Smart Clothes as a Tangible User Interface to Affect Human Emotions using Haptic Actuators

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ABSTRACT

Affective haptic research is a rapidly growing field. Today, more smart haptic clothes are being studied and implemented which are aimed to effect its users emotionally. However, they have some limitations. This research intends to improve the existing literature and contribute by involving consumers directly in the design of a smart haptic jacket by adding heat, vibration actuators, and by enhancing portability. In this thesis, we are interested in six basic emotions: love, joy, surprise, anger, sadness, and fear. An online survey was designed and conducted on 92 respondents that gave feedback of what it is expected from an affective haptic jacket. The results of this survey assisted in the general design, and the feedback helped to build a prototype. 86% of the respondents expressed interest in the system and are willing to try it when it is ready. A detailed design architecture is provided along with details on the hardware and software used for the implementation. Finally, the prototype was evaluated on 14 participants using the actual prototype haptic jacket based on a QoE comparison between the absence and the presence of haptic actuation. The proposed system showed improvement over a similar system that is designed for the same purpose.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
A	Amperes
API	Application Programming Interface
AR	Augmented Reality
BJT	Bipolar Junction Transistor
C	C programming language
DC	Direct Current
DOF	Degrees of Freedom
GUI	Graphical User Interface
HCI	Human Computer Interaction
HD	High Definition
Hz	Hertz
I/O	Input/Output
I2C	Inter-Integrated Circuit (pronounced: I-squared-cee)
IDC	Insulation-Displacement Connector
IDE	Integrated Development Environment
iFeel_IM	Intelligent System for Feeling Enhancement Powered by Affect-Sensitive Instant Messenger
MCRLab	Multimedia Communications Research Laboratory
MIT	Massachusetts Institute of Technology
PCB	Printed Circuit Board
QoE	Quality of Experience
REM	Remote Emotions Server
RoHS	Restriction of Hazardous Substances Directive
SITE	School of Information Technology and Engineering
SMS	Short Message System
SOAP	Simple Object Access Protocol
USB	Universal Serial Bus
V	Volts
XML	Extensible Markup Language

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CHAPTER 1

Introduction

1.1 Background and Motivation

“Emotions are at the heart of social psychology and are part of what makes social psychology so interesting.” W. G. Parrott [1, page 1]. Human emotions can be defined as a set of feelings that occur in a certain manner and affect behavior. Some emotions can be evoked socially by touch, such as a handshake, a hug, or a tickle [2]. Improving emotional involvement, in entertainment for example, by improving video and audio is coming closer to its limits [9]. For the future of emotions however, research has been concerned for some time about stimulating emotions using haptic feedback systems [45,46]. This is also referred to as “Affective Haptics” [6], which is becoming more popular by time. It mainly focuses on systems that evoke or affect a human’s emotional condition by the sense of touch. In other words, "Affective haptics" is an area of research that is being much more addressed recently and is concerned about the design of systems and devices that can intensify, evoke, or further influence the emotional state of a person by the sense of touch [19].

Involving emotional haptics is also considered an important aspect of many research today. Recent research reveal that the absence of comforting touch could cause social problems and may even lead to early death [27]. In Romania, thousands of orphans lacked affectionate touch for being raised in facilities that were overcrowded which caused the spread of emotional and social problems [25].

This thesis is intended to incorporate consumers' opinions and currently available haptic technologies in improving Human Computer Interaction (HCI) by providing an affective haptic jacket. This jacket will be able to immerse its user emotionally in the application it is designed for, and provide a better experience. A study was carried out at the beginning of the research to collect the available data, which was analyzed carefully and used in implementing an interactive haptic jacket prototype.

The proposed system will be able to satisfy different applications with the availability of proper interfacing software design. One possible application is enhancing video gaming and movie watching experiences. Just like the concept of subtitles in movies, synchronized instructions can be sent to the haptic jacket in specific times to evoke emotions based on the current scene in a movie or a video game. Another possible application for the proposed haptic jacket is helping visually impaired people understand emotions of people in front of them by analyzing facial expressions. Facial expression recognition for emotion analysis is already being addressed in current research [5]. Such software can analyze facial expressions and use the data with a simple interfacing software to evoke emotions in the proposed haptic jacket.

1.2 Existing Problems

Current systems vary in existing problems and differ depending on the objective of each system and application. The addressed problems may be summarized in the following points:

- **Consumer independency in design:** Most available systems depend mostly in their design on researchers and persons experienced in haptic technologies, electronics, and/or software, and dismiss feedback from regular and technology illiterate consumers. This may result in systems that are unwanted or unrealistic to most people.
- **Dependency and lack of application portability:** In order to create a more stable and robust system, some systems are designed specifically for a given set of applications. However, this limits the user to a specific application and makes the device useless if it was required for a different application. For example, a haptic jacket that is designed to work with a specific game console cannot be used while watching a movie, and vice-versa.

- **Limitedness of hardware:** Most haptic jackets available today limit their hardware to vibration actuators. They lack other different types of actuators that can stimulate warmth and tightness.
- **Limitedness of affected body areas:** Most available haptic clothes only affect the chest and arms.

1.3 Objective and Contribution

The carried out study is intended to improve the results of related research by adding extra features and involving consumers directly into the design and operation of a haptic jacket. As a contribution to currently available and similar projects, heat actuators were added to stimulate warmth during certain emotion evocation. Also, the design is made to become portable and application independent where only a simple interfacing program is required for each application.

To summarize, the contribution of this thesis to current research in related areas is intended as follows:

- **Direct involvement of consumers in the research:** To enhance this project's robustness and chances of approval from consumers, this system was designed mostly based on a survey that was created beforehand. 92 respondents of both genders responded with their expectations of such a gadget, and a majority of whom expressed interest in the project.

- **Application independent portable design:** The system architecture is designed to be able to receive simple instructions consisting of the required emotion to be activated, and the duration of which this emotion should be evoked. The system, however, will need a simple Application Programming Interface (API) for each specific application.
- **Use of heat actuators and sensors:** In this design, thermoelectric coolers were used to stimulate warmth in certain areas of the jacket. Also, to prevent accidental injuries, heat sensors were attached to every heat actuator to ensure safe operation and avoid burns.
- **Including more body areas:** In our design, in addition to the chest and arms areas, we added affective haptic actuators and sensors to the neck area for a higher quality user experience.

1.4 Thesis Organization

The remainder of this thesis is organized as follows:

Chapter 2 starts by describing emotional haptic technologies and the main emotions related to this research. Then, it presents overviews of a number of different systems and research related to haptic wearable clothes and/or to emotional involvement in human computer interaction. It also discusses different drawbacks, if applicable, for each system. In the end, this chapter provides a comparison table to discuss the important differences amongst these systems based on specific characteristics. Finally, a summary of this chapter is given along with the contribution points provided by our research.

Chapter 3 explains the proposed system architecture in detail. It starts with a description of how the design data was collected using an online survey, and then presents the complete survey results. Then it gives a brief overview of the whole system, followed by a description of the components of the system. After that, it gives a detailed architecture description of the whole system and the prime material needed for implementation. Finally, this chapter provides a table summarizing different possible scenarios of the system.

Chapter 4 gives a detailed description of the implementation process of this system. It explains the circuitry and the steps followed for the implementation of the prototype. After that, it provides details on all the hardware and software used during the research. Finally, this chapter provides a section on the main problems faced and the lessons learned during the research.

Chapter 5 provides information on the evaluation process of the prototype. It starts by explaining the evaluation procedure and the material used for the evaluation. Then, the results of the evaluation is given and compared to a similar system in the same area of research. Finally, a summary of the concluded remarks is given.

Finally, in **chapter 6** we summarize the work done in this research, we provide a conclusion, and propose future work that can contribute to this field.

CHAPTER 2

Literature Study and Related Work

2.1 Background

The skin is the largest organ in a human's body, and the sense of touch can be considered as one of the most complex senses. The sense of touch can be divided into two sub-senses: kinesthetic and cutaneous. Kinesthetic stimulation is roughly related to forces exerted on the joints and muscles, while cutaneous stimulation is felt through the skin. For example, kinesthetic stimulation can be felt by carrying heavy objects which can be felt on wrists and elbows, and cutaneous stimulation can be felt by identifying different frequencies of vibration or different levels of heat, or even the sense of balance [21].

Conventional systems for human-computer interaction usually ignore important social communication mediums such as the sense of touch, and only support channels such as sound or/and vision [6]. Affective haptics research, however, have recently introduced the sense of touch to the formula. People want to become more immersed into new technology and are always looking for something new [9]. The involvement of haptic wearable devices can also become a major assistance to visually impaired people in the areas of multimedia and social involvement. Some research is currently involved in designing haptic wearable devices as a complementary device to audio described movies [15], which will eliminate the need of specific extra descriptions in the movie (i.e. who is talking, how far the person talking is from the camera, … etc).

In addition, audio/visual description of multimedia is reaching its limits with today's advances in technology, such as HD and/or 3D video and high quality audio, and is in need for further improvements in different aspects [3,9]. This research is looking to improve the involvement of users in multimedia through altering their emotional states, or further improving their emotional immersion through wearable haptic clothes.

There are some differences in the classifications of basic human emotions amongst researchers and theorists. However, the majority of them classify basic emotions into "love", "joy", "surprise", "anger", "sadness", and "fear", and some replace "love" instead of "disgust" [11,12,13,14]. Professor W. G. Parrott of psychology at Georgetown University presents these six emotions as the basic emotions, and further classifies them into secondary and tertiary emotions (or feelings) as follows [1]:

- Love:
    - Affection: adoration, compassion, liking, caring, tenderness, attractiveness, fondness, ...
    - Lust: desire, passion, arousal, ...
    - Longing.
    - ...

- Joy:
    - Cheerfulness: amusement, jolliness, enjoyment, gladness, happiness, satisfaction, ...
    - Optimism: hope, eagerness, ...
    - Zest: excitement, enthusiasm, thrill, exhilaration, ...
    - Pride: triumph, ...
    - Contentment: pleasure, ...
    - Relief.
    - ...
- Surprise:
    - Surprise: astonishment, amazement, …
- Anger:
    - Rage: anger, fury, outrage, hostility, bitter, hatred, dislike, ...
    - Disgust: contempt, loathing, ...
    - Irritability: annoyance, grumpiness, grouchiness, aggrevation, ...
    - Envy: jealousy, ...
    - …
- Sadness:
    - Shame: regret, remorse, guilt, ...
    - Neglect: defeatism, alienation, humiliation, insult, isolation loneliness, rejection, ...
    - Suffering: anguish, agony, hurt, ...
    - Sympathy: pity, ...

  - Disappointment: displeasure, dismay, ...
  - …
- Fear:
  - Nervousness: suspense, distress, dread, uneasiness, anxiety, ...
  - Horror: shock, alarm, fright, fear, panic, hysteria, horror, …

Parrott's model was followed throughout this research since all related research are very close in this concept.

2.2 Related Work

Some of the latest research topics related to the topic of this thesis and to emotions and haptic wearable clothes are listed in the following sub-sections.

2.2.1 Interpersonal Haptic Communication in Second Life

Social physical interactions, such as a handshake, a hug, or a tickle, could stimulate emotions and cause an emotional reaction for people. A group of researchers in the MCRLab at the University of Ottawa have developed an add-on that works with the Second Life [16] virtual environment to provide physical communication functions to users through a haptic jacket. This jacket, using a set of carefully placed vibrotactile actuators, provide the sensation of touch to the user based on the signals received from the Second Life add-on. These signals are produced by annotating different parts of the Second Life avatar, and then actuating the corresponding actuators in the haptic jacket [2].

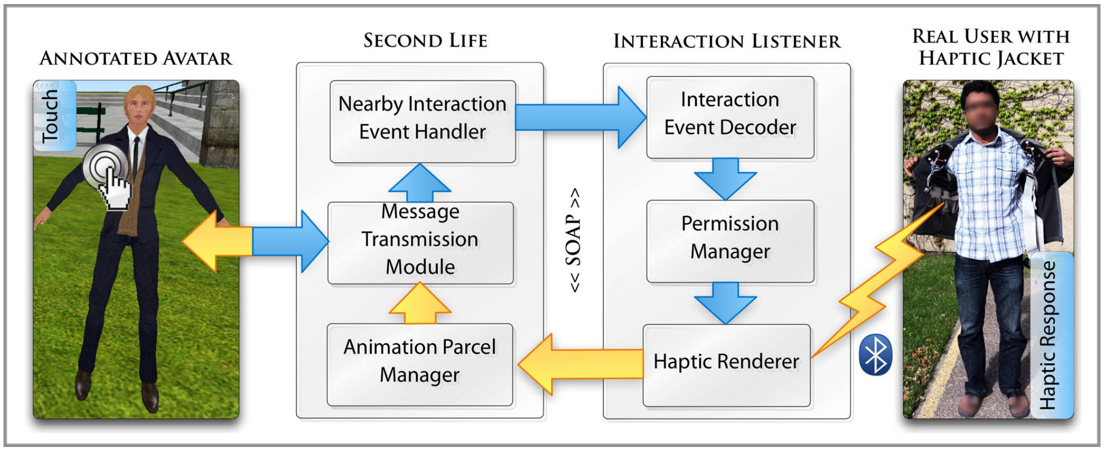


Figure 2.1 Second Life and haptic communication system block diagram [2]

2.2.2 HugMe: Synchronous Haptic Teleconferencing

Another implementation related to this topic is the HugMe system, which was created in the School of Information Technology and Engineering (SITE) at the University of Ottawa. The HugMe system is a synchronous haptic teleconferencing system aimed to provide the ability to express intimacy remotely. The system presented is compatible with a tolerable bandwidth of 30-60 Hz for haptic data. Using a 3-DOF force feedback device, the user can touch a remote user who, in turn, can feel the touch on the contacted skin through a wearable jacket. This jacket contains an array of vibrotactile actuators that activate depending on the touched locations [3].

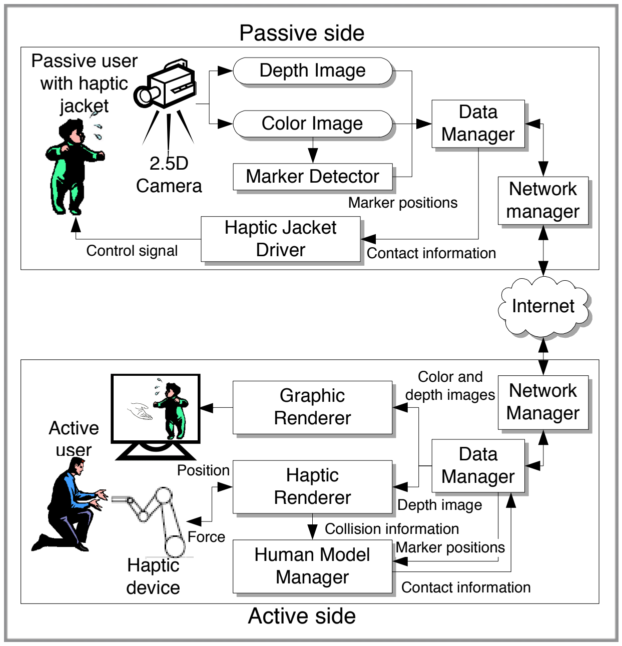


Figure 2.2 HugMe block diagram [3]

2.2.3 A Body-Conforming Tactile Jacket to Enrich Movie Viewing

A wearable jacket was also developed in Philips Research Europe that is focused on influencing movie watchers emotions by creating tactile stimuli to their bodies. The jacket is body-conforming and contains 64 tactile stimulators. It attempts to increase the user's emotional immersion by rendering emotional effects to the user's skin. This project is based on the idea that emotions are accompanied by different physical reaction, and that by stimulating these physical reactions using the jacket, the accompanied emotions could be evoked [4, 9].

Figure 2.3 Philips research emotional haptic jacket [9]

2.2.4 Adding Haptic Feature to YouTube

Embedding of haptic technologies into different virtual reality applications have been researched in several applications. They enabled users to interact with virtual objects and feel tactile and force feedback in these systems. These systems include medical, military and even entertainment. Video media have also included haptic modality to further enhance user experience.

The work in [17], however, introduced a custom made web browser with a plug-in that creates tactile content to be simulated on a wearable vibrotactile jacket. This plugin-in enables online video viewers to feel haptic feedback while watching YouTube videos through this jacket. The plug-in works by creating a sequence of arrays in XML format. These arrays are composed of timestamps and actuating values for the operation of the jacket. Viewers can feel the haptic feedback by choosing YouTube videos that contain annotated files with tactile content, which is saved on an on-demand server. The XML files are then transmitted to the jacket while the video is watched. The custom made browser and the haptic device driver are open source, and are created using Java to enable them to operate in most operating systems [17].

