Haptic Controls in Cars for Safer Driving

By

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Abstract

With the spread of latest state of the art technologies geared towards utilization of the human senses, haptic technologies have been introduced as a way of utilising the sense of touch to either solve real world problems or to enhance present experiences. This thesis focuses on using haptic technology in cars to make the driving experience safer. Modern vehicles carry GPS, music systems, sunroofs and a number of other electronic gadgets. Interaction with these devices while driving often takes the driver's eyes "off the road" and raises safety concerns. We are proposing a unique haptic design that uses the 'sense of touch' as a mode of controlling or coordinating the various technologies and convenience devices found within a car. A pattern of distinguishable haptic feedback linked to a corresponding device allows the user to operate these devices through 'sense of touch' and eliminates reliance on visual interaction.

This design will help to reduce the driver's distractions, as it will be installed in an easily accessible location such as on the steering wheel. A simulation has been done using a haptic interface "i.e. desktop phantom to test the system" and a prototype has been developed which can be installed in any vehicle. This prototype has been tested to work with a limited number of convenient devices. However, further development and enhancements can be made to incorporate more devices and other user preferences. The main objective of this research is to integrate various functionalities in a robust manner, which will focus on the driver's safety by ensuring "constant vision on the road". Distinguishable distinct haptic responses will act as unique depictions for specific convenient devices within the car, allowing the driver to interact and manipulate the settings of the device based on the detection and identification of the various unique haptic depictions.

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List of Acronