]	.401	.000	-3.66	-1.67
3	1	1.33 [*]	.401	.007	.34	2.33
	2	2.67 [*]	.401	.000	1.67	3.66

a. Dependent Variable: scores

b. The error term is Mean Square (Error) = .963.

From Figure 5-5, it can be seen that the average score of the response on Question 3 with the interface V2 is lower than that of the interface V1 but the score of the interface V3 is the highest one. This means that V3 (anxiety) is most annoying to the participants. As earlier mentioned, V3 is designed deliberately to be departed away from the proper emotion emulator to the temperature state of a machine. The result here has thus verified my early speculation that the improper design

of an emotion emulator to a machine state could lead to a poor emotional experience of human users. Nevertheless, the proper design of an affective interface, V2 in this case, could create a good emotional experience of human users.

5.3.2.3 Analysis of the questionnaire data on Question 1, 2, 4 and 5

In the following, the results with discussions are presented for Questions 1, 2, 4, and 5. The response to these questions is relevant to the user's emotion and cognition as well (see the previous discussion in Section 5.2.3 as well). In particular, the two affective interfaces, V2 and V3, are focused in the following discussion, because they are affective interfaces.

(1) Question 1 (Q1):

Q1 asks if the user enjoys with the affective interfaces. The scores of the response to Question 1 in V2 and V3 are shown in Figure 5-6.

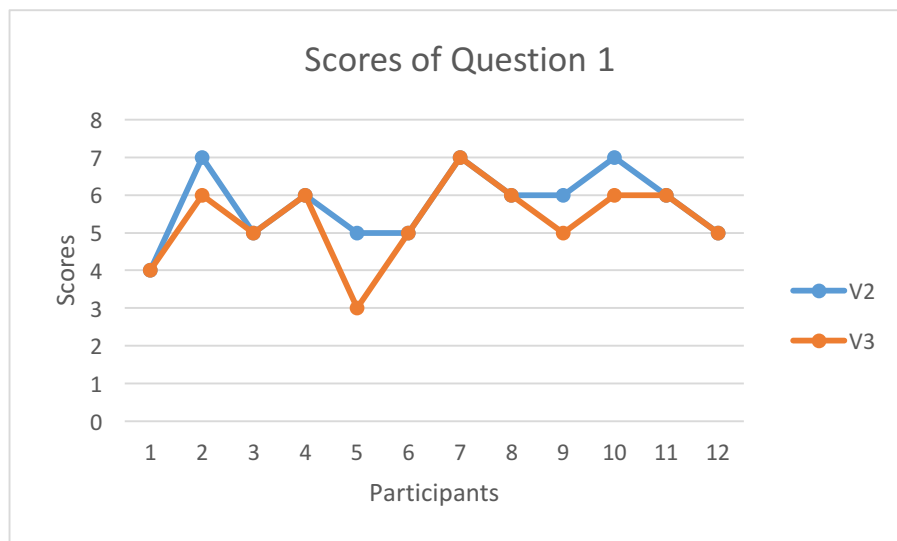


Figure 5-6. Scores of Q1

Normal probability and Homogeneity of variances tests were conducted to see if the data meets the requirement of ANOVA. The results of the normal probability tests are shown in Table 5-19,

which means that the data of all the dependent variables did fit a normal distribution ($p= 0.217 > 0.05$), so the assumption of ANOVA is satisfied.

Table 5-19. One-Sample Kolmogorov-Smirnov Test for Q1

		Scores
N		24
Normal Parameters ^{a,b}	Mean	5.54
	Std. Deviation	1.021
	Absolute	.215
Most Extreme Differences	Positive	.161
	Negative	-.215
Kolmogorov-Smirnov Z		1.053
Asymp. Sig. (2-tailed)		.217

a. Test distribution is Normal.

b. Calculated from data.

The result of Homogeneity of variances test is shown in Table 5-20. From Table 5-20 it can be seen that $p=0.386 > 0.050$, suggesting that each variance of dependent variable be equal and therefore the data meet the Homogeneity of variances assumption of ANOVA.

Table 5-20. Test of Homogeneity of Variances for Q1

F	df1	df2	Sig.
1.118	5	18	.386

a. Dependent Variable: scores

b. Design: Intercept + interface + block + interface * block

The result of ANOVA is shown in Table 5-21. From Table 5-21 it can be seen that there is no significant difference between the V2 and V3 interfaces ($p=0.371 > 0.05$) as well as no significant difference on the block factor ($p=0.792 > 0.05$). So the two different affective interfaces do not

influence the user’s emotion – enjoyment in this case. This result means that affective interfaces do not change the user’s emotion on the task performed (the game in this case).

Table 5-21. Tests of Between-Subjects Effects for Q1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.708 ^a	5	.342	.276	.920
Intercept	737.042	1	737.042	596.258	.000
block	.583	2	.292	.236	.792
interface	1.042	1	1.042	.843	.371
block * interface	.083	2	.042	.034	.967
Error	22.250	18	1.236		
Total	761.000	24			
Corrected Total	23.958	23			

a. Dependent Variable: scores

b. R Squared = .071 (Adjusted R Squared = -.187)

(2) Question 2 (Q2):

Q2 asks the participants’ self-evaluation about their game performance. The scores of the response to Question 2 in V2 and V3 are shown in Figure 5-7.

Normal probability and Homogeneity of variances tests were conducted to see if the data meets the requirement of ANOVA. The results of the normal probability tests in Table 5-22 indicated that the data of all the dependent variables did not fit a normal distribution ($p= 0.258 > 0.05$), which meets the assumption of ANOVA.

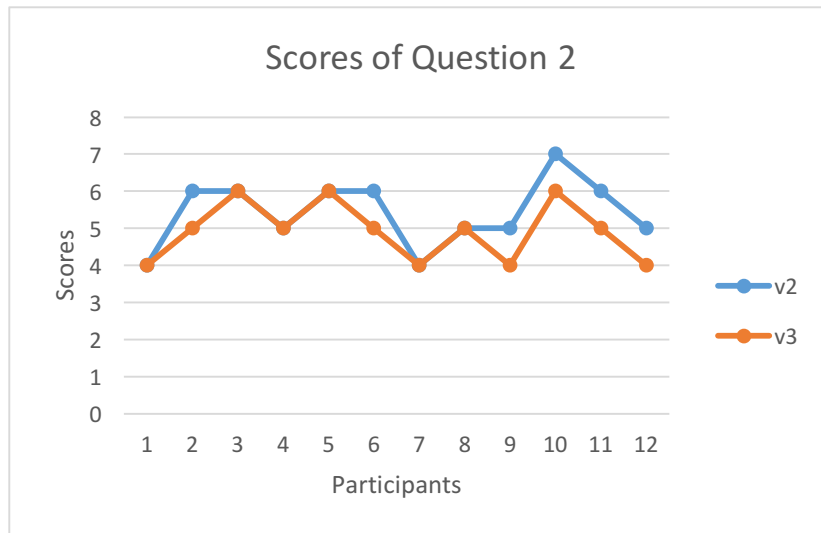


Figure 5-7. Scores of Q2

Table 5-22. One-Sample Kolmogorov-Smirnov Test for Q2

		scores
N		24
Normal Parameters ^{a,b}	Mean	5.17
	Std. Deviation	.868
	Absolute	.206
Most Extreme Differences	Positive	.201
	Negative	-.206
Kolmogorov-Smirnov Z		1.011
Asymp. Sig. (2-tailed)		.258

a. Test distribution is Normal.

b. Calculated from data.

Table 5-23. Test of Homogeneity of Variances for Q2

F	df1	df2	Sig.
.300	5	18	.906

a. Dependent Variable: scores

b. Design: Intercept + interface + block + interface * block

The result in Table 5-23 ($p=0.906>0.050$) indicated that each variance of dependent variable was equal and therefore the data meets the Homogeneity of variances assumption of ANOVA. The result of ANOVA is shown in Table 5-24.

Table 5-24. Tests of Between-Subjects Effects for Q2

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.333 ^a	5	.467	.560	.729
Intercept	640.667	1	640.667	768.800	.000
interface	1.500	1	1.500	1.800	.196
block	.083	2	.042	.050	.951
interface * block	.750	2	.375	.450	.645
Error	15.000	18	.833		
Total	658.000	24			
Corrected Total	17.333	23			

a. Dependent Variable: scores

b. R Squared = .135 (Adjusted R Squared = -.106)

Results from Table 5-24 show that there is no significant difference between the two interfaces ($p=0.196>0.05$) and between the different blocks ($p=0.951>0.05$). The results in Section 5.3.2.1 showed that the affective interface V3 creates a negative emotion with the user, though it improved the user's reaction time or task performance. The result on Question (2) suggests that an affective interface, regardless of whether it may create a negative emotion with users, may not necessarily degrade the users' task performance. This result is in agreement of the common sense, as the interface here is only for the warning purpose but not for task performance. This result also suggests that there be no coupling between the task performed and the warning interface, which

means that the conclusion drawn from the present study on the interface is not dependent on particular tasks.

(3) Question 4 (Q4):

Q4 asks if the participant feels the temperature alarm is useful. The scores of the response to Question 4 in V2 and V3 are shown in Figure 5-8.

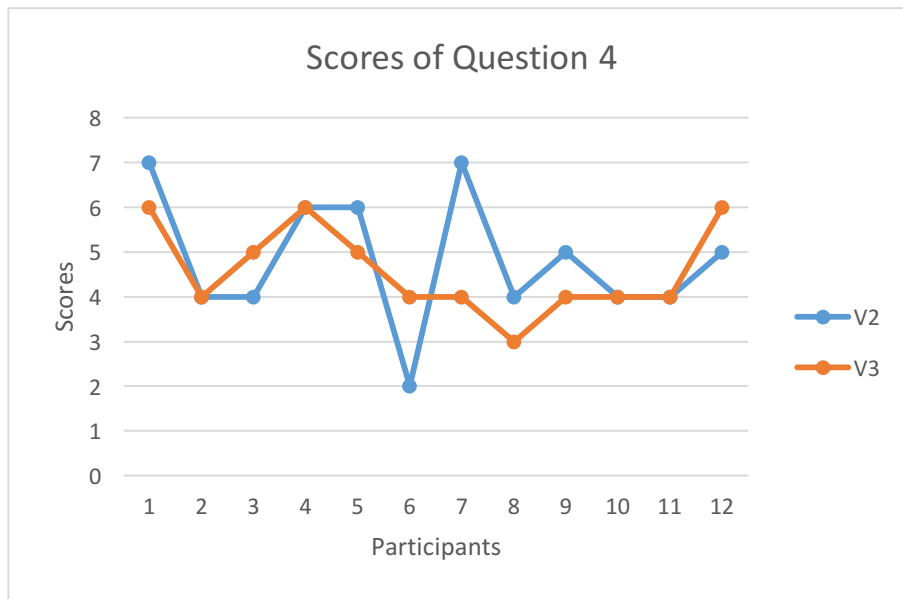


Figure 5-8. Scores of Q4

Normal probability and Homogeneity of variances tests were conducted to see if the data meets the requirement of ANOVA. The results of the normal probability tests in Table 5-25 indicate that the data of the dependent variables did not fit a normal distribution ($p= 0.082 > 0.05$), which means the experimental data meets the assumption of ANOVA.

Table 5-25. One-Sample Kolmogorov-Smirnov Test for Q4

		scores
N		24
Normal Parameters ^{a,b}	Mean	4.67
	Std. Deviation	1.167
	Absolute	.258
Most Extreme Differences	Positive	.258
	Negative	-.201
Kolmogorov-Smirnov Z		1.263
Asymp. Sig. (2-tailed)		.082

a. Test distribution is Normal.

b. Calculated from data.

Table 5-26. Test of Homogeneity of Variances for Q4

F	df1	df2	Sig.
2.558	5	18	.064

a. Dependent Variable: scores

b. Design: Intercept + interface + block + interface * block

The result in Table 5-26 ($p=0.064>0.050$) indicated that each variance of dependent variable was equal and therefore the data meets the Homogeneity of variances assumption of ANOVA. The result of ANOVA is shown in Table 5-27. The results from Table 5-27 show that there is no significant difference between V2 and V3 ($p=0.740>0.05$). This result is in agreement with the common sense of interfaces, namely interfaces are a product or device, which have a function (i.e. usefulness to something – warning in this case), and the degree of emotion that an interface possesses should not change the usefulness of the interface.

Table 5-27. Tests of Between-Subjects Effects for Q4

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.833 ^a	5	.967	.657	.661
Intercept	522.667	1	522.667	355.019	.000
block	4.333	2	2.167	1.472	.256
interface	.167	1	.167	.113	.740
block * interface	.333	2	.167	.113	.894
Error	26.500	18	1.472		
Total	554.000	24			
Corrected Total	31.333	23			

a. Dependent Variable: scores

b. R Squared = .154 (Adjusted R Squared = -.081)

(4) Question 5 (Q5):

Q5 asks if the interface is interesting. The scores of the response to Question 5 in V2 and V3 are shown in Figure 5-9.

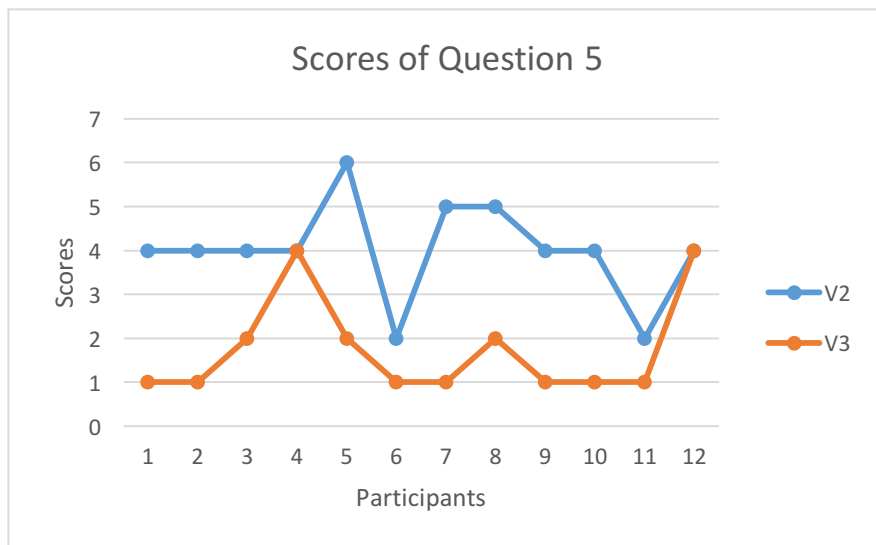


Figure 5-9. Scores of Q5

Normal probability and Homogeneity of variances tests were conducted to see if the data meet the requirement of ANOVA. The results of the normal probability tests indicated that the data of all the dependent variables did fit a normal distribution ($p= 0.079 > 0.05$), which meets the assumption of ANOVA.

Table 5-28. One-Sample Kolmogorov-Smirnov Test for Q5

		scores
N		24
Normal Parameters ^{a,b}	Mean	2.88
	Std. Deviation	1.597
	Absolute	.259
Most Extreme Differences	Positive	.208
	Negative	-.259
Kolmogorov-Smirnov Z		1.271
Asymp. Sig. (2-tailed)		.079

a. Test distribution is Normal.

b. Calculated from data.

Table 5-29. Test of Homogeneity of Variances for Q5

F	df1	df2	Sig.
2.155	5	18	.105

a. Dependent Variable: scores

b. Design: Intercept + interface + block + interface × block

The result in Table 5-29 ($p=0.105 > 0.050$) indicated that each variance of dependent variable was equal and therefore the data meets the Homogeneity of variances assumption of ANOVA. The result of ANOVA is shown in Table 5-30.