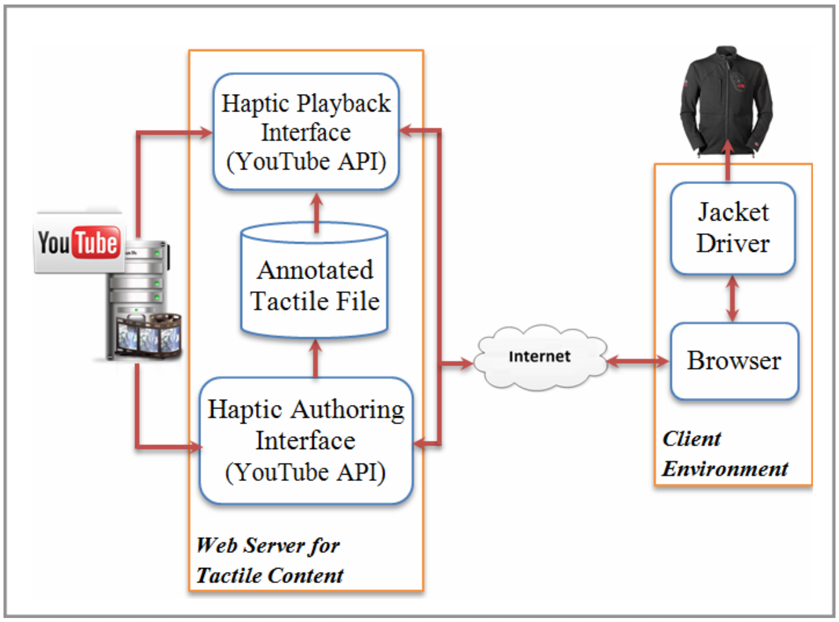


Figure 2.4 Tactile video web service block diagram [17]

2.2.5 SMS Text Based Affective Haptic Application

This system discusses complete text analysis for SMS messages looking for secondary level emotions [1] and communicating them to the user using haptic vibrotactile devices. Using a haptic phone or a haptic jacket, this application prototype maps every emotion into a distinct vibration pattern.

The overall system is composed generally of an emotion server, and a mobile client. The application is in action when the receiving phone forwards received messages to the remote emotions server (REM) using Simple Object Access Protocol (SOAP). The message is then analyzed and related emotions are extracted. Finally, emotion vectors are created and sent back to the phone which, in turn, forwards that vector to the haptic device, which may be the same phone, another phone, or a haptic jacket [18].

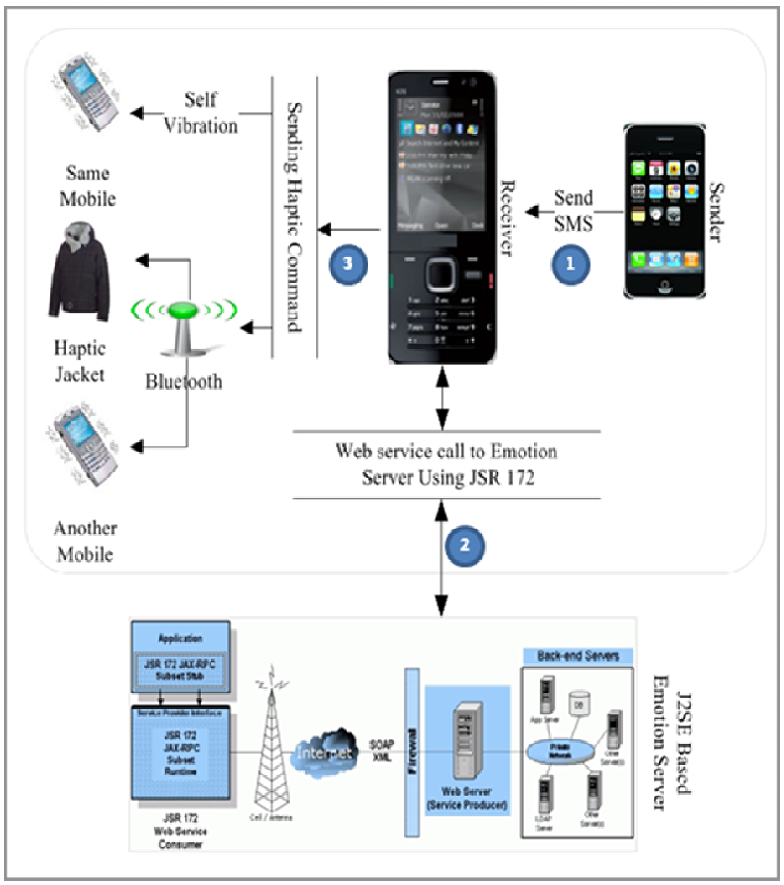


Figure 2.5 SMS service high level design [18]

2.2.6 Automatic Fiducial Points Detection for Facial Expressions Using Scale Invariant Feature

This research is focused on facial expression recognition by identifying 26 fiducial points on a person's face. Their method has three major steps. The face area is first detected and recognized from the overall frame. Then, candidate feature points are extracted. Finally, the 26 fiducial points are detected and localized [5].

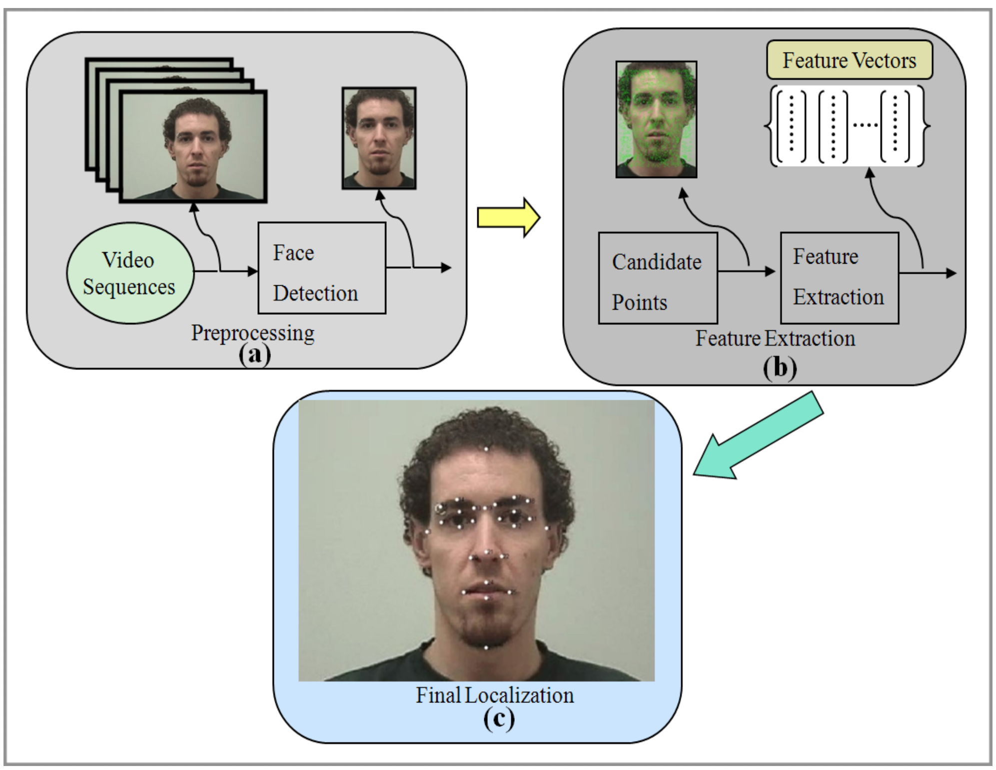


Figure 2.6 Block diagram showing proposed detection algorithm [5]

2.2.7 iFeel_IM: Augmenting Emotions During Online Communication

Conventional systems for human-computer interaction usually ignore important social communication mediums such as the sense of touch, and only support channels such as sound or/and vision. Affective haptics research, however, have recently introduced the sense of touch to the formula. “Affective Haptics” is becoming more popular by time. It mainly focuses on systems that evoke or affect a human’s emotional condition by the sense of touch [6, 19].

This research introduces iFeel_IM! (Intelligent System for Feeling Enhancement Powered by Affect-Sensitive Instant Messenger), which is a system that uses haptic and visual devices during online conversations to communicate experienced emotions during that conversation [6, 19].

It consists of 4 affective haptic devices:

HaptiHeart: Depending on the intended emotion, the HaptiHeart device reproduces different patterns of heartbeats. For example, it associates sadness with an intense heartbeat, while anger is associated with a quick and strong heartbeat.

HaptiHug: reproduces a human-hug pattern by creating pressure on the user's chest and back at the same time.

HaptiTickler: This device uses the element of surprise and unpredictability to tickle the user's ribs using vibration motors that operate similar to human fingers.

HaptiButterfly: This device was intended only to evoke "joy". It produces a series of vibrations attached to the user's abdomen to give a "butterflies" like feeling.

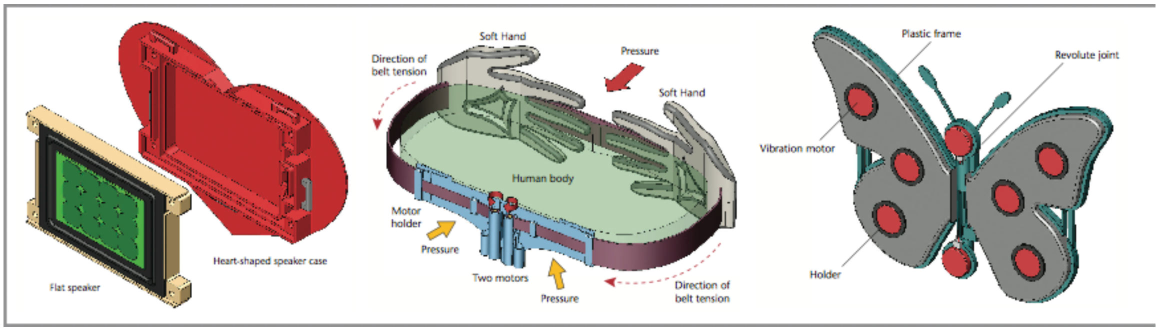


Figure 2.7 iFeel_IM the HaptiHeart, HaptiHug, and HaptiButterfly [6]

2.2.8 iFeeling: Vibrotactile Rendering of Human Emotions on Mobile Phones

Rehman and Liu conducted a research to assist visually impaired people to better interact with others in social events. The iFeeling system is a vibrotactile rendering system that exploits current mobile phone technologies and use them in emotional communications. The system uses a video camera attached to the visually impaired person to recognize one of four emotional states by reading lip expressions. The four addressed emotional states are "normal", "happy", "surprised", and "sad". The recognized expression is then converted to a specific vibration pattern and intensity that can be recognized by the user [10].

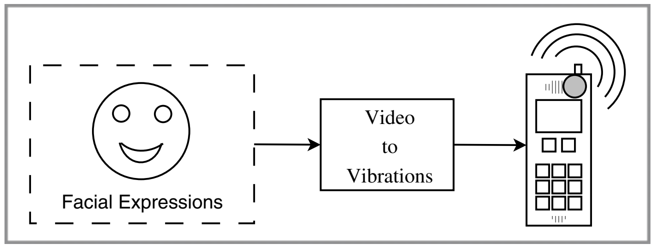


Figure 2.8 A block diagram of expressive lips video to vibration [10]

2.2.9 Haptics in Audio Described Movies

This work describes a proposed system represented by a belt to be worn on the waist of visually impaired people while watching audio described movies. The belt contains seven vibration motors separated by equal spaces, and a control box. The aim of this belt is to assist visually impaired people in understanding specific information about conversations in audio described movies. Vibration motors activate simultaneously with audio conversations to distinguish actors and the distances between them, or the distance between an actor and the camera [15].

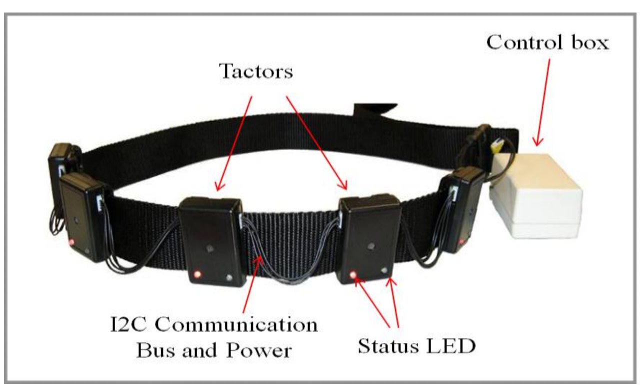


Figure 2.9 Vibrotactile belt for audio described movies [15]

2.2.10 Huggy Pajama: A Mobile Parent and Child Hugging Communication System

Huggy Pajama is a wearable and mobile HCI system that allows its users to remotely feel and hug each other. It is mainly intended for parents who travel a lot and want to keep in touch with their children and express affections constantly [20, 26].

The system is composed of a small, mobile doll that has a pressure sensing circuit embedded in it to sense different levels of force produced by human interaction (i.e. the hug). Then, it sends the sensed hug signals to a haptic jacket (or pajama) that, in turn, simulates the measured hug and gives its wearer the feeling of a hug. The doll (the input device / hugging interface) and the jacket (the output device) communicate through the internet, and simulate the hug using hardware that include air pockets, heating elements, and color changing fabric [20].

The system has three modes of operation [20]:

- Remote touch and hug: to communicate touching and hugging sensed by the input device (the doll) to the haptic jacket.
- Haptic pajama: to reproduce hugging and warmth feeling to the person wearing the jacket.

- Distance and emotion indication: to represent the distance between the child and the parent by the color changing fabric.

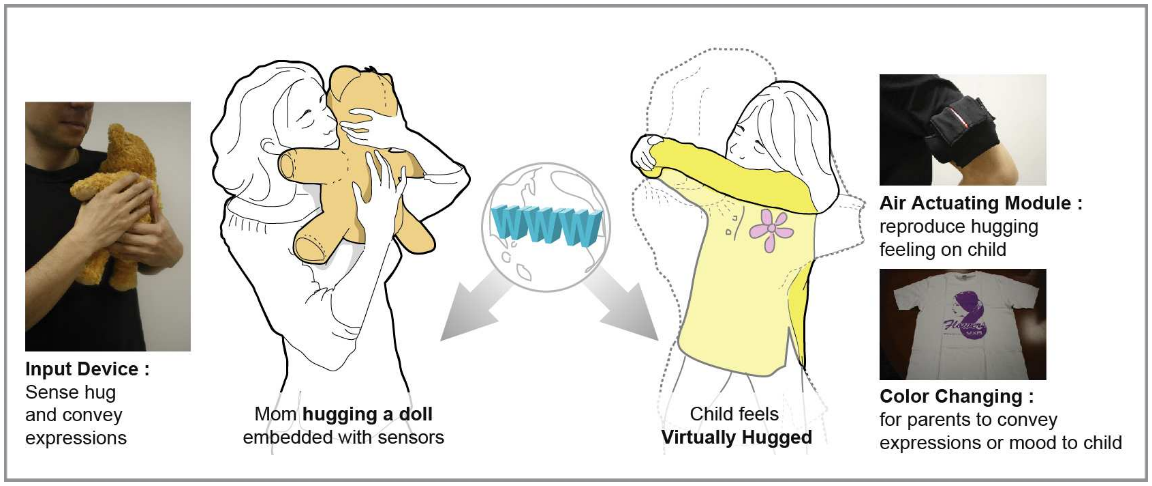


Figure 2.10 Overview of Huggy Pajama [20]

2.2.11 The Huggable: A Therapeutic Robotic Companion for Relational, Affective Touch

The Huggable is basically a robotic animal that is aimed to replace real animals in hospitals, nursing homes, and other therapeutic facilities in order to avoid fears of allergies, bites, or diseases. It is designed in the MIT Media Lab aimed at promoting interaction and as a useful tool for research and healthcare. The Huggable consists of temperature, force, and electric field sensors, and communicate via 802.11g wireless connection. For motion, it has a 3-DOF neck, a 2-DOF coupled eyebrow, a 1-DOF coupled ear, and a 2-DOF coupled shoulder mechanism. This system is able to detect weather it is being touched softly or it is being slapped, and weather it is being touched by a human or an object by using the electric field and temperature sensors embedded in it. It also consists of cameras for face detection, and speakers in the mouth to provide audio output. The Huggable is intended to be more than a fun interactive pet replacement. It is also designed to improve people's overall health and comfort [22].

Figure 2.11 The huggable (left) and skin sensors (right) [22]

2.2.12 TapTap - A Haptic Wearable for Asynchronous Distributed Touch Therapy

TapTap is intended for use in understaffed hospitals, traveling lovers or parents, or for physical therapists to provide "therapeutic touch at a distance, repeatably and to more than one person" [29]. It is mainly a wearable haptic system that allows distributed transmission of tactile data asynchronously. It can record and playback different simulations of human touch. The study discusses two implemented prototypes.

The first prototype reproduces simulations of most common kinds of human touch: tap, press, stroke and contact. They use vibrating motors, solenoids, air bladders, and Paltier junctions. The second prototype, however, was made to be more size free and user independent. It is also created to overcome problems faced by the first prototype that were discovered after users' QoE tests. The second prototype embeds actuators in a scarf-like device that can be emptied from electronic circuits for safe washing [29].

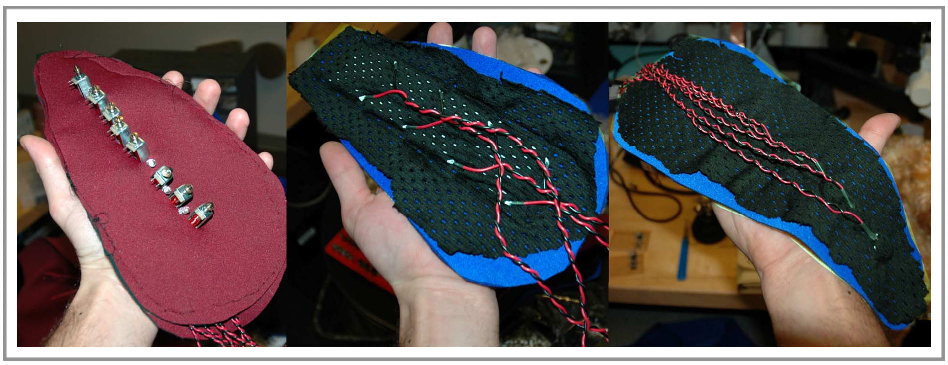


Figure 2.12a TapTap first prototype [29]

Figure 2.12b TapTap second prototype [29]

2.2.13 A Mobile Pet Wearable Computer and Mixed Reality System for Human-Poultry Interaction Through the Internet

Motivated from the importance of poultry as animals with feelings that are poorly treated by the society, researchers have made considerable efforts in implementing a system that can emotionally connect humans and chicken using haptic technology and augmented reality (AR). It is not easy to keep poultry as pets in modern societies, especially in offices and work locations. This system is composed mainly of an office system, and a backyard system that can be connected wirelessly and via the internet. Vibrotactile actuators are incorporated in a lightweight jacket to be worn by the pet. The owner can communicate touch to the pet through a dummy pet that represents and replaces the live pet in the office system. Electrodes are also attached to the pet's thighs to sense activities in its muscles and for the owner to feel the its movement.

The human-poultry interaction can be viewed in this system with different modes. The system offers 3D visualization of the pet in an AR environment that displays the pet's movements in addition to a 2D display for XY [28] positioning. The system also offers haptic sense and remote touch between the human fingers and the pet. Finally, physical stimulation is provided to the user's feet to feel the pet's movements via the electrodes attached to the its legs [30].

Figure 2.13 A chicken wearing the mobile-computer-pet-jacket [30]

2.2.14 The Hug Shirt

The Hug Shirt allows users to send hugs at a distance. It was featured in TIME magazine's website as one of the best nominated inventions of 2006 [32]. The system works by transferring received hug instructions via SMS to actuators and sensors embedded in the shirt using bluetooth. Hugs can be sent either by creating a hug SMS instruction using a provided mobile java application, or by touching specified locations on another input shirt that is designed for this purpose. The Hug Shirt runs on rechargeable batteries, and is built using components that comply with the Restriction of use of Hazardous Substances (RoHS) [31,33].

Figure 2.14 The Hug Shirt [31]

2.3 Comparison

Based on the above review of most recent literature, we summarize them by addressing the following characteristics and showing the differences between each system with respect to these characteristics:

- **General Objective:** the objectives behind designing the system and what it adds to the literature.
- **Type of System:** what kind of system it is and how it can be used.
- **Special Requirements:** this aspect specifies whether the system requires additional systems to work with, or if it is portable and independent of other systems.

- **Types of Haptic Hardware:** what kinds of haptic hardware does it use or need to interact with its user.
- **Body Areas of Interest:** which of the body areas does the system affect/ use to operate.
- **Targeted Users:** what kind of application users the system is designed for (movie viewers, gamers, IM users, …etc), or whether the system is designed for a specific group of people (i.e. visually impaired, …etc).

Table 2.1 Related work comparison

Research Title	General Objective	Type of System	Special Requirements	Types of Haptic Hardware	Body Areas of Interest	Targeted Users
Interpersonal Haptic Communication in Second Life [2]	Touch communication	Add-on	Designed for Second Life [16], requires haptic jacket	Vibrotactile actuators	Arms and chest	Second Life users
HugMe: Synchronous Haptic Teleconferencing [3]	Touch communication	Teleconferencing system	Network based	Vibrotactile actuators, and a 3-DOF force feedback device	Arms and chest	Teleconferencing users
A Body-Conforming Tactile Jacket to Enrich Movie Viewing [4,9]	Increasing emotional immersion in movie viewing	Haptic jacket	N/A*	Vibrotactile actuators	Arms, chest, and back	Movie viewers
Adding Haptic Feature to YouTube [17]	Touch communication	Web browser and plug-in	Designed for YouTube, requires haptic jacket	Vibrotactile actuators	Arms and chest	YouTube viewers
SMS Text Based Affective Haptic Application [18]	Emotion extraction and communication	SMS service software	Requires haptic device and SMS service	N/A*	N/A*	SMS users

Research Title	General Objective	Type of System	Special Requirements	Types of Haptic Hardware	Body Areas of Interest	Targeted Users
Automatic Fiducial Points Detection for Facial Expressions Using Scale Invariant Feature [5]	Facial expression recognition	Software	N/A*	N/A*	N/A*	All
iFeel_IM: Augmenting Emotions During Online Communication [6, 19]	Touch and emotion communication	A set of haptic and visual devices	Designed for online conversations	Vibrotactile actuators, and a pressure belt	Chest and abdomen	Online conversationalists
iFeelng: Vibrotactile Rendering of Human Emotions on Mobile Phones [10]	Emotion communication	Vibrotactile rendering system	N/A*	Vibrotactile actuators	N/A*	Visually impaired people
Haptics in Audio Describes Movies [15]	Describe audio described movies	Haptic belt	N/A*	Vibrotactile actuators	Waist and hand	Visually impaired people
Huggy Pajama: a mobile parent and child hugging communication system [20, 26]	Hug and distance communication	Remotely controlled haptic jacket	Requires internet connection	air pockets, heating elements, and color changing fabric	Upper body	Traveling parents
The Huggable: a therapeutic robotic companion for relational affective touch [22]	Replacing pets	Robotic animal	N/A*	Electric field and temperature sensors	N/A*	Psychological therapy
TapTap - A Haptic Wearable for Asynchronous Distributed Touch Therapy [29]	Touch communication and reproduction	Haptic wearable devices	N/A*	Vibrotactile actuators, solenoids, air bladders, and Paltier junctions	1st prototype: Arms and shoulders / 2nd prototype: scarf	Physical therapy and traveling parents/ lovers

Research Title	General Objective	Type of System	Special Requirements	Types of Haptic Hardware	Body Areas of Interest	Targeted Users
A mobile pet wearable computer and mixed reality system for human-poultry interaction through the internet [30]	Remote human-poultry communication and monitoring.	Haptic and augmented reality system	Requires internet connection	Vibrotactile actuators, electrodes, and a haptic reading dummy	N/A*	Human-poultry interaction
The Hug Shirt [31]	Hug communication	Haptic shirt	Requires SMS service	Vibrotactile actuators, and touch sensors	N/A*	All
Our System	Increasing emotional immersion and stimulation	Haptic jacket	Interfacing application	Vibrotactile actuators, thermal actuators, and temperature sensors	Arms, chest, and neck	All

* N/A: not applicable / not specified.

2.4 Summary and Contribution

From the related studies and the comparison table, it can be shown that there are some research that is mostly focused on the haptic interfacing aspect, other research that is mostly focused on the emotional aspect, and only a very few that is strictly focused on the integration of emotional stimulation and haptic interfacing in the same system. Also, a lot of the discussed research do a representation and communication of information rather than actually doing an effect on the user.

One of the closely related research from the above mentioned studies is the iFeel_IM [6, 19] is a very popular study on affective haptics that addresses emotions in Second Life. However, it is limited to the domain of SecondLife [18]. Another closely related research is the body-conforming jacket by Philips research [4, 9]. This research, however, is strictly designed for movie viewing [9]. The Hug Shirt from Cute Circuit [31] requires SMS service to operate, while the SMS text based affective haptic application [18] mentioned in section 2.2.5 requires a haptic device to operate. HugMe [3] and Huggy Pajama [20, 26] focus on the importance of real time and remote interaction, but are strictly designed for internet communication. TapTap [29] may be very close to Huggy Pajama. It uses a good combination of haptic hardware and is improved in its second prototype based on users' experience. However, in comparison to our research, it focuses on touch therapy rather than affecting emotions directly. The Huggable [22] and the human-poultry interaction research consider another approach in haptic technology and HCI. They consider people that enjoy the company of pets but are unable to directly interact with them for any reason.

Our research contributes in the topic of emotional haptics by designing and implementing an emotion stimulating haptic jacket that is based on an empirical study rather than pure theory, and eliminating some of the shortcomings of the systems described above while attempting to improve some of the other qualities. In comparison to all the above mentioned research, the proposed system aims to be as portable as possible and application independent. It includes vibrotactile and heat actuators in addition to temperature sensors all around the chest area, the arms, and around the neck. The system is designed to accommodate the needs of different consumer groups and with the minimum possible specific requirements.

CHAPTER 3

Proposed System and Design

In this chapter, a detailed description of the proposed system is explained including an explanation of the overall architecture design and the different modules associated with it. It starts by describing how the data was collected using an online survey. The results of the survey are shown in detail. After that, it explains the general architecture of the implemented system based on the results of this survey by providing a system overview and an explanation of the affective haptic components of the system. Then, a detailed system architecture is provided, followed by a summary of the possible scenarios of the system.

3.1 Online Survey

The main concept used to construct this survey was based on the list of emotions defined in the Parrot 2001 [1] model of social psychology as described earlier. The goal was to figure out which part of the body represents which emotion. A total of 92 responses were collected in this survey, 58 of which were by male respondents and 34 were by females. All except for one were between the ages of 18 and 29.

3.1.1 Data Collection

In the conducted survey, respondents were asked to give their own opinion on how each (but not necessarily all) of the basic emotions mentioned above can be represented physically using actuators embedded in smart clothes. In the survey, in addition to providing the ability for respondents to give their own ideas, three basic types of haptic feedback were suggested:

- Vibration
- Beats
- Warmth

As a reference, figure 3.1 was added to the survey to assist in providing more accurate and unified results. The areas of interest are:

1. Neck
2. Chest (right side)
3. Chest (left side)
4. Abdomen
5. Lower stomach
6. Arms

The survey was created on www.surveymonkey.com using http://www.surveymonkey.com/s/KWXBWP3 as the response collecting link. It was started on February 8, 2011, and closed on February 22, 2011 (two weeks). The number of responses varied for each part of the survey even though a total of 92 users contributed in it. This is because the respondents were only asked to answer the parts they wanted, and may skip questions. The starting page of the survey contained the following text:

> Hi!
> This survey is intended to find ways to communicate emotions from the digital world to be physically felt and understood by a human being. It is a part of a research project being held in the Multimedia Communications Research Laboratory (MCRLab) in the University of Ottawa (http://www.mcrlab.uottawa.ca).
>
> The main reason behind conducting this survey is to find the best solutions and ideas, and develop smart clothes that can represent emotions physically!
>
> ___________
>
> Example: Fear
>
> Imagine yourself watching a horror movie, and you want to feel scared so you can fully experience the movie.
>
> When you're scared, you feel:
>
> Strong heartbeats in the chest ==> strong beats in the left chest area (area 3 in the image below)
> Fast breathing ==> air pumps in the overall chest area (areas 2 and 3 in the image below)
> etc...
>
> (check the image below)
>
> ___________
>
> Remember:
> (1) There are no wrong answers! Be creative!!!
> (2) You don't have to fill everything!
>
> For more information on this project: fha@mcrlab.uottawa.ca

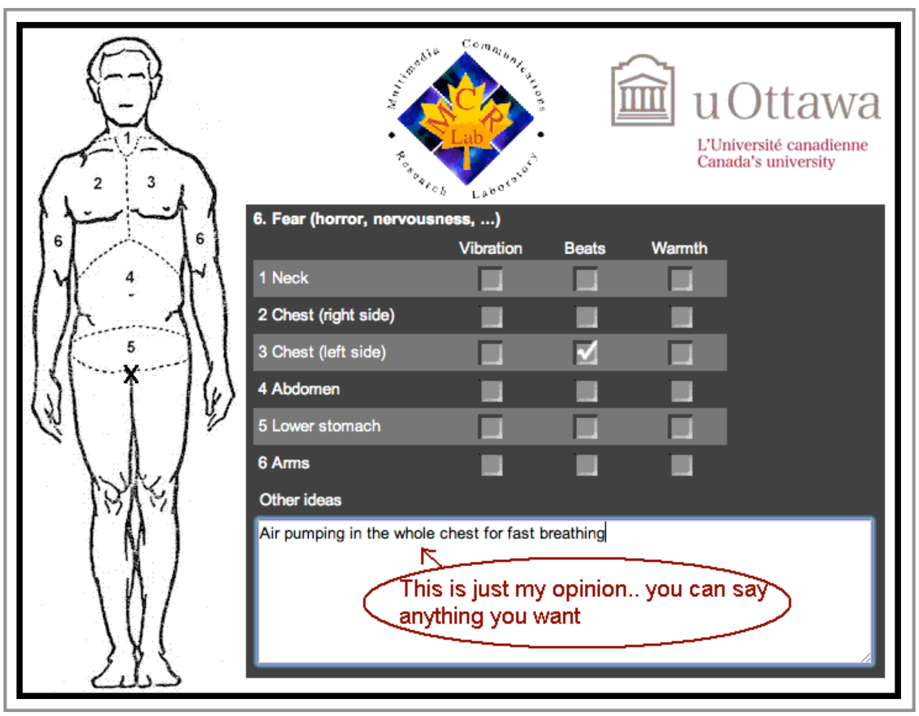


Figure 3.1: Example given to assist in responding to the online survey

The survey was designed based on the emotions we are focusing on, and also on the most common haptic actuation hardware. We used check boxes to count the number of responses for each type of haptic actuation, for each body area, for each emotion. Also, a text box was provided for any other ideas the users may have [figure 3.1].

3.1.2 Survey Results

The results of the conducted survey are shown in the following tables and charts. The below tables show the results in terms of a count of responses for each type of haptic feedback, and charts show the results as a percentage of the total number of responses for that specific emotion. Each time a respondent checks a checkbox in the survey, the count for that specific item is increased. The most interesting and implementable ideas provided by the respondents are also described below. After that, the responses were analyzed and an overall system was proposed and will be discussed in section 3.2.

A. Love (affection, lust, …)

The survey results show that the majority of respondents suggested heartbeats simulation in the jacket to represent “love”. Also, it can be noticed that there is a good number of responses that suggest warmth in the neck and the abdomen area. One written response also suggested warmth all over the body. Total number of responses: 91.

Table 3.1 Responses for "Love"

	Vibration	Beats	Warmth
1 Neck	8	7	37
2 Chest (right side)	11	21	25
3 Chest (left side)	10	58	22
4 Abdomen	20	4	35
5 Lower stomach	27	4	24
6 Arms	18	4	22

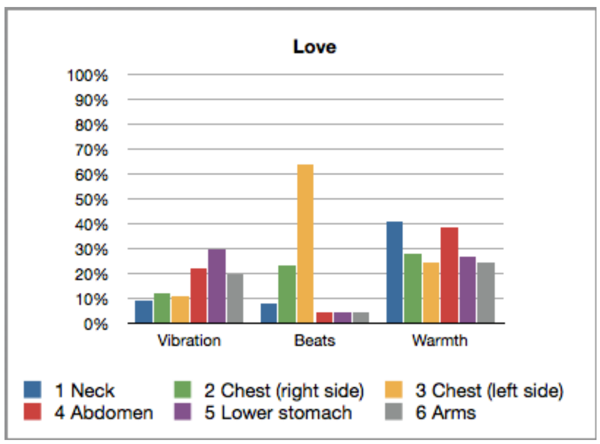


Figure 3.2 Responses for "Love"

B. Joy (cheerfulness, pleasure, pride, relief, …)

To evoke 'joy" the results of the survey show that the majority of responses voted for heartbeats in the left chest side. Some of the written responses suggested the simulation of heartbeats to be soft, and to simulate one long breath. Total number of responses: 87.

Table 3.2 Responses for "Joy"

	Vibration	Beats	Warmth
1 Neck	21	11	23
2 Chest (right side)	13	17	23
3 Chest (left side)	15	33	25
4 Abdomen	17	10	20
5 Lower stomach	20	7	16
6 Arms	25	9	13

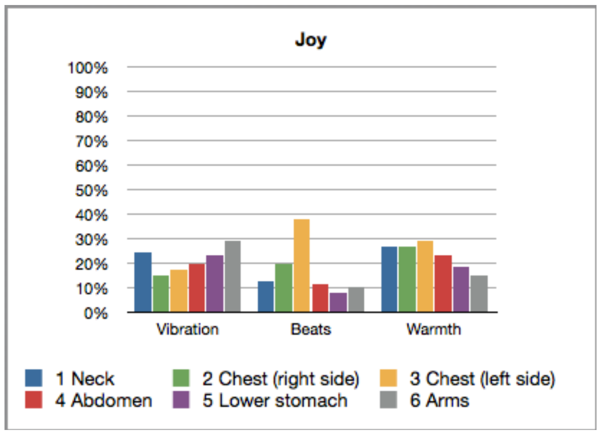


Figure 3.3 Responses for "Joy"

C. Surprise (amazement, astonishment, …)

“Surprise” can be evoked by vibration in almost all the upper body in a shiver-like manner, coupled with a sudden, strong, and fast heartbeats that fade out after a few seconds. Some respondents also suggested simulating benign sense of goose bumps, lowering body temperature, and hardening of the body. The last part can be implemented by tightening the worn jacket mechanically. Total number of responses: 88.