Table 5-30. Tests of Between-Subjects Effects for Q5

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	32.875 ^a	5	6.575	4.596	.007
Intercept	198.375	1	198.375	138.670	.000
block	.750	2	.375	.262	.772
interface	30.375	1	30.375	21.233	.000
block * interface	1.750	2	.875	.612	.553
Error	25.750	18	1.431		
Total	257.000	24			
Corrected Total	58.625	23			

a. Dependent Variable: scores

R Squared = .561 (Adjusted R Squared = .439)

The result from Table 5-30 shows that there is a significant difference between V2 and V3 ($p=0.000<0.50$). This means that different affective interfaces have a different influence on the user's emotion (interesting in this case). Further, from Figure 5-9 it can be found that V2 has a higher score than V3, suggesting that V2 is more interesting than V3. This seems to be in agreement with the result obtained from the analysis of data to Question 3, where V3 is found very annoying.

5.4 Concluding remarks

First, the statistic design of the experiment is sound, and the data generated meet all the assumptions for ANOVA. Second, the general hypothesis in Objective 3 of this thesis has been tested positively. In particular, the result from the experiment (both the task performance and the questionnaire) has shown that the affective interface which makes a machine have "emotion" or which emulates machine states with emotions could significantly influence users' cognition and emotion, and the interfaces designed with emotional expressions are significantly better than the traditional interface in terms of the user's task performance. However, the affective interface may

create a negative emotion with the user. Furthermore, different affective interfaces have significant differences in terms of the user's feeling of entertainment for interfaces.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Overview and conclusions

This thesis presented a study on affective interfaces. The primary question in interest was whether an affective interface that shows the machine state in a human-like emotion would significantly change the human behavior. The secondary question was whether there is a systematic approach to design an affective interface in literature.

The primary question was partially answered by a previous student in our research group, Modi (2011), with a simulated test-bed for the vehicle driving. The study positively tested the hypothesis – i.e., an affective interface that shows the machine state in a human-like emotion would significantly change the human behavior. This thesis aimed at conducting a similar experiment on a physical test-bed. Regarding the secondary question, a preliminary study was conducted by the author of this thesis, which concluded that there was not a systematic approach to affective interfaces, particularly ones that show the machine state with human-like emotions.

Three research objectives were then proposed in this thesis, which are revisited here for the convenience of readers.

Objective 1: *To develop a general design theory and methodology for generalized human-machine interfaces including the affective interface.*

Objective 2: *To design and construct a test-bed for the study of the affective interface – in particular enabling to conduct an experiment on it to test the general hypothesis, as described before.*

Objective 3: *To conduct an experiment to test the general hypothesis.* For the convenience of readers, the general hypothesis is re-visited below.

A literature review was conducted first, covering the areas including emotion theory, interface design theory and methodology, and affective interface. Attention was also given to the so-called persuasive interface in literature. The review has given a further justification for the need of the study of this thesis, in particular the three objectives, and given a clarification of the scope. A particular note is that this thesis is not intended to cover the persuasive interface subject; however, the result may have some implication to persuasive interfaces.

Development of a general and systematic approach to interface incorporating the affective attribute was described in detail in Chapter 3. Applying the proposed approach to a computer laptop for the temperature monitoring and control was performed in order to explore the effectiveness of the approach. The interface was taken as a test-bed for testing the hypothesis of the thesis – i.e., whether an affective interface that shows the machine state emotionally would significantly change the human mental state and behavior. An experiment was then performed on the test-bed as developed to the hypothesis of the thesis and was described in Chapter 5.

The following conclusions can be drawn from this study:

- (1) The affective interface that shows the machine state with an emotion, e.g., overheat in a component of the machine being expressed as a fatigue state of the human, would significantly change the human user's behavior relevant to interacting with the machine.
- (2) Emulated emotions of machine states must be as close as possible to the perception of

humans; otherwise, a negative effect on human's emotion may be generated.

- (3) The proposed approach to the affective interface is systematic and rational. The whole design process is encoded in the five steps, which integrate several existing theories such as FBS for work domain analysis (Lin et al., 2003; Lin and Zhang, 2004), three-phase interface design methodology (Lin et al., 2006) and PCP theory (Wickens & Carswell, 1995).

6.2 Contributions

There are four main contributions made in this thesis:

- (1) In the area of interface, this study has given a comprehensive elaboration on the concept of interface, including the difference among the concepts of human-machine interaction system and human-robot interaction and the notion of the interface that shows the machine state with the human emotion. This notion may lay a foundation for developing the machine with emotional intelligence. It is noted that Picard (1997) outlined the characteristics of the machine that has emotional intelligence by mimicking the human system but did not explicitly relate to the machine state.
- (2) In the area of interface design theory and methodology, this study has extended the PCP theory by proposing the emotional proximity for designing an interface over all the three design phases (i.e., concept design phase, layout design phase, detail design phase). In the current literature, there are some studies on affective interface design, but these studies are focused on designing an interface for aesthetic attribute only.
- (3) In the area of emotional intelligence, this study designed and constructed a general-purpose test-bed – i.e., a laptop computer machine. The test-bed can be used for studying the problem of mapping the machine state to the human emotion. In this study, overheat in the machine was mapped to the human emotion 'fatigue', which is in fact an example of the study.
- (4) In the area of affective interface or affective machine, this study was perhaps the first

experiment to show the significant effect of the affective interface that shows the machine state with the human emotion on the human user on a real test-bed system (i.e., laptop computer machine). It is noted that the first such a kind of experiment done on a simulated test-bed may refer to the work of Modi (2011) and a less comprehensive experiment of the affective machine may refer to Potkonjak et al. (2002).