Table 3.3 Responses for "Surprise"

	Vibration	Beats	Warmth
1 Neck	27	18	16
2 Chest (right side)	16	27	8
3 Chest (left side)	17	47	8
4 Abdomen	17	16	12
5 Lower stomach	23	14	13
6 Arms	27	7	11

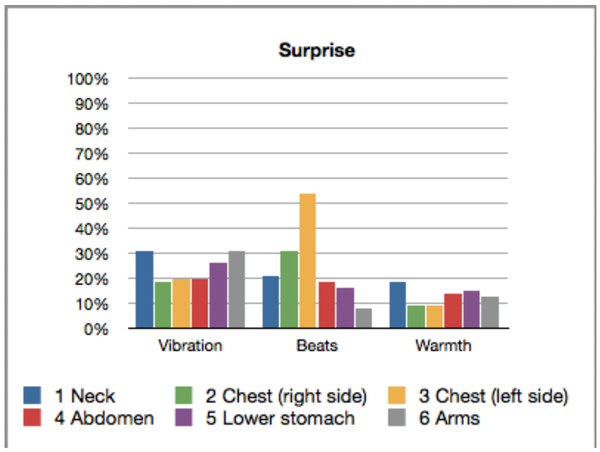


Figure 3.4 Responses for "Surprise"

D. Anger (irritation, rage, disgust, envy, …)

“Anger” can be evoked by some warmth around the neck and vibration in the arms with strong heartbeats in a normal speed. Other ideas written include tightening the neck and the chest for harder breathing, and simulating fast breathing. Total number of responses: 90.

Table 3.4 Responses for "Anger"

	Vibration	Beats	Warmth
1 Neck	25	21	32
2 Chest (right side)	16	35	15
3 Chest (left side)	18	47	14
4 Abdomen	22	18	16
5 Lower stomach	20	15	20
6 Arms	40	21	22

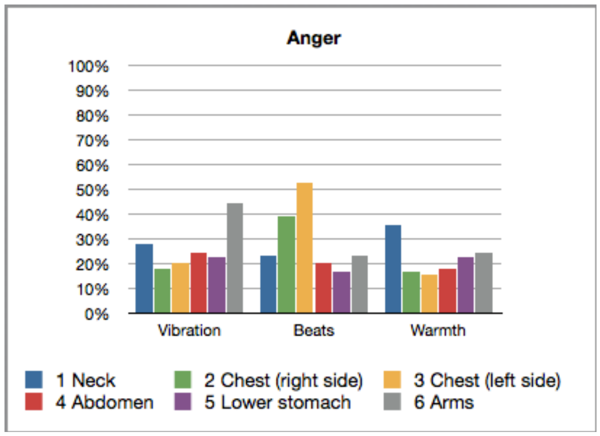


Figure 3.5 Responses for "Anger"

E. Sadness (suffering, disappointment, shame, sympathy, …)

According to the survey results, it is not very clear what is expected from a haptic jacket to evoke sadness as can be seen from table 5. However, one clear and possible idea is to simulate chest tightness. Other written responses include slow heartbeats and cold body temperature. Total number of responses: 83.

Table 3.5 Responses for "Sadness"

	Vibration	Beats	Warmth
1 Neck	19	14	30
2 Chest (right side)	8	13	25
3 Chest (left side)	11	22	23
4 Abdomen	19	11	25
5 Lower stomach	15	13	25
6 Arms	14	6	24

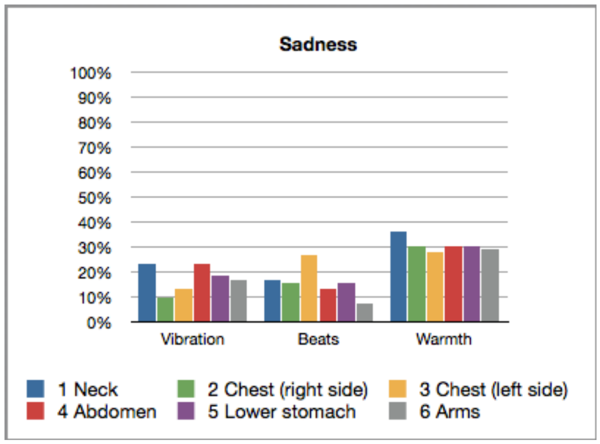


Figure 3.6 Responses for "Sadness"

F. Fear (horror, nervousness, …)

Results for “Fear” seem to be very similar to “anger” with a difference in the neck area where vibration is suggested, and in the speed of heartbeats where it was suggested to be faster. Some other written responses suggested neck tightening, all body shaking, and fast breathing. Hence, it will be difficult to distinguish the two feelings. Total number of responses: 89.

Table 3.6 Responses for "Fear"

	Vibration	Beats	Warmth
1 Neck	32	21	14
2 Chest (right side)	22	37	9
3 Chest (left side)	26	56	9
4 Abdomen	30	20	13
5 Lower stomach	32	23	12
6 Arms	40	18	11

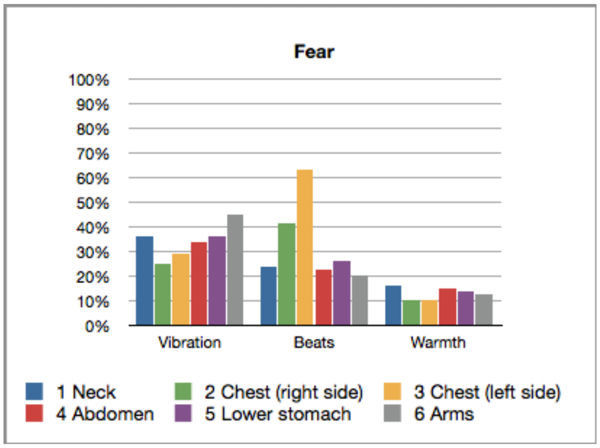


Figure 3.7 Responses for "Fear"

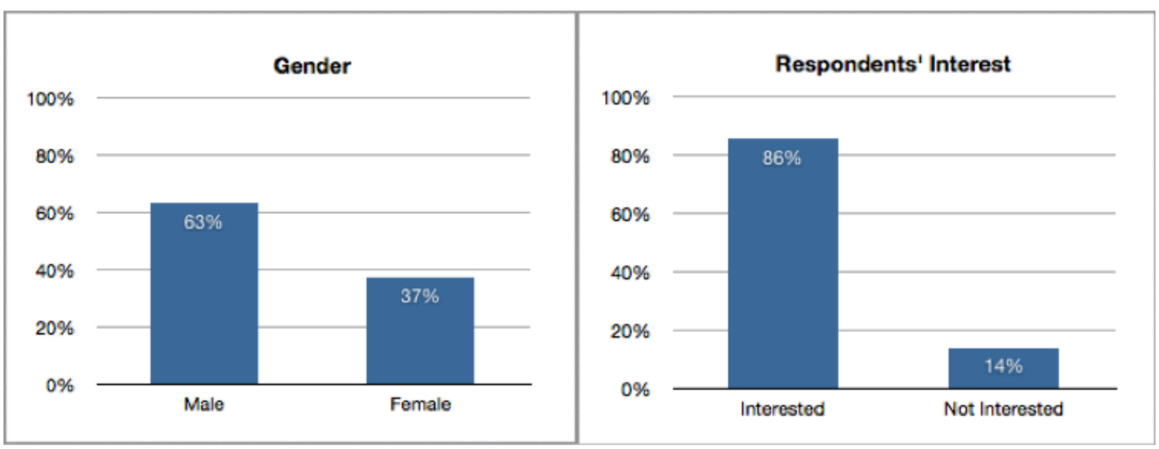


Figure 3.8 Gender of survey respondents and interest rate

At the end of the survey, respondents were asked if having a haptic jacket with focus on emotions is of interest to them. The results show that 78 responded positively, 13 responded negatively, and one respondent skipped this question.

3.2 System Overview

The results of the survey were analyzed extensively, and possible solutions were discussed to bring the results into real life. A prototype of the jacket in the MCRLab at the University of Ottawa to reflect the results of this study (see section 4.3).

To make the most of the outcome of the conducted survey and to better plan the implementation of this system, we applied the Iterative & Incremental Development (IID or also called I&I) (see figure 3.9) software project planning process until the current prototype was reached. I&I has been proven to be an effective project planning process in software projects management [7]. The iteration steps followed in our project are as follows:

- Analysis: we started by designing a general architecture of the overall system, followed by analyzing the testing results for further improvements.
- Design: decisions on the hardware devices needed and the best wiring approaches based on the general architecture.

- Implementation: implementing the reached design, and making any necessary changes.
- Testing: each iteration adds a little to the prototype. The prototype is tested to ensure satisfying operation.

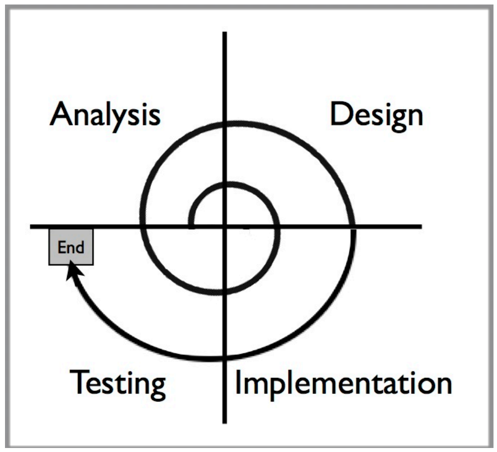


Figure 3.9 Iterative and Incremental Development process followed in the implementation of the jacket

The system is designed such that most calculations for the operation of the jacket are done on the jacket side, which results in a more independent architecture. An Arduino Duemilanove [23] microcontroller is used to control different types of actuators, as well as reading temperatures from temperature sensors embedded in the jacket. The microcontroller's control drivers are connected through a personalized circuit to the different actuators and sensors, and is controlled via a previously defined set of instructions that are sent by an external device. The instructions contain three bytes: the first byte is the number representing the emotion (1:love, 2:joy, etc...), and the second and third bytes represent the duration of which the emotion should be activated in seconds. The external device may be a PC or another digital system that is pre-defined and programmed to interact with our system. The external device, a PC for example, and the jacket system can be connected via USB (see figure 3.10a) or wirelessly via bluetooth (see figure 3.10b). A more detailed explanation of the system will be discussed in section 3.4.

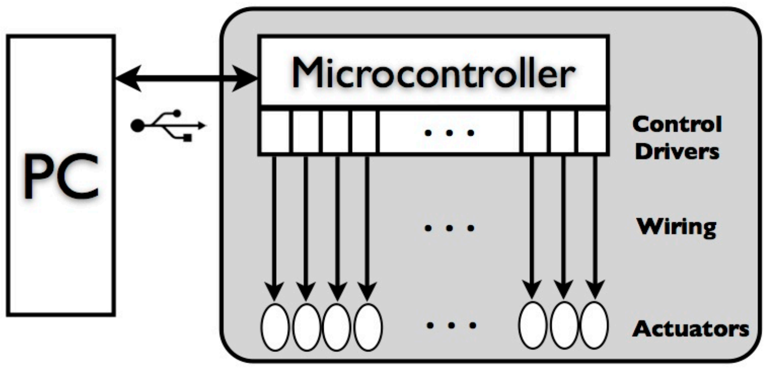


Figure 3.10a Interaction with system via USB

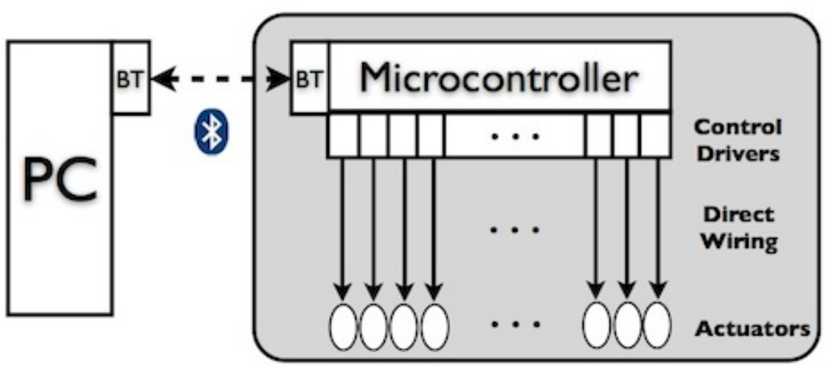


Figure 3.10b Interaction with system via bluetooth

3.3 Affective Haptic Components

Affective Haptics, is becoming more popular by time in the areas of human-computer interaction (HCI). The main focus of affective haptics is on systems that evoke or affect a human's emotional condition using the sense of touch [6]. The data collected from the conducted survey was highly valuable in the overall design of the operation of our system. The designing decisions were made based on the direct input of the consumers, and the scenarios were agreed upon as shown in figure 3.11.

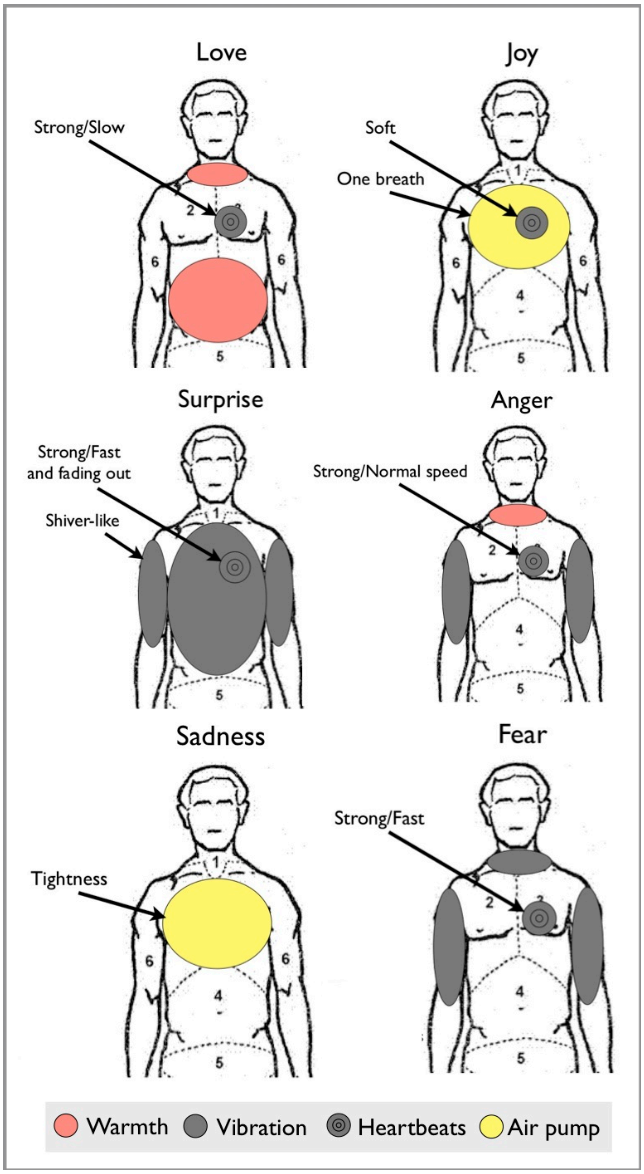


Figure 3.11 Proposed system implementation

As shown in figure 3.11, different scenarios are to be implemented, and different affective haptic components are required. Based on these scenarios, the designed system is designed to be composed of the following 6 affective haptic elements:

A. Chest Vibration

A number of carefully localized vibrotactile actuators are distributed in the inside of the jacket in the chest area. They were distributed approximately 12 cm apart in a grid pattern. These actuators are instructed by the microcontroller to activate when stimulating the “surprise” emotion.

B. Neck Vibration

Two small vibrotactile actuators were placed on each side inside of the jacket’s collar. These actuators vibrate when activating the “fear” emotion in the jacket.

C. Neck Warmth

Two thermoelectric coolers (more on that in section 4.1.1) are also placed on each side inside the jacket’s collar to give a warm feeling in the case of stimulating “love” and “anger”.

In order to avoid accidental increase in temperature, tiny electronic thermometers were directly attached to the heat actuators. Their role is strictly to monitor the temperature of the actuators and give feedback while they are activated.

D. Heartbeat Simulation

It was proven in research that changing the rate of heartbeats can change a human's emotional state, and that each emotion has a different and distinct heartbeat rate [6]. Also, the Merck Manual of Medical Information states that "the normal heart rate at rest is usually between 60 and 100 beats per minute", which is approximately between 1.00 Hz and 1.67 Hz. However, lower frequencies may also be normal in young adults especially if they exercise regularly. Besides responding to exercise and inactivity, the heart beats' frequency also responds to stimuli such as pain and anger [8]. In the implementation of the prototype, this information was used such that the heartbeats' rate is different depending on the activated emotion.

E. Arms Vibration

A set of vibrotactile actuators were embedded in the inside of the sleeves around the arms. The microcontroller gives instructions to these actuators to vibrate in the case of stimulating "fear" and "anger".

F. Arms Shivering

A shiver-like feeling is simulated using the set of vibrotactile actuators inside the sleeves. The microcontroller is set up to instruct the actuators to vibrate in a specific and calibrated order for specific durations and give a shiver-like feeling around the arms. This function is used in the case of stimulating “surprise”. Five vibrotactile actuators are placed on the back and front of each bicep, and are programmed to actuate for 100 ms in turns from shoulder to elbow. The number of vibrators and the durations of vibration were selected to represent the shiver feeling in the best way possible after several trials.

3.4 Detailed System Architecture

The jacket is designed such that it can be used in different applications. It operates by connecting it to a computer or a pre-set digital system that gives direct instructions and evoke each emotion for the desired duration.

Here, we used an Arduino Duemilanove microcontroller to control the jacket. The microcontroller is connected directly to the computer that has an interfacing application. This interfacing application is responsible for giving instructions that the jacket (or to the microcontroller) can understand.

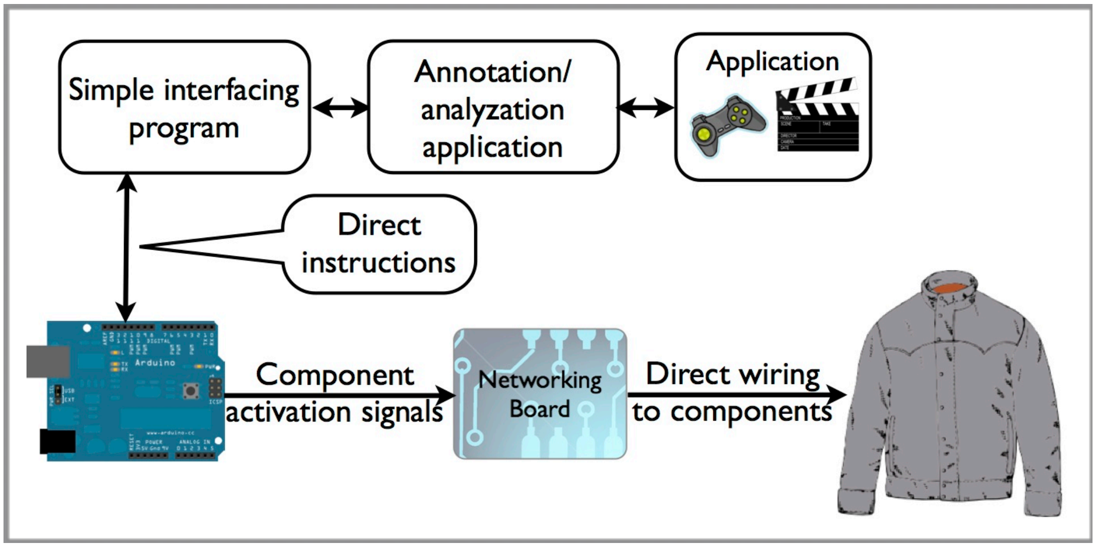


Figure 3.12 System architecture

The microcontroller is programmed to receive six simple and direct instructions representing the six emotions discussed above (see figure 3.12). Also, it receives the duration desired to activate each emotion. The format of receivable instructions is a simple one. The microcontroller receives instructions as a set of 3 bytes from the interfacing program. The first byte represents the emotion number (1: love, 2: joy, 3: surprise, 4: anger, 5: sadness, and 6: fear). The second and third bytes represent the duration of which the emotion shall be activated in the jacket (in seconds). For example, sending the bytes 456 will activate anger for 56 seconds, and 654 will activate fear for 54 seconds.

The microcontroller's input and output pins are connected to what we call the "networking board". The networking board contains all the circuitry needed to control the jacket. It also contains necessary voltage regulators to accommodate different voltage requirements by the jacket's components, as well as BJT transistors to control power thirsty components. This networking board is designed to be connected to the jacket through pluggable wires to make it easy to improve and to replace parts when necessary (please refer to figure 3.13).

Let us consider watching a movie as our application to further describe this architecture. This movie contains scenes of "Love", "Anger", and "Surprise". In subtitled movies, the text is created in a separate file that sends segments directly to the screen in a timely basis synchronous with specific scenes. We can think of the annotation/analyzation part in figure 3.12 as subtitles. The interfacing program will be designed to understand the scene ("love," "anger," or surprise") from the annotation/analyzation part and send the appropriate instruction to the jacket with the duration of that specific scene. Then, the microcontroller will activate the appropriate actuators in the jacket, through the networking board, to stimulate the emotion.

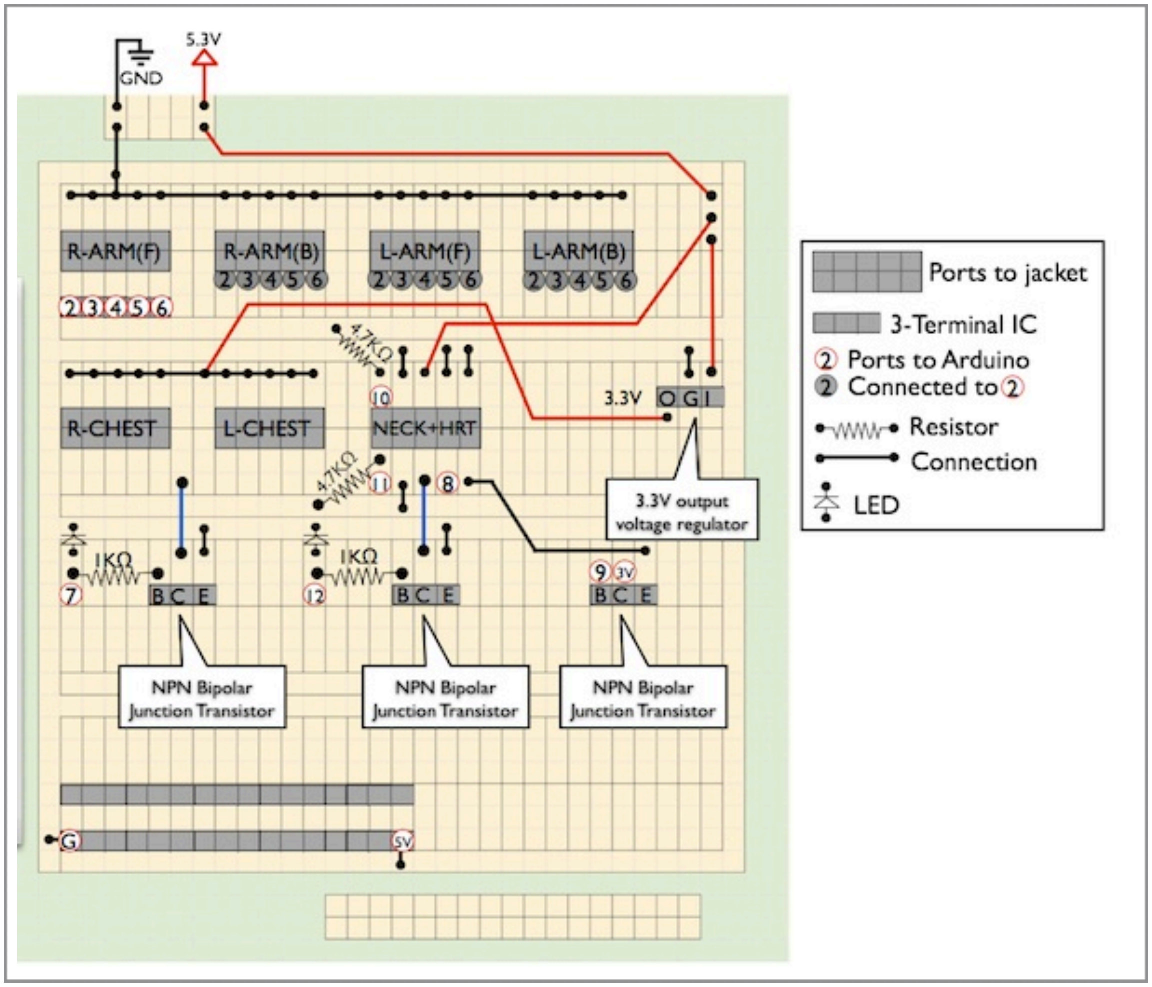


Figure 3.13 Networking Board final design

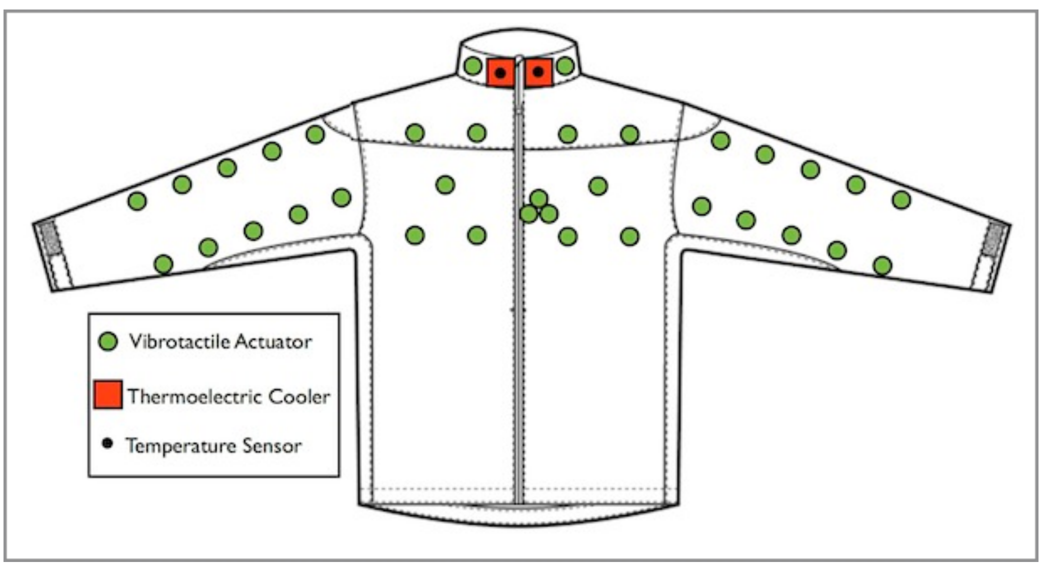


Figure 3.14 Distribution of actuators and sensors on the jacket

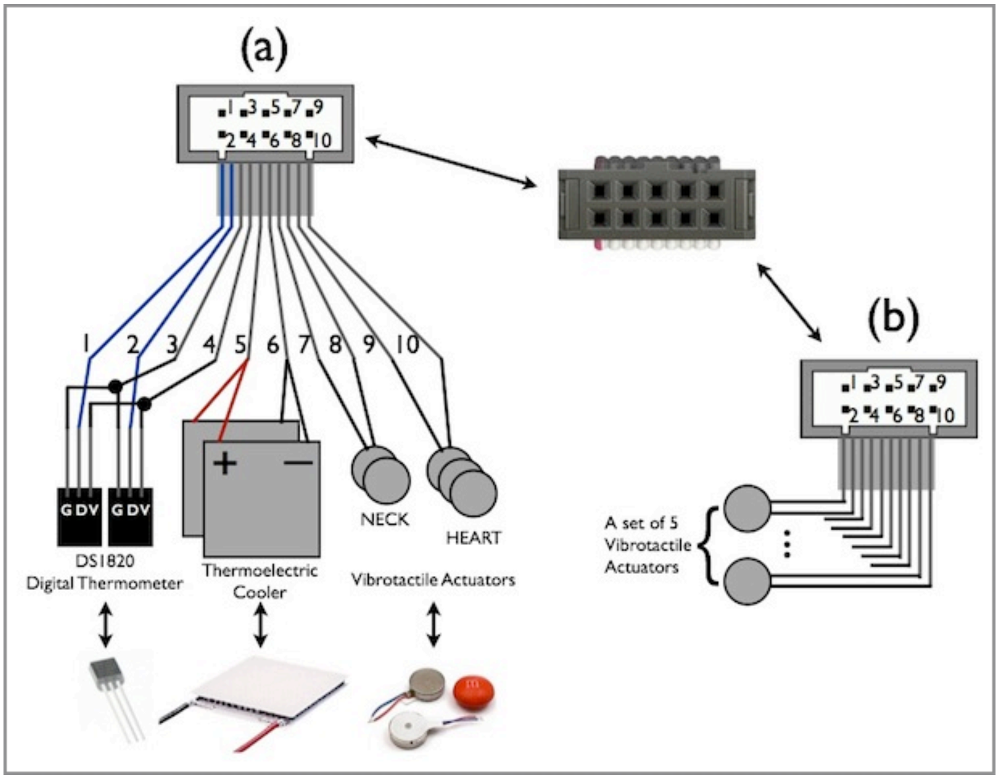


Figure 3.15 Two types of jacket ports: (a) NECK+HRT, and (b) All others

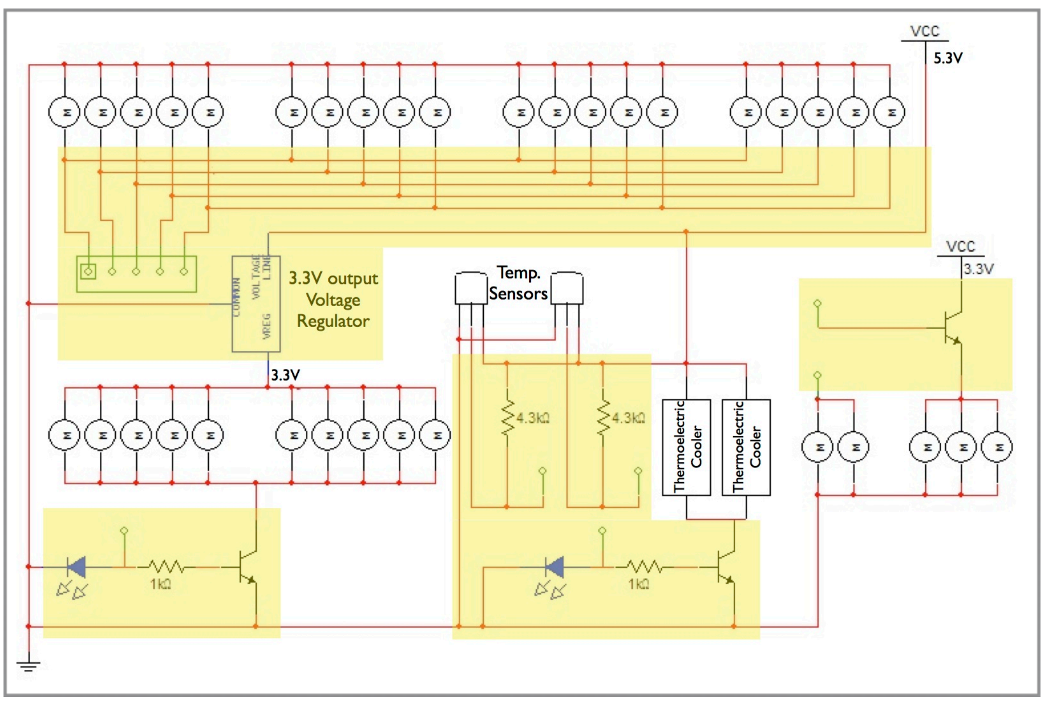


Figure 3.16 Complete system circuit highlighting parts implemented on the networking board

3.5 Prime Devices and Material

To implement this system, different hardware and electronic parts are needed. The market is full of products that are potentially usable in our system. However, many products were dismissed either due to crucial reasons, or simply due to high prices where quality is almost similar. Following is the main devices needed for the implementation of our system indicating important characteristics to ensure acceptable quality. A more technical and detailed description of the used material is described in chapter 4.

A. Vibrotactile Actuators

Vibrotactile actuators are one of the key requirements for the system since most affective haptic components highly depend on them. Therefore, the quality of actuators chosen from the market must be comparatively high. The actuator's weight should be very light, and barely noticeable when worn. It must be small in size, must uses low voltage (less than 5V), and must consume very little power. The reason for these requirements is that most microcontrollers available in the market can not provide more than 5V, and provide very little current, and thus devices connected to it are preferred to comply as much as possible.

B. Heat Actuators

For the same reasons mentioned above, heat actuators must be small in size and require no additional hardware to operate. There exists many heat actuators in the market, but very little that are in small sizes. The main issue with heat actuators is that they consume a lot of energy in comparison to any other electronic hardware. One other important issue concerning heat actuators is the duration they need to warm up and to cool down.

C. Temperature Sensors

Temperature sensors must be used to ensure safe operation of the heat actuators and to avoid accidental burns.