6.3 Limitation and future work

There are a couple of limitations in this thesis that warrant further studies; as well there are some extensions to this thesis. They are discussed in this section. **First**, the mapping between the machine state and the human-like emotion needs more study. The current literature including this thesis seems to find this mapping in an ad-hoc manner. To study the mapping, more experiment may be performed on the test-bed. **Second**, the machine state in the current literature including this thesis appears to be related to the physical state of the machine. It is perhaps interesting to see the cognitive state of the machine (e.g., robot) be mapped to the human-like emotion. This may be a foundation to have a machine system that has a coupled relationship among emotion, cognition, and action and to develop emotional intelligence on the machine. **Third**, this study only showed the influence of the human-like emotion further linked to the machine state on the human state and behavior. However, the issue that how the machine cognition and action may be influenced by the human-like emotion of the machine has not been addressed. This remains to be seen whether the following scenario makes sense; the laptop machine takes action not based on the specific overheat in the machine but based on the human-like emotion label (e.g., fatigue). **Last**, the problem of how to design affective interfaces of a machine so that it can have a better collaboration with human users on a common goal warrants future work.

REFERENCES

1. Affect. (n. d.). In *Wikipedia*. Retrieved January 26, 2016, from <https://en.wikipedia.org/w/index.php?title=Affect&oldid=701756147>
2. Alvarado Mendoza, P., Angelelli, A., & Lindgren, A. (2011). Ecological interface design inspired human machine interface for advanced driver assistance systems. *IET Intelligent Transport Systems*, 5(1), 53-59.
3. Anuar, N., & Kim, J. (2014). A direct methodology to establish design requirements for human–system interface (HSI) of automatic systems in nuclear power plants. *Annals of Nuclear Energy*, 63, 326-338.
4. Arbeláez-Estrada, J. C., & Osorio-Gómez, G. (2015, June 13). Natural User Interface for color selection in conceptual design phase. *International Journal on Interactive Design and Manufacturing*. doi:10.1007/s12008-015-0279-y
5. Bickmore, T., Picard, Rosalind W., & Cassell, Justine. (2003). *Relational Agents: Effecting Change through Human -computer Relationships*, ProQuest Dissertations and Theses.
6. Cai, M. Y., Lin, Y., and Zhang, W.J. Study of the optimal number of rating bars in the Likert scale. In proceedings of 18th International Conference on Information and Web-based Application & Service (iiWAS 2016), Nov. 27-30, 2016, Singapore. Accepted.
7. Cohen, J. (1988). *Statistical power analysis for the behaviour sciences*. Hillsdale, New Jersey, USA: Lawrence Erlbaum Associates Inc. pp.17-20.
8. Emotion. (n. d.). In *Wikipedia*. Retrieved October 12, 2016, from <https://en.wikipedia.org/w/index.php?title=Emotion&oldid=744017735>
9. Emotional intelligence. (n. d). In *Wikipedia*. Retrieved December 27, 2016, from https://en.wikipedia.org/wiki/Emotional_intelligence
10. Feeling. (n. d.). In *Wikipedia*. Retrieved December 27, 2016, from

https://en.wikipedia.org/wiki/Feeling#cite_note-1

11. Fogg, B., Bedichevsky, D., & Tester, J. (1998). Persuasive computing. *ACM SIGCHI Bulletin*, 30(4), 71-72.
12. Freeney, D. (2014). Usability versus Persuasion in an Application Interface Design (Master's thesis). Mälardalen University, Eskilstuna, Sweden.
13. Gupta, M. M. (2016). Personal communication, April 15.
14. Hockenbury, D. H. & Hockenbury, S. E. (2007). *Discovering psychology*. New York: Worth Publishers.
15. Hu, X., Xie, L., Liu, X., & Wang, Z. (2013). Emotion expression of robot with personality. *Mathematical Problems in Engineering*, 10.
16. Interaction. (n. d.). In *Wikipedia*. Retrieved October 13, 2016, from <https://en.wikipedia.org/w/index.php?title=Interaction&oldid=744137443>
17. Johannsen, G. (2007). Human–Machine Interaction, In H. Unbehauen, (Ed.), *Encyclopedia of Life Support Systems (EOLSS): Control Systems, Robotics, and Automation*. Paris: EOLSS Publishers.
18. Knickerbocker, H., Johnson, R., & Altarriba, J. (2015). Emotion effects during reading: Influence of an emotion target word on eye movements and processing. *Cognition and Emotion*, 29(5), 784-806.
19. Kumar, H., Ahmed, Z., Shetty, A., Bangera, N., & Bangera, V. (2014). I-Car: An Intelligent and Interactive Interface for Driver Assistance System. *Science, Technology and Arts Research Journal*, 3(2), 197.
20. Latin square. (n. d.). In *Wikipedia*. Retrieved September 24, 2016, from https://en.wikipedia.org/w/index.php?title=Latin_square&oldid=740905021
21. Lin, Y, & Zhang, W.J. (2004). Towards a novel interface design framework: Function–behavior–state paradigm. *International Journal of Human - Computer Studies*, 61(3), 259-297.
22. Lin, Y., Zhang, W. J., Koubek, R. J., & Mourant, R. R. (2006). On integration of interface