D. Microcontroller

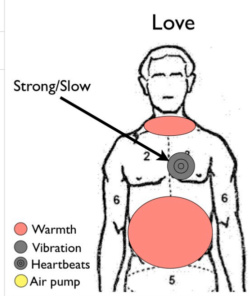
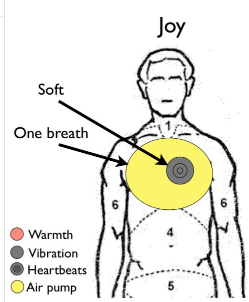
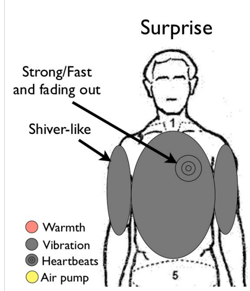
The main points concerning choosing a suitable microcontroller are:

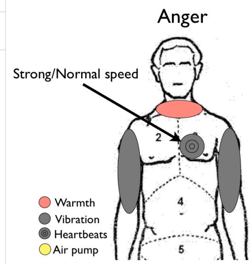
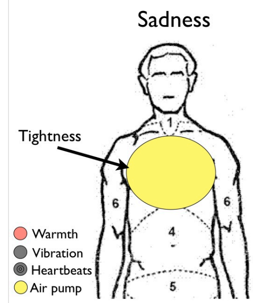
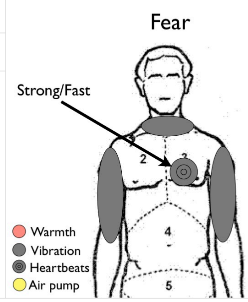
- Availability of a sufficient number of controlling I/O pins for many sensors and actuators connected to it.
- Providing enough power to operate most of the connected devices.
- Ease and efficiency of programming.

3.6 System Scenarios

As previously mentioned, there are six main scenarios for the operation of the jacket that represent the six basic emotions followed in this research [1]. The following table describes how each scenario operates.

Table 3.7 System scenarios based on the survey's results

Emotion	Operation	Description Figure
Love	Neck warmth	
	Abdomen warmth	
	Slow heartbeats	
Joy	Chest air pump (one breath)	
	Normal speed heartbeats	
Surprise	Arms shivering	
	Chest vibration	
	Fading speed heartbeats	

Emotion	Operation	Description Figure
Anger	Neck warmth	
	Arms vibration	
	Normal speed heartbeats	
Sadness	Chest air pump (tightness)	
Fear	Neck vibration	
	Arms vibration	
	Fast heartbeats	

CHAPTER 4

Implementation

4.1 Circuitry and Procedure

The circuit shown in figure 3.16 was mostly implemented on what we previously defined as the "Networking Board". The networking board contains most of the hardware and connections, and is designed to make the overall system more manageable and easier to maintain. Figure 3.16 showed the complete circuit design including all the used electronic parts and end devices (vibrotactile actuators, thermoelectric coolers, and temperature sensors) highlighting the parts that were implemented on the networking board.

The circuit was first implemented on a flat surface for easy access to all hardware and for easier management of cables and connections. Also, it made it much easier to do many initial tests before embedding the system into a wearable jacket.

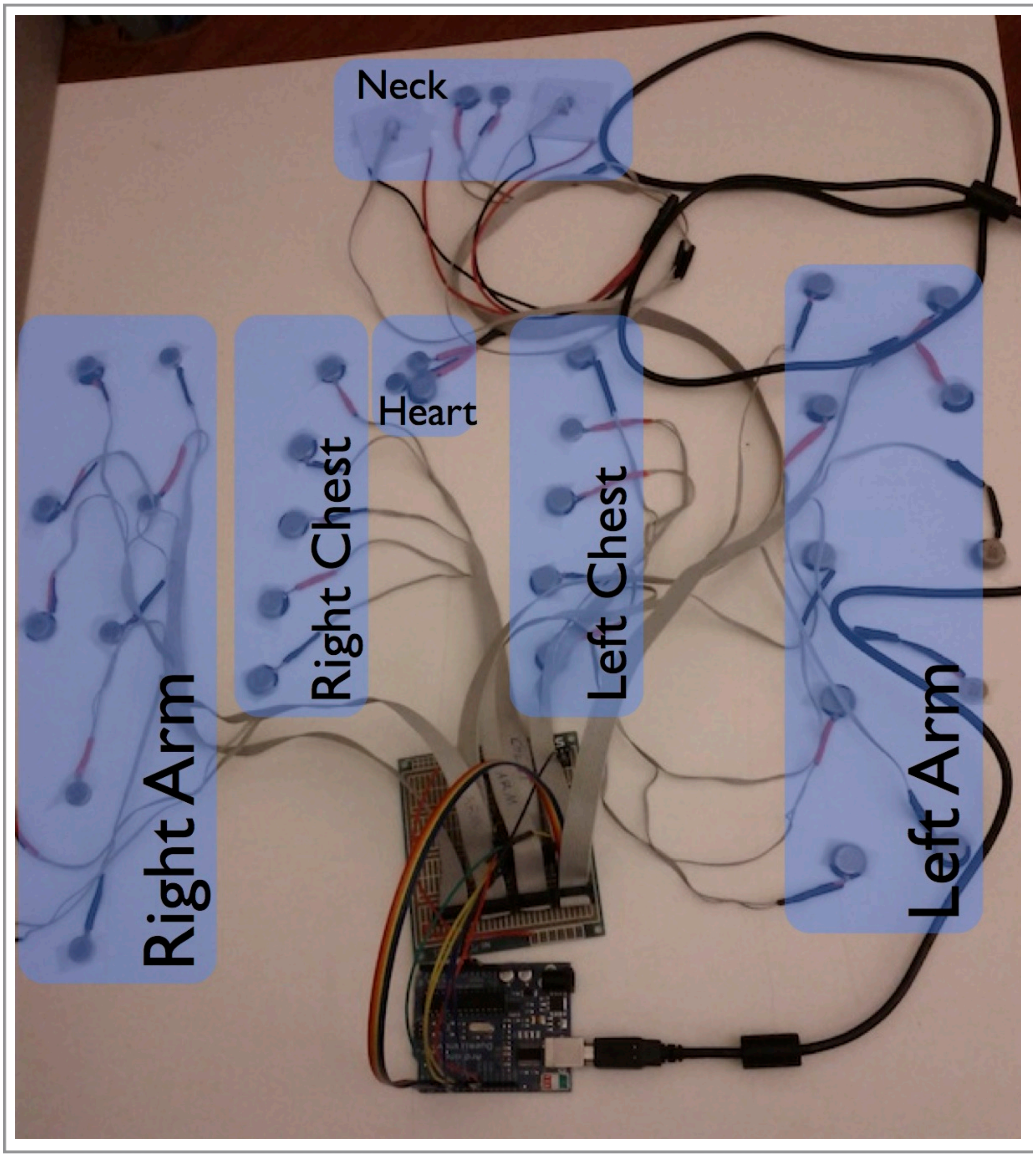


Figure 4.1 Initial flat surface implementation of the system

After completing the implementation of the jacket system and during initial tests, it was noted that heartbeats were barely noticeable and their vibrations were too week in comparison to other haptic actuators. This was due to the low current supply from the control pins of the Arduino microcontroller. In order to rectify this problem, a BJT transistor (shown in figure 4.2b) was added to the circuit in figure 4.2a to allow a higher supply of current from the 3.3V pin on the Arduino microcontroller. Figure 4.2c shows the final implementation of the networking board after fixing the low current drive problem. A detailed explanation of all the used parts and material is covered in section 4.2.1.

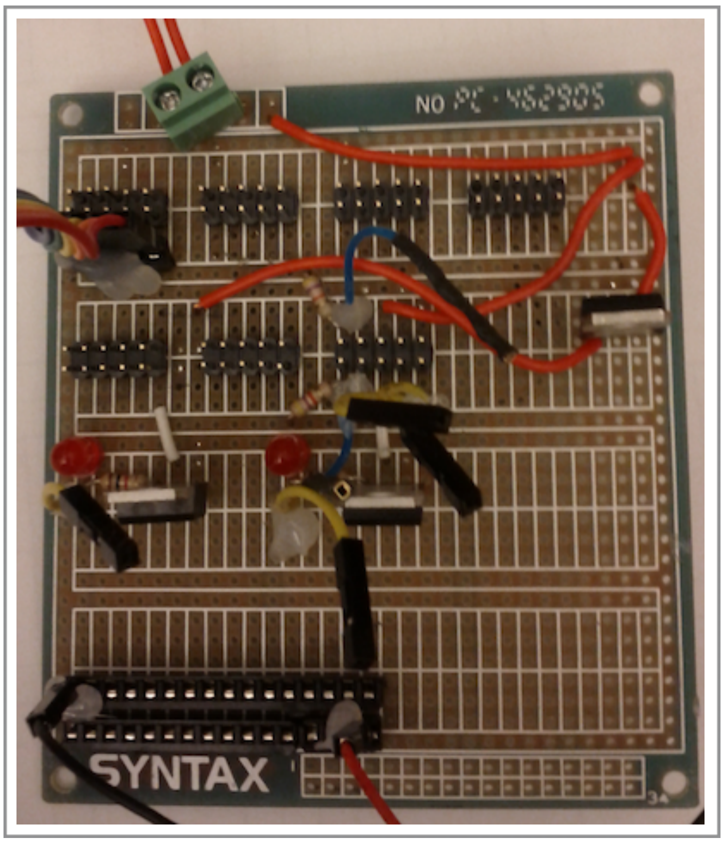


Figure 4.2a Networking Board implementation

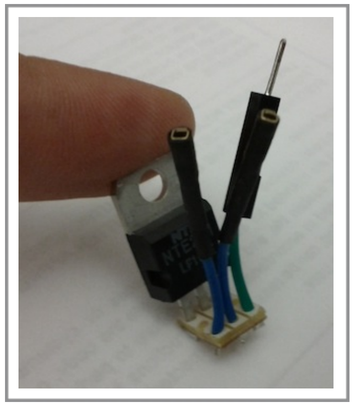


Figure 4.2b A BJT transistor added to the circuit in 4.2a above to enhance heartbeats strength

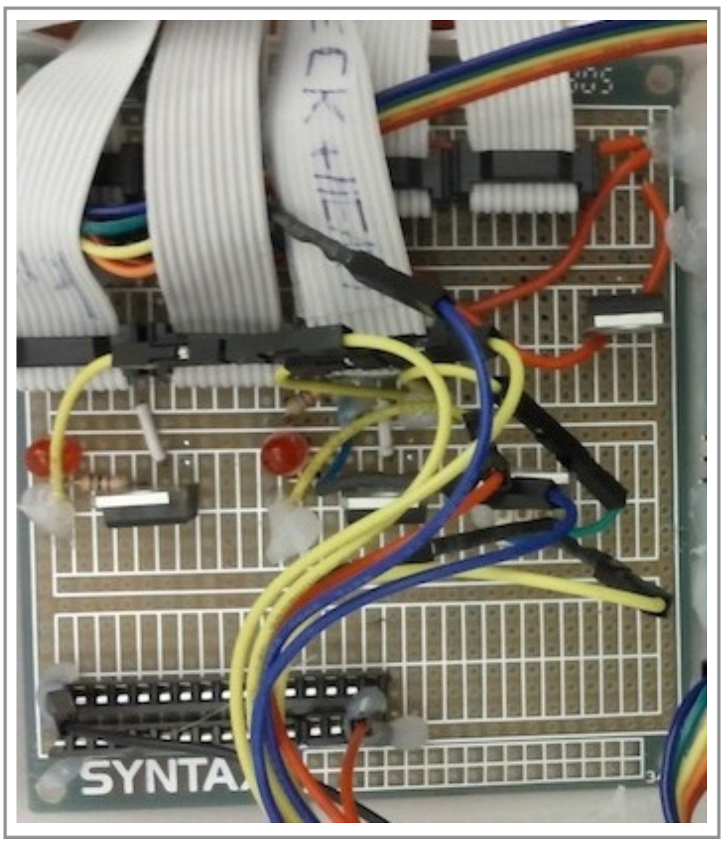


Figure 4.2c Final version of the networking board including the added transistor in 4.2b (figure 3.13 shows a clearer view)

4.1.1 Hardware Used

Different electronic and non electronic parts were used in the implementation of our system. The next subsections will explain all the parts and material used in detail.

A. Vibrotactile Actuators

The vibrotactile actuators were used for their following advantages [34]:

- They are very light weighted (1.2 grams) and small in size (10.0 mm diameter x 3.4 mm thick).
- They use low voltage for operation (2.5 ~ 3.8V), ideally 3V.
- They consume very little power (75 mA).
- They do not require any additional hardware to operate, which results in a more compact size and weight.

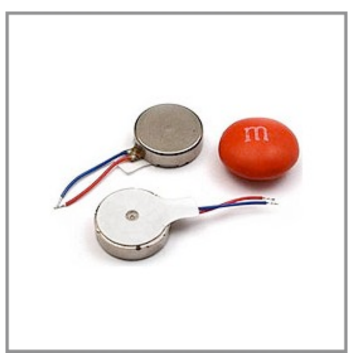


Figure 4.3 Vibration motor compared to m&ms chocolate

B. Thermoelectric Coolers

The thermoelectric coolers were chosen for their small sizes and extremely thin figure compared to other heat actuators available in the market [35]. The used heat sensors have the following characteristics:

- Size: 40 x 40 x 3.6 mm.
- Power consumption: ~7A.
- Require 15.4V ideally. However, in our system they were used at 5.3V and provided acceptable outcome.
- They can heat up to 69 degrees C.

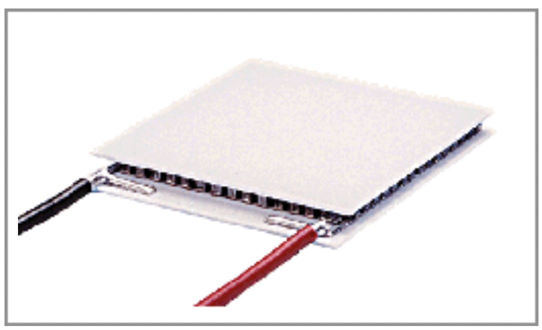


Figure 4.4 Thermoelectric Cooler

C. Digital Temperature Sensors

Digital heat sensors were attached to the thermoelectric coolers embedded in the jacket in order to avoid burns and accidental rises in temperature. Regardless of the duration of operation in the jacket, the microcontroller is programmed to shut down the heat actuators when they reach a maximum of 45 degrees C.

The temperature sensors were not so straight forward to use. They require a 4.7K ohm pull up resistors connected to a 5V power supply. In addition, they also require set-up coding at each startup. However, the DS18B20 digital thermometer has many advantages including the following [36]:

- Requires connection to one digital port only from the microcontroller.
- Requires a minimum of 3.0V.
- Measures temperatures from -55 to +125 degrees C.
- Accurate up to an error of 0.5 degrees C between -10 and +85 degrees C.
- Very small in size and weight, which was the most important characteristic for our application.

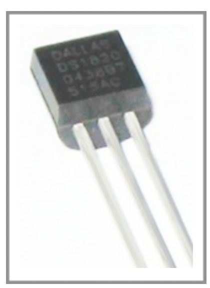


Figure 4.5 Temperature sensor

D. Microcontroller

The microcontroller board used for this system is the Arduino Duemilanove with an ATMega microcontroller [23] which is a very popular microcontroller board for digital control systems of small sizes. It was available in the market since 2009 (duemilanove means 2009 in Italian) and is currently replaced with a newer version called the "Arduino Uno". This board was selected amongst different microcontroller boards due to different reasons. Most importantly, it was chosen due to its ease of programming, which is using its open source Arduino software that is very similar to the C programming language. Moreover, this board supports up to 14 digital I/O pins, 6 analog pins, a 3.3V power supply, and a 5V power supply. These specifications were very important in the implementation of our system. The Arduino Duemilanove also has the following features:

- Operates at 5V which makes it compatible with USB ports.
- Provides up to 40mA DC current for each I/O pin, and 50mA for its 3.3V output pin.
- Runs at a clock speed of 16MHz.
- Provides serial and ground pins.
- Has a reset button.
- Contains a built-in bootloader.

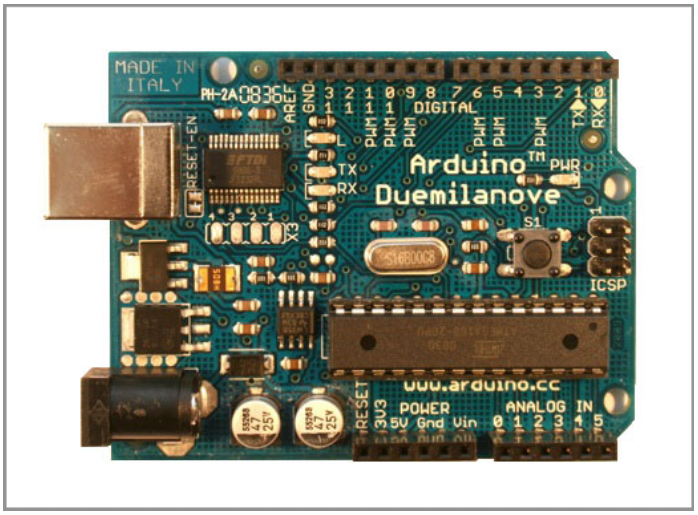


Figure 4.6 Arduino Duemilanove microcontroller board

E. Voltage Regulator

An NTE1904 integrated circuit positive 3 terminal voltage regulator [37] was used to allow high current draw from a 5.3V external power supply but with 3.3V. This device was added to the networking board after realizing that using the 5.3V provided by the power supply was too strong to operate the 10 vibrotactile actuators embedded in the chest area of the jacket. This chip is simply used by connecting its three terminals to the input voltage, ground, and the 3.3V device respectively.

F. Bipolar Junction Transistors

For each of the power thirsty components in the jacket: chest vibrators, heart vibrators, and thermoelectric coolers, an NTE261 NPN BJT transistor [38] was used. This device allows input from an external power supply that can offer higher DC current drain than the Arduino microcontroller board. NTE261 chips can support up to 4A, withstands up to 100V collector-emitter and collector-base voltages, and controlled by up to 5V emitter-base voltage.

G. Other Components

The networking board can be considered as a motherboard for our system. It was built completely on a SYNTAX PCB board [39] that was chosen due to its convenient size and suitable printed internal connections. Also, 10-way grey ribbon cables were used for connecting all the devices embedded in the jacket to the networking board through 10-pin IDC connectors. This method was chosen to easily plug and unplug devices from the networking board when hardware improvements are needed. For connections inside the control box (i.e. between the networking board and the Arduino board), different types of small sized jumpers from SparkFun electronics were used. Finally, LEDs were used to visually identify the mode of operation for crucial components on the networking board.

4.1.2 Software Used

A. Arduino 0023

The Arduino IDE is designed as fraction of a hardware/software platform that is easy enough to be suitable for people that are new in digital electronics programming. It is an open source software that can be downloaded for free from the Arduino website, and is designed to work with any of the list of Arduino microcontroller boards. The Arduino software allows users to write, compile and upload programs to the Arduino boards in C or Processing language. Figure 4.7 shows a snapshot of the Arduino IDE and a sample of the Emotions Jacket code [40].

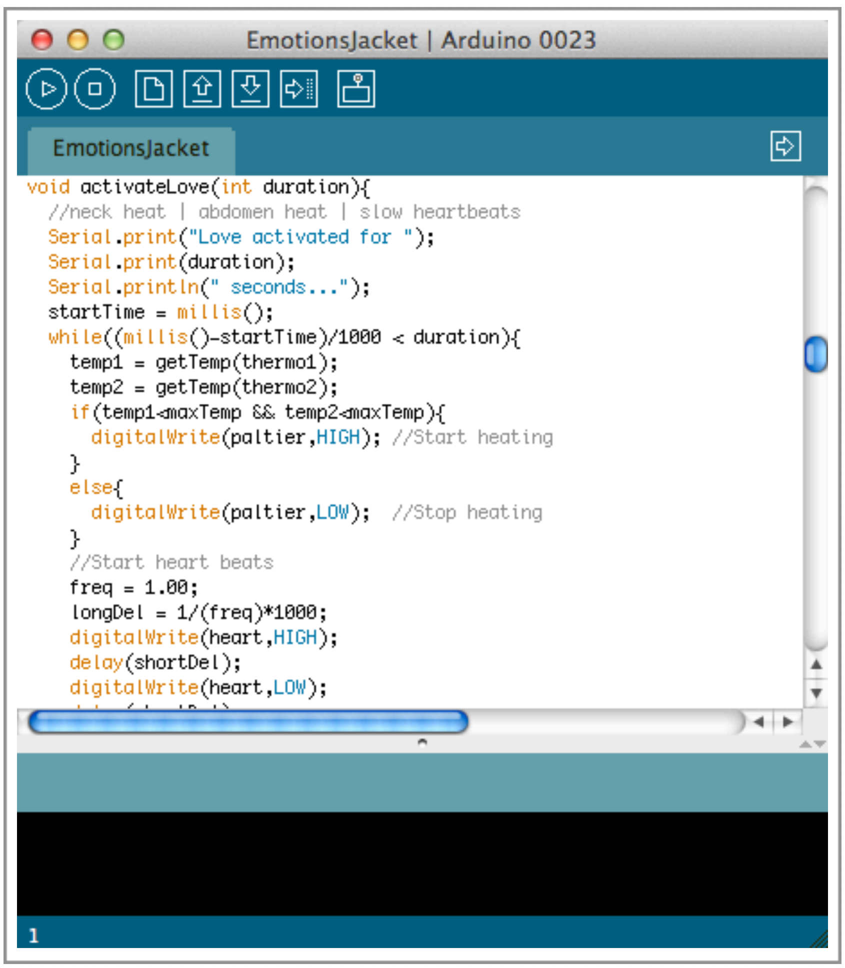


Figure 4.7 Snapshot of the Arduino IDE

B. NI Multisim '10

National Instruments' NI Multisim is a powerful electric and electronic circuits simulator [41]. It is a widely used tool amongst engineers, educators, and students for analyzing circuit behavior, and overcomes the difficulties of using SPICE for circuits' analyzing and simulating. NI Multisim was used in our project to independently simulate different parts of the system, and to draw the overall circuit shown in figure 3.16.

C. CoolTerm 1.4

CoolTerm is an easy to use serial port communication application. It is a freeware program that is available for Windows, Mac, and Linux, and was written in REALBasic [42]. The Arduino microcontroller board was programmed to send response messages after each instruction is received, and this tool was used to send instructions and receive response messages to/from the jacket system through USB serial port.

D. Custom Built Evaluation Software

For evaluation purposes, a media player was built in the MCRLab to test and evaluate the jacket system. This software plays short videos, and sends instructions to the jacket system in pre-defined instants and for specific durations that is synchronized with specific emotional scenes. This software will be explained in more detail in the evaluation chapter of this thesis.

4.2 Problems Faced

During the implementation of this project, valuable lessons were learned when some difficulties related to power, wiring, lack of specific devices, ... were faced. In this section, some of the most important faced problems are listed along with the solutions followed to overcome them.

A. High power requirement: The purchased thermoelectric coolers were the most suitable heat actuators found during this research. However, they are very high power consumers and require a power supply of around 15V and 7A DC current to operate in ideal conditions. This was an issue since the Arduino microcontroller board can not provide power even close to this demand. Therefore, an external power supply device was used in multiple different trials with different voltage and current supply until the most suitable supply for the system was found at 5.3V and 1.8A supply. The tests involved trials for connecting the heat devices in parallel and in series, and keeping in mind that the most acceptable voltage supply was 6V in order to make the system able to work with batteries and to become as portable as possible.

In addition, BJT transistors were used to control the power coming from the external power supply and provide high current. Hours were spent to find the suitable BJT transistor that can be used with our system.

B. Safety: In order to avoid incidental burns from the thermoelectric coolers, it was necessary to monitor their temperature digitally and control their output. Therefore, digital temperature sensors were purchased and attached each one of the thermoelectric coolers.

C. Calibration: For shivering the arms, each vibrotactile actuator had to operate in it's own turn to provide a realistic shiver-like feeling. Therefore, each actuator was instructed to operate for 100ms, and stop to actuate the next one, and so on. Also, to simulate heartbeats, some intensive research was done until the best timings were agreed upon. Each heartbeat consists of two separate sub-beat mechanisms, and each sub-beat sounds for a specific duration. Also, the duration between every sub-beat must be known. This information was necessary and different for each emotion. Finally, power calibration was needed for different affective haptic component in the jacket. Neck vibration, for example, require very little DC current, while the 10 chest vibrators required much more. Heartbeats' vibration actuators also needed to be distinguishable while the chest is vibrating. All these notes were taken into consideration and different power assignments were given to different parts of the system.

D. Synchronization: The Arduino microcontroller can not be programmed to do multithreading. This was a problem when actuating heartbeats while another affective haptic component was operating. To overcome this problem, the code instructions were synchronized such that each affective haptic component activates in its appropriate instant and for appropriate duration. In other words, the overall code was written in a way as if multithreading was predefined.

4.3 Final Prototype Photos

Figure 4.8 Final Prototype

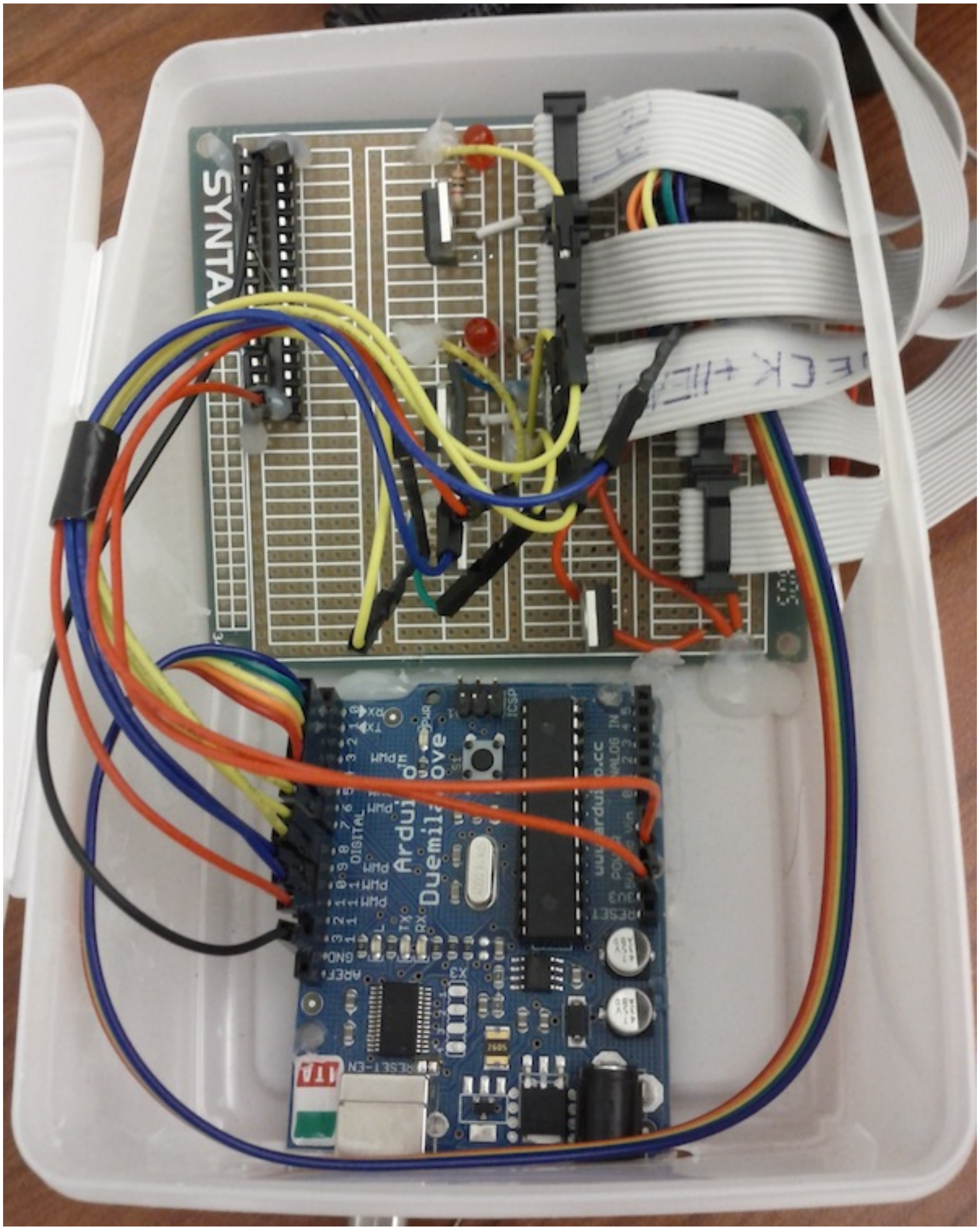


Figure 4.9 Control box showing the Networking Board connected to the Arduino microcontroller

Figure 4.10 Inside the left sleeve and control box

Figure 4.11 Inside the collar

Figure 4.12 Inside the left side chest area showing 3 vibrotactile actuators for the heartbeats

Figure 4.13 Inside the right side chest area

CHAPTER 5

Evaluation

5.1 Procedure

To evaluate the overall system proposed in this thesis, cooperative efforts have been done in the MCRLab in order to come up with the most accurate results possible. Different evaluation processes were discussed and compared to other similar systems in this field. We decided to do a multimedia based test on multiple people and conduct a quality of experience (QoE) questionnaire. After that, the results of this questionnaire were compared to a similar system.

The evaluation of the overall system was done in the following steps:

1. A media player software was built in the MCRLab that plays videos synchronous with timed instructions to be sent to the haptic jacket. The media player plays six previously selected short videos (< 1 minute each). Each video represents one of the six emotions used in our research.
2. Fourteen volunteers participated in our test. They were asked to wear the haptic jacket during the whole test.
3. Each short clip was played twice. Once with the haptic jacket being active, and once without activating the jacket. The order is completely random for every video and for every participant.

4. After watching all the videos, participants were asked to fill a short QoE questionnaire [43].

More details will be provided in the following sections.

5.1.1 Custom Built Software

The software built specifically for this test plays previously selected videos synchronized with timed instructions to the haptic jacket. The GUI of this media player contains a window for viewing the video, six buttons for playing each video, and a checkbox for selecting weather to enable or disable haptic feedback while playing the video.

To provide a non-biased response from the participants, the buttons contained no description of what type of emotion is represented in the videos.

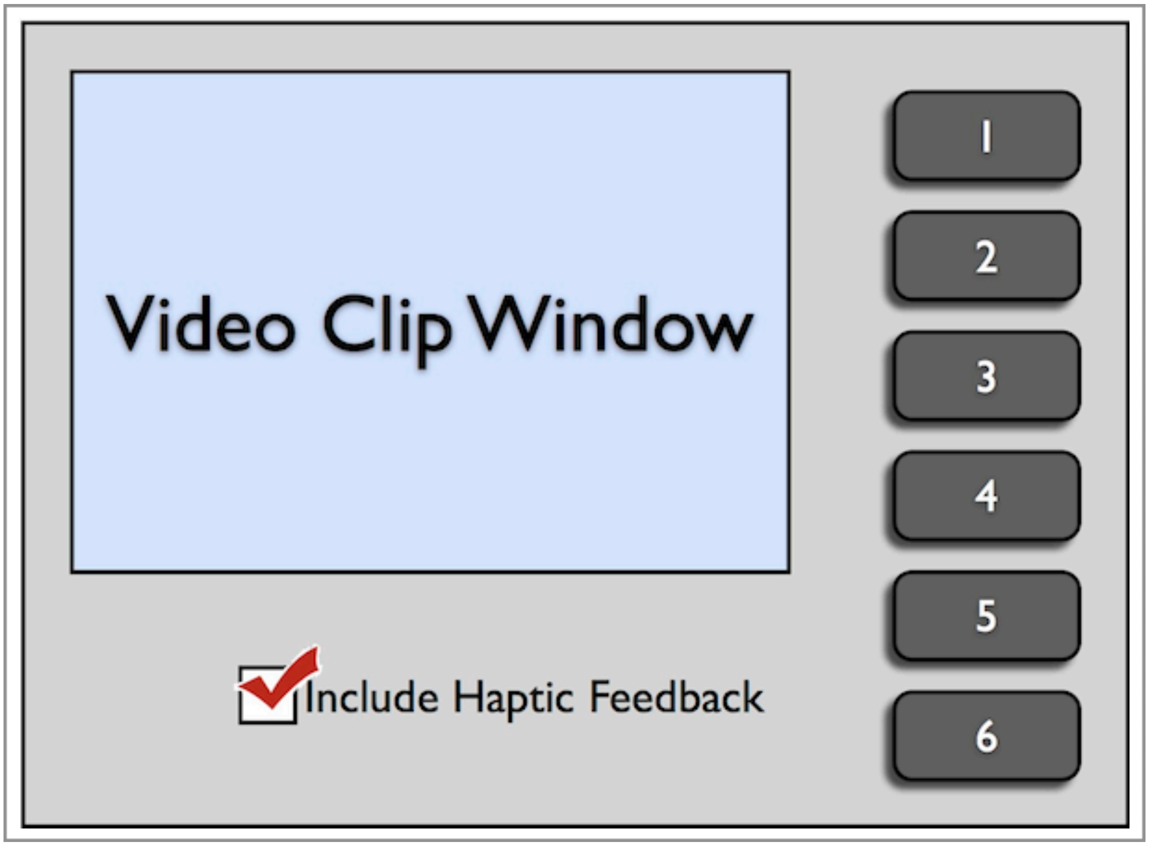


Figure 5.1 Description of the GUI for the evaluation media player

5.1.2 The Videos

Short videos can not stimulate emotions as easy as long movies. In a movie, viewers take their time to understand the idea behind the movie and get involved emotionally. For short videos however, viewers can make use of the haptic features of the jacket to expedite emotional involvement.

The following is a description of each of the videos played by the media player:

1. Love: the first video shows an animated love scenes where a girl is sitting alone in a homecoming dance while a love song is playing during the whole video. She sadly leaves the dance to meet a guy just outside the doors where they exchange looks and then start going out together. It then shows scenes where they kiss and share memorable photos. The whole video is 53 seconds long, and haptic feedback is set to be played right at the beginning of the video for the whole duration.
2. Joy: this clip shows the moment when a soldier comes back from war to meet his wife and his dog. The 37 second video shows how the dog is so happy to see his best friend after a long absence by continually barking and running around the soldier. The soldier sits down on the floor at the entrance of the house continuously playing and hugging the dog. While playing this video, haptic feedback is set to play for the whole duration.
3. Surprise: this video is 38 seconds long. It shows a woman swimming in the quiet ocean peacefully reaching for the tip of her small boat to get on it. Suddenly, a very big whale jumps out of the ocean right next to her and the boat and almost swallowing them. Haptic feedback starts playing right at the moment where the whale jumps out of the ocean.
4. Anger: a famous actor is trying to take a picture alone without his fans. A female fan continuously tries to talk to him during that time and is standing too close to him making it impossible for him to take that shot. He suddenly looses his temper and slaps her in her face and starts screaming

furiously at her. The video is 37 seconds long, and haptic feedback starts playing right when the famous actor looses his temper.