- design methods: Can debates be resolved? *Interacting with Computers*, 18(4), 709-722.
23. Liu, C., Lin, Y., Teng, H., Wang, Z., & Zhang, W. (2015). An Experimental Study on Three General Interface Layout Designs for Chemical Process Plants. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 25(4), 500-514.
 24. Lo, S., & Helander, M. (2007). Use of axiomatic design principles for analyzing the complexity of human-machine systems. *Theoretical Issues in Ergonomics Science*, 8(2), 147-169.
 25. Lund, L. (2015). Aesthetics in User Interface Design: The Influence on Users' Preference, Decoding and Learning. Retrieved from http://www.divaportal.se/smash/get/diva2:842669/FULLTEXT02.pdf;jsessionid=axk8ZET3s4-JCA0ccSE444TQFGBz02uqOxX_C--z.diva2-search7-vm
 26. Ma, Q., Pei, G., & Wang, K. (2015). Influence of negative emotion on the framing effect: Evidence from event-related potentials. *Neuroreport*, 26(6), 325-32.
 27. MacLennan, J. (2003). *Effective communication for the technical professions*. Toronto: Prentice Hall.
 28. Mazaeva, N. M., & Bisantz, A. (2013). Ecological interface design of a photo camera display: Method and example. *Proceedings of the Human Factors and Ergonomics Society*, 1343-1347.
 29. McGill, J. (2014). Emotion, Cognition and Artificial Intelligence. *Minds and Machines*, 24(2), 189-199.
 30. Modi, S (2011). Improving Human-Machine Interaction. (Unpublished master's thesis). University of Saskatchewan, Saskatoon, Canada.
 31. Mokarian, M., & University of Saskatchewan, College of Graduate Studies Research. (2007). *Visual Balance in Engineering Design for Aesthetic Value*.
 32. Mood. (n. d.). In *Wikipedia*. Retrieved December 27, 2016, from [https://en.wikipedia.org/wiki/Mood_\(psychology\)](https://en.wikipedia.org/wiki/Mood_(psychology))
 33. Nakadai, K., Mizumoto, T., & Nakamura, K. (2015). Robot-Audition-based Human-

- Machine Interface for a Car. *IEEE International Conference on Intelligent Robots and Systems, 2015*, 6129-6136.
34. Norman, D. (2004). *Emotional design: Why we love (or hate) everyday things*. New York: Basic Books.
 35. Nuzzo, P., Sangiovanni-Vincentelli, A., Sun, X., & Puggelli, A. (2012). Methodology for the design of analog integrated interfaces using contracts. *IEEE Sensors Journal, 12*(12), 3329-3345.
 36. Orellana, D.W., & Madni, A.M. (2014). Human System Integration Ontology: Enhancing Model Based Systems Engineering to Evaluate Human-system Performance. *Procedia Computer Science, 28*, 19-25.
 37. Otto, G. (2012, April 01). U.S. Navy Developing Human-Like Fire Fighting Robot. *U.S. News & World Report*, p. 1. Retrieved from <http://www.usnews.com/news/articles/2012/04/05/us-navy-developing-human-like-fire-fighting-robot-navy-developing-human-like-fire-fighting-robot>
 38. Pajusalu, M. (2012). The Evaluation of User Interface Aesthetics. (Master's thesis). Tallinn University, Estonia.
 39. Pessoa, L. (2015). Précis on The Cognitive-Emotional Brain. *Behavioral and Brain Sciences, 38*. doi: <http://dx.doi.org.cyber.usask.ca/10.1017/S0140525X14000120>
 40. Picard, R.W. (1997). *Affective computing*. Cambridge, Mass.: MIT Press.
 41. Picard, R.W. (2003). What does it mean for a computer to “have” emotions? In R. Trappl et al. (Eds.), *Emotions in humans and artifacts*. Cambridge, Mass.: MIT Press.
 42. Portet, F., Vacher, M., Golanski, C., Roux, C., & Meillon, B. (2013). Design and evaluation of a smart home voice interface for the elderly: Acceptability and objection aspects. (Report). *Personal and Ubiquitous Computing, 17*(1), 127.
 43. Potkonjak, V., Radojicic, J., & Tzafestas, S. (2002). Modeling Robot “Psycho-Physical” State and Reactions – A New Option in Human–Robot Communication Part 1: Concept and Background. *Journal of Intelligent and Robotic Systems, 35*(4), 339-352.

44. Rosenman, M.A, & Gero, J.S. (1998). Purpose and function in design: From the socio-cultural to the techno-physical. *Design Studies*, 19(2), 161-186.
45. Russell, J. A. (1980). A Circumplex Model of Affect. *Journal of Personality and Social Psychology*, 39, 1161–1178. doi:10.1037/h0077714
46. Schmitt, A., Minker, Wolfgang, & SpringerLink. (2013). Towards Adaptive Spoken Dialog Systems. *Springer New York*. doi:10.1007/978-1-4614-4593-7
47. Schütte, S. (2005). *Engineering emotional values in product design: kansei engineering in development* (Doctoral dissertation, Linköping University, Linköping, Sweden). Retrieved from <http://www.diva-portal.org/smash/get/diva2:20839/FULLTEXT01.pdf>
48. Shayganfar, M. L., Rich, C., & Sidner, C. (2012). A design methodology for expressing emotion on robot faces. *IEEE International Conference on Intelligent Robots and Systems*, 4577-4583.
49. Shubin, H., Falck, D., & Johansen, A. (1996). Exploring color in interface design. *Interactions*, 3(4), 36-48.
50. St-Cyr, O., Jamieson, G.A., & Vicente, K. J. (2013). Ecological interface design and sensor noise. *International Journal of Human - Computer Studies*, 71(11), 1056-1068.
51. Suh, N.P. (1990). Design of thinking design machine. *Annals of the CIRP*, 39(1), 145-149.
52. Suzuki, S., Igarashi, H., Kobayashi, H., Yasuda, T., & Harashima, F. (2013). Human Adaptive Mechatronics and Human-System Modelling. *International Journal of Advanced Robotic Systems*, 10, 152.
53. Vicente, K. J., & Rasmussen, J. (1992). Ecological Interface Design- Theoretical Foundations. *IEEE Transactions on Systems Man and Cybernetics*, 22(4), 589-606.
54. Wang, C. (2010). Understanding and modeling of aesthetic response to shape and color in car body design. (Master's thesis). University of Saskatchewan, Saskatoon, Canada.
55. Wang, J., Nicol, T., Skoe, E., Sams, M., & Kraus, N. (2008). Emotion Modulates Early Auditory Response to Speech. *Journal of Cognitive Neuroscience*, 21(11), 2121-2128.
56. West, G., Al-Aidroos, L., Susskind, N., & Pratt, J. (2011). Emotion and action: The effect

- of fear on saccadic performance. *Experimental Brain Research*, 209(1), 153-158.
57. White, S. W., Mazefsky, C. A., Dichter, G. S., Chiu, P. H., Richey, J. A. & Ollendick, T. H. (2014). Social-cognitive, physiological, and neural mechanisms underlying emotion regulation impairments: Understanding anxiety in autism spectrum disorder. *International Journal of Developmental Neuroscience*, 39, 22-36.
58. Wickens, C., & Carswell, C. (1995). Proximity compatibility principle: Its psychological foundation and relevance to display design. *Human Factors*, 37(3), 473-494.
59. Wodehouse, A., & Sheridan, M. (2014). Design for 'quality of use': Emotion and physical interface design. *Proceedings of the International Conferences on Interfaces and Human Computer Interaction 2014, Game and Entertainment Technologies 2014 and Computer Graphics, Visualization, Computer Vision and Image Processing 2014 - Part of the Multi Conference on Computer Science and Information Systems, MCCSIS 2014*, 91-98.
60. Wright, P., Mosser-wooley, D., Wooley, B., & Cavazos, J. (1997). Techniques & tools for using color in computer interface design. *Crossroads*, 3(3), 3-6.
61. Xue, L. (2015). *A redundant interface design* (Unpublished master's thesis, East China University of Science and Technology, Shanghai, China).
62. Xue, L., Liu, C. J., Lin, Y., & Zhang, W.J. (2015). On redundant human-robot interface: Concept and design principle. *Advanced Intelligent Mechatronics*. doi: 10.1109/AIM.2015.7222546
63. Yang, J., Zeng, J., Meng, X., Zhu, L., Yuan, J., Li, H., & Yusoff, N. (2013). Positive words or negative words: Whose valence strength are more sensitive to? *Brain Research*, 1533, 91-104.
64. Zhang W.J., 1994. An Integrated Environment for CAD/CAM of Mechanical Systems, Ph.D. thesis, printed by Delft University of Technology, The Netherlands.
65. Zhang, W. J., Lin, Y., & Sinha, N. (2011). On the function-behavior-structure model for design. *Proceedings of the Canadian Engineering Education Association*.
66. Zhang, W. J., van Luttervelt, C. A. (2011). Towards a Resilient Manufacturing System. *Annals of CIRP*, 60(1), 469-472.

APPENDIX A CERTIFICATE OF ETHICS APPROVAL FOR THE EXPERIMENT



UNIVERSITY OF
SASKATCHEWAN

Behavioural Research Ethics Board

Certificate of Approval

PRINCIPAL INVESTIGATOR
Chris Zhang

DEPARTMENT
Mechanical Engineering

BEH#
16-172

INSTITUTION(S) WHERE RESEARCH WILL BE CONDUCTED
University of Saskatchewan

STUDENT RESEARCHER(S)
Haili Lu

FUNDER(S)
UNFUNDED

TITLE
Research on Affective Interface-Towards a Machine that has Emotion

ORIGINAL REVIEW DATE
11-May-2016

APPROVAL ON
13-May-2016

APPROVAL OF:
Application for Behavioural Research Ethics
Review
Recruitment Email
Participant Consent Form
Survey Questions

EXPIRY DATE
12-May-2017

Full Board Meeting

Delegated Review

CERTIFICATION

The University of Saskatchewan Behavioural Research Ethics Board has reviewed the above-named research project. The proposal was found to be acceptable on ethical grounds. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project, and for ensuring that the authorized research is carried out according to the conditions outlined in the original protocol submitted for ethics review. This Certificate of Approval is valid for the above time period provided there is no change in experimental protocol or consent process or documents.

Any significant changes to your proposed method, or your consent and recruitment procedures should be reported to the Chair for Research Ethics Board consideration in advance of its implementation.