5. Sadness: this 34 second video shows a young woman standing in an elevator while an ex-lover comes in. She starts to show a sad face and quietly starts crying in an awkward moment for both of them during the elevator trip.
6. Fear: this short clip shows a series of unrelated scary scenes where multiple shocking moments occur. The video is 59 seconds long, and haptic feedback is played almost during the whole clip.

5.1.3 Questionnaire

After each participant completed watching the evaluation videos, they were asked to fill a short questionnaire composed of eight questions. The first six questions were selected from a list of an intensive research related to video games' QoE evaluation [43]. These questions were selected based on their relevance to our subject, and to be compared to a similar system's evaluation results [9]. The last two questions also serve our purpose, but were inspired from another research [2].

The questionnaire is composed of statements describing the quality of the system experienced by the participant. Each participant is asked to rate these statements using the 5-point Likert scale, where 5 being *Strongly Agree* and 1 being *Strongly Disagree*. Likert scale has been commonly used for cognitive perception evaluation of users [44]. The statements used in our questionnaire are as follows:

- I felt myself "drawn in"
- I enjoyed myself
- My experience was intense
- I had a sense of being in the movie scenes
- I responded emotionally
- I felt that all my senses were stimulated at the same time
- The system is easy to get familiar with
- I would consider using this system

5.1.4 Testing Scenario

After the media player was designed for the evaluation purpose of this system, participants were asked individually to try out the jacket and give their feedback. Each participant was accompanied to a quiet room to avoid distractions, and was asked to take off heavy clothes and/or any worn accessories (watches, bracelets, …). After that, they were asked to wear the jacket prototype completely zipped and sit facing the computer where the media player is installed. Then, they were given a brief description of how the test will be conducted as described in steps 3 and 4 of section 5.1.

Each participant was given the choice to choose whether to first play the videos with haptic feedback or without, and each test took less than 20 minutes.

5.2 Results and Comparison

In this section, we show the results of the questionnaires filled by the evaluation participants, and compare our results with one portion of another evaluation conducted on a very similar haptic system [4, 9].

5.2.1 Results

The results of the conducted questionnaires are shown in the following table. They describe an average of the results for all participants showing the general rating and the variance. “Absent” represents ratings when haptic actuation is switched off, and “Present” represents ratings when haptic actuation is switched on in the jacket.

Table 5.1 Evaluation results

	Absent	Variance	Present	Variance
I felt myself "drawn in"	2.14	0.59	3.64	1.02
I enjoyed myself	2.00	0.46	4.07	0.53
My experience was intense	1.79	0.64	3.29	0.84
I had a sense of being in the movie scenes	1.43	0.42	3.36	0.25
I responded emotionally	1.71	0.37	3.57	0.57
I felt that all my senses were stimulated at the same time	1.64	0.40	3.36	0.40
The system is easy to get familiar with	-	-	4.21	1.10
I would consider using the system	-	-	3.71	0.99

5.2.2 Comparison

Philips research [9] introduced a similar jacket that is intended to influence movie watchers emotions by creating tactile stimuli to their bodies. The following table lists the major differences in the design of the Philips jacket and our jacket:

Table 5.2 Major differences in the design of our system and the Philips system

	Philips System	Our System
Consumers' input in the design	No	Yes
Haptic stimulation	Vibrotactile	Heat and Vibrotactile
Number of vibrotactile actuators	64	35
Number of heat actuators	0	2
Approximate distance between actuators (cm)	15	12
Number of evaluation participants	14	14

As mentioned previously, the Philips system was selected amongst different others due to its high similarity to our system in purpose and design. Also, the evaluation process we followed in our system is very similar to a part of the evaluation process followed by them. The following table shows a comparison of the evaluation results for each system. The percentages shown under each system represent the increase in ratings from “absent haptics” to “present haptics” for each statement for both systems.

Table 5.3 Evaluation results comparison

	Philips System	Our System
I felt myself "drawn in"	6.4%	70.0%
I enjoyed myself	0.6%	103.6%
My experience was intense	13.4%	84.0%

I had a sense of being in the movie scenes	15.1%	135.0%
I responded emotionally	-1.3%	108.3%
I felt that all my senses were stimulated at the same time	27.6%	104.3%

5.3 Summary

The evaluation results in comparison to the Philips' system evaluation show a big improvement. These results may be due to the direct involvement consumers in the design of the system, the including of heat actuators in the jacket, or to the fewer number of vibrotactile actuators embedded in the jacket. Fewer actuators may have made the system less confusing, and differentiating between present and absent haptic stimuli was easier.

It was also noted during the evaluation process that participants gave comments on the jacket that were somewhat common for groups with almost similar body builds. For example, smaller sized participants who found the jacket a bit large and spacious suggested that heartbeats were too strong, while larger sized people thought that heartbeats were adequate. Therefore, consumers with different sizes will need jackets that fit.

CHAPTER 6

Conclusion and Future Work

6.1 Conclusion

It is essential to have input and output devices for human computer interaction. However, I/O devices should not be limited to a mouse, a keyboard, and a screen. Humans can understand output from a computer through more than two senses, and can send input to the computer system using other than their two hands [24]. This is one reason that makes haptic research a very important research to be added to technology and multimedia today.

This thesis presented a wearable haptic system that is aimed to enhance users' involvement in movie watching and video gaming by attempting to influence their emotional immersion. The design of this system directly included consumers' opinions on what the jacket should and should not do. The results of this study assisted greatly in the design of the basic architecture of the system.

A prototype was built according to the proposed system. We used vibrotactile and heat actuators along with temperature sensors in the implementation of the jacket. Most of the connections and controlling hardware in the overall circuit was built on the networking board, which is a PCB designed specifically for this system. To control the system, we used an Arduino Duemilanove microcontroller board, which was chosen for its relatively small size, ease of programming, and adequacy of hardware.

After the system prototype was completed, it was tested and improved in both hardware and software aspects to produce more realistic feeling when it is worn. The final prototype was tested on fourteen subjects that mostly gave a positive feedback on their experience and system quality.

What makes this design distinguishable is that it can be considered somewhat portable. Any application that requires or can be improved by emotional involvement can use this jacket system. A simple programming interface can be built with such applications to interact with the presented jacket system. After all, in the evaluation chapter of this thesis, this jacket system has proven to positively influence users' immersion in an application that can be improved by users' emotional involvement.

6.2 Future Work

For future improvements to this system, air pumping devices may be added to stimulate pressure and chest tightness in the case of evoking "joy" and "sadness" as described in chapter 3. These devices need to be light weight, energy efficient, and small. Also, adding more heat and vibrotactile actuators to the back of the body may result in even more realistic emotional involvement. For “fear”, or “sadness,” the cold side of thermoelectric coolers may be used to represent an unpleasant feeling. Also, a mechanical stress belt can be used instead of air pumping to stimulate chest tightness or a hug similar to the iFeel_IM system [6].

In addition, different sizes for the jacket may be of importance. Evaluation subjects of different body builds gave different comments. It was noted that evaluation subjects gave comments that were somewhat common for the same group of body sizes.

Furthermore, since heartbeat rates differ between people depending on their age, sex, fitness, and as well as other factors, a heartbeat rate sensor can be attached to the jacket system to read the user’s actual heartbeat rate. The responding stimulation of heartbeats in the jacket system can be a resulting percentage increase or decrease to the actual rate read by the sensor depending on the intended emotion.

Finally, one idea to assist in the high power consumption issue of the system is to embed devices that can make use of the mechanical movements of the users. Kinetic energy harvesting sensors that convert the collected energy into electrical energy can be attached to the jacket system and support the existing energy source while providing more power to the system.

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APPENDIX

Arduino Code

```
#include <OneWire.h>         //Required for operating thermometers
//=== Pin Connections===
int arms[5]  = {2,3,4,5,6};  //pin 2 = shoulders, to pin 6 = elbows
int chest    = 7;            //Controls BJT to operate 10 vibrators on both chest sides
int neck     = 8;
int heart    = 9;
int thermo1  = 10;
int thermo2  = 11;
int paltier  = 12;           //Controls BJT to operate 2 thermoelectric coolers connected
to the neck
//==== Static Variables ===
int maxTemp  = 45;           //Max allowed temperature for paltiers (Celsius)
//==== Manipulated Variables ===
int inst     = -1;
int emotion;                 //Emotion instruction received via serial port
int duration;                //Duration of emotion activation (s)
unsigned long startTime = 0; //To time the duration of an active function;
int temp1, temp2;
//==== Private Variables ===
double freq;                 //Heart beats frequency
double shortDel = 250;       //Duration between sub-beats (ms)
double longDel = 0;          //Duration between beats (depends on the mode)

//=======================================================================
//========================== APPLICATION ================================
//=======================================================================
void setup() {
  for(int i=0; i<5; i++){
    pinMode(arms[i], OUTPUT);
  }
  pinMode(chest, OUTPUT);
  pinMode(neck,OUTPUT);
  pinMode(heart,OUTPUT);
  pinMode(thermo1,INPUT);
  pinMode(thermo2,INPUT);
  pinMode(paltier,OUTPUT);
  Serial.begin(9600);
}
void loop() {
  if(inst==-1){
    Serial.println("Please enter a 3-digit instruction:");
    inst = getSerialInstruction();
    emotion = inst/100;
    duration = inst-(emotion*100);
  }
  else{
    switch(emotion){
      case 0:
        standBy();
        break;
      case 1:
        activateLove(duration);
        standBy();
        break;
      case 2:
        activateJoy(duration);
        standBy();
        break;
      case 3:
        activateSurprise(duration);
        standBy();
```

```
        break;
      case 4:
        activateAnger(duration);
        standBy();
        break;
      case 5:
        activateSadness(duration);
        standBy();
        break;
      case 6:
        activateFear(duration);
        standBy();
        break;
      default: Serial.println("ERROR: Illegal instruction recieved!");
               Serial.println("
_________________________________________________________________________________");
               Serial.println("| Instruction format: (emotion number)(duration in seconds
<0-99>)                |");
               Serial.println("| Emotions are: 0-Stand by, 1-Love, 2-Joy, 3-Surprise, 4-
Anger, 5-Sadness, 6-Fear |");
               Serial.println("| Example: 456 returns 'Anger' for 56 seconds
|");
               Serial.println("
---------------------------------------------------------------------------------");
      break;
    }
    inst = -1; //Wait for a new instruction
  }
}
//==========================================================================
//========================== CONTROL FUNCTIONS =============================
//==========================================================================
void standBy(){  //Holds down the jacket from making any action
  Serial.println("Standing by...");
  for(int i=0; i<5; i++){
    digitalWrite(arms[i], LOW);
  }
  digitalWrite(chest, LOW);
  digitalWrite(neck, LOW);
  digitalWrite(heart, LOW);
  digitalWrite(paltier, LOW);
}
//==========================================================================
void activateLove(int duration){
  //neck heat | abdomen heat | slow heartbeats
  Serial.print("Love activated for ");
  Serial.print(duration);
  Serial.println(" seconds...");
  startTime = millis();
  while((millis()-startTime)/1000 < duration){
    temp1 = getTemp(thermo1);
    temp2 = getTemp(thermo2);
    if(temp1<maxTemp && temp2<maxTemp){
      digitalWrite(paltier,HIGH); //Start heating
    }
    else{
      digitalWrite(paltier,LOW);  //Stop heating
    }
    //Start heart beats
    freq = 1.00;
    longDel = 1/(freq)*1000;
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(shortDel);
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(longDel);
  }
}
//==========================================================================
```

```
void activateJoy(int duration){
  //chest air pump (one breath) | normal heartbeat
  Serial.print("Joy activated for ");
  Serial.print(duration);
  Serial.println(" seconds...");
  startTime = millis();
  while((millis()-startTime)/1000 < duration){
    //Start heart beats
    freq = 1.17;
    longDel = 1/(freq)*1000;
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(shortDel);
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(longDel);
  }
}
//===========================================================================
void activateSurprise(int duration){
  //shiver arms | chest vibration | fading heartbeats
  Serial.print("Surprise activated for ");
  Serial.print(duration);
  Serial.println(" seconds...");
  freq = 3.00;
  startTime = millis();
  while((millis()-startTime)/1000 < duration){
    //Shiver Arms
    digitalWrite(chest,HIGH);
    shiverArms();
    //Fading heart beats
    longDel = 1/(freq)*1000;
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(shortDel);
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(longDel);
    if(freq>1.00){
      freq = freq - 0.25;
    }
    else{
      freq = 3.00;
    }
  }
}
//===========================================================================
void activateAnger(int duration){
  //neck heat | arms vibration | normal heartbeats
  Serial.print("Anger activated for ");
  Serial.print(duration);
  Serial.println(" seconds...");
  startTime = millis();
  while((millis()-startTime)/1000 < duration){
    temp1 = getTemp(thermo1);
    temp2 = getTemp(thermo2);
    if(temp1<maxTemp && temp2<maxTemp){
      digitalWrite(paltier,HIGH); //Start heating
    }
    else{
      digitalWrite(paltier,LOW);  //Stop heating
    }
    //Vibrate Arms
    vibrateArms();
    //Start heart beats
    freq = 1.17;
    longDel = 1/(freq)*1000;
    digitalWrite(heart,HIGH);
```

```
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(shortDel);
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(longDel);
  }
}
//============================================================================
void activateSadness(int duration){
  //chest air pump (tightness)
  Serial.print("Sadness activated for ");
  Serial.print(duration);
  Serial.println(" seconds...");
  startTime = millis();
  while((millis()-startTime)/1000 < duration){

  }
}
//============================================================================
void activateFear(int duration){
  //neck vibration | arms vibration | fast heartbeats
  Serial.print("Fear activated for ");
  Serial.print(duration);
  Serial.println(" seconds...");
  startTime = millis();
  while((millis()-startTime)/1000 < duration){
    //Vibrate Arms
    digitalWrite(neck,HIGH);
    //Vibrate Arms
    vibrateArms();
    //Start heart beats
    freq = 2.00;
    longDel = 1/(freq)*1000;
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(shortDel);
    digitalWrite(heart,HIGH);
    delay(shortDel);
    digitalWrite(heart,LOW);
    delay(longDel);
  }
}
//============================================================================
//========================== PRIVATE FUNCTIONS ===============================
//============================================================================
int getSerialInstruction(){
  //Gets an instruction via serial port, and sets emotion and duration variables
  byte incomingByte = 0;
  int inst[3] = {-1,-1,-1};
  int i = 0;
  unsigned long startTime;
  while(true){ //run until something is returned
    if(Serial.available()){
      startTime = millis();
      incomingByte = Serial.read();
      if(incomingByte>='0' && incomingByte<='9'){
        inst[i++]= incomingByte-48; //Convert from ASCII byte to int
        if(i==3){  //Instruction ready
          return (inst[0]*100)+(inst[1]*10)+inst[2];
          inst[0] = -1;
          i=0;
        }
      }
      else{
        Serial.println("INPUT ERROR. Only digits are valid.");
        Serial.println("Please enter a 3-digit instruction:");
        i=0;
      }
    }
```

```
    else if(inst[0]>=0 && millis()-startTime>1000){
      Serial.println("Timed out...");
      Serial.println("Please enter a 3-digit instruction:");
      inst[0] = -1;
      i=0;
    }
  }
}
//============================================================================
void vibrateArms(){
  for(int i=0; i<5; i++){
    digitalWrite(arms[i],HIGH);
  }
}
//============================================================================
void shiverArms(){
  for(int i=0; i<5; i++){
    digitalWrite(arms[i],HIGH);
    delay(250);
  }
  delay(1000);
  for(int i=0; i<5; i++){
    digitalWrite(arms[i],LOW);
    delay(250);
  }
}
//============================================================================
int getTemp(int thermoPin){
  //Setup
  byte i;
  byte present = 0;
  byte data[12];
  byte addr[8];
  int  temp;
  OneWire ds(thermoPin);  // reading pin (initializes pinMode)
  //Main
  if (!ds.search(addr)) {
      ds.reset_search();
      return -999;
  }
  if (OneWire::crc8(addr,7) != addr[7]) {
      Serial.print("CRC is not valid!\n");
      return -999;
  }
  if (addr[0] != 0x28) {
      Serial.print("Device is not a DS18S20 family device.\n");
      return -999;
  }
  ds.reset();
  ds.select(addr);
  ds.write(0x44,1); // start conversion, with parasite power on at the end
  delay(1000); // maybe 750ms is enough, maybe not
  present = ds.reset();
  ds.select(addr);
  ds.write(0xBE); // Read Scratchpad
  for (i=0 ; i<9 ; i++){ // we need 9 bytes
    data[i] = ds.read();
  }
  temp=(data[1]<<8)+data[0];//take the two bytes from the response relating to
temperature
  temp=temp/16;//divide by 16 to get pure celcius readout
    Serial.print("T");
    Serial.print(thermoPin);
    Serial.print(" = ");
    Serial.println(temp);
  return temp;
}
```