ONGOING REVIEW REQUIREMENTS

In order to receive annual renewal, a status report must be submitted to the REB Chair for Board consideration within one month prior to the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions: <http://research.usask.ca/for-researchers/ethics/index.php>

Vivian Ramsden, Chair
University of Saskatchewan
Behavioural Research Ethics Board

Please send all correspondence to:

Research Ethics Office
University of Saskatchewan
Box 5000 RPO University, 223-110 Science Place
Saskatoon SK S7N 5C9
Telephone: (306) 966-2975 Fax: (306) 966-2069

APPENDIX B AXIOMATIC DESIGN THEORY: BRIEF INTRODUCTION

The Axiomatic Design Theory (ADT) is developed by Num P. Suh in the 1980s. There are two axioms with several corollaries to facilitate particular applications. Axiom 1 states (Fan et al., 2015): For a product which has several FRs at the same level in the hierarchy of product, they must be independent to each other, and further, DPs that fulfil FRs must maintain this independency. Axiom 1 is essentially a tool to check if a design, namely pairs of FR-DP, is good or bad. That is, if a design violates Axiom 1, the design is considered bad. There may be more than one design that meets Axiom 1. Axiom 2 is to choose the best one among all the design candidates that meet Axiom 1. Axiom 2 states: For each design, there is a quantity called information content which is tied to any design, the best design is with the minimum information content.

APPENDIX C COMPUTER CODE FOR THE TEMPERATURE INTERFACE

Interface design

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;

using System.Text;
using System.Windows.Forms;
using System.Reflection;

namespace WindowsFormsApplication3
{
    public partial class Form1 : Form
    {
        private int m_btnState = 0;
        String[] soundName = { "/voice1.wav", "/voice2.wav", "/voice3.wav" };
        private int limitTemp = 70;
        System.Media.SoundPlayer sndPlayer ;

        public Form1()
        {
            InitializeComponent();
            sndPlayer = new System.Media.SoundPlayer(Application.StartupPath +
            @soundName[m_btnState]);
            label1.Text = getTemp.RefreshInfo_Elapsed().ToString() + "°C";
            setpicWidth(getTemp.RefreshInfo_Elapsed());
            //playSound(m_btnState);
        }

        private void label1_Click (object sender, EventArgs e)
        {
```

```

}

private void timer1_Tick(object sender, EventArgs e)
{
    label1.Text = getTemp.RefreshInfo_Elapsed().ToString() + "°C";
    setpicWidth(getTemp.RefreshInfo_Elapsed());
    label5.Text = "Alarming temperature:" + limitTemp + "°C";
    label7.Text = soundName[m_btnState];
}

private void Form1_Load(object sender, EventArgs e)
{
}

private void setpicWidth(float temp)
{
    int minTemp = 0;
    float maxTemp = getTemp.maxTEMP;
    label3.Text = minTemp.ToString() + "° C";
    label4.Text = maxTemp.ToString() + "° C";
    double updateWidth = (((temp * 219) / (maxTemp - minTemp)));
    this.pictureBox1.Width = (int)updateWidth;
    if (temp > limitTemp) playSound(m_btnState, 1);
    else playSound(m_btnState, 0);
}

private void playSound(int i, int type)
{
    if (type == 1) {
        sndPlayer.PlaySync();
        sndPlayer.Stop();
    }
    else sndPlayer.Stop();
}

private void button1_Click(object sender, EventArgs e)
{
    m_btnState = 0;
    sndPlayer = new System.Media.SoundPlayer(Application.StartupPath +
@soundName[m_btnState]);
    sndPlayer.Load();
}

```

```

        setpicWidth(getTemp.RefreshInfo_Elapsed());
    }

    private void button2_Click(object sender, EventArgs e)
    {
        m_btnState = 1;
        sndPlayer = new System.Media.SoundPlayer(Application.StartupPath +
@soundName[m_btnState]);
        sndPlayer.Load();
        setpicWidth(getTemp.RefreshInfo_Elapsed());
    }

    private void button3_Click(object sender, EventArgs e)
    {
        m_btnState = 2;
        sndPlayer = new System.Media.SoundPlayer(Application.StartupPath +
@soundName[m_btnState]);
        sndPlayer.Load();
        setpicWidth(getTemp.RefreshInfo_Elapsed());
    }

    private void textBox1_TextChanged(object sender, EventArgs e)
    {
        String input = textBox1.Text;
        try
        {
            limitTemp = Convert.ToInt32(input);

        }
        catch
        {
            //textBox1.Text = " Integer";
        }
    }
}
}

```


Temperature read

```
using System;
using System.Collections.Generic;

using System.Text;
using System.Timers;
using GetCoreTempInfoNET;

namespace WindowsFormsApplication3
{
    class getTemp
    {
        static CoreTempInfo CTInfo;
        public static float maxTEMP = 100;

        public static float RefreshInfo_Elapsed()
        {
            //Initiate CoreTempInfo class.
            CTInfo = new CoreTempInfo();

            //Attempt to read shared memory.
            bool bReadSuccess = CTInfo.GetData();

            //If read was successful the post the new info on the console.
            if (bReadSuccess)
            {
                List<float> tempure = new List<float>();
                uint index;

                for (uint i = 0; i < CTInfo.GetCPUCount; i++)
                {
                    maxTEMP = CTInfo.GetTjMax[i];
                    for (uint g = 0; g < CTInfo.GetCoreCount; g++)
                    {
                        index = g + (i * CTInfo.GetCoreCount);
                        tempure.Add( CTInfo.GetTemp[index]);
                    }
                }
            }
        }
    }
}
```

```
}
float tempall = 0;
for (int i = 0; i < tempure.Count; i++)
{
    tempall += tempure[i];
}
return tempall/tempure.Count;
}
else
{
    return 0;
}
}
}
}
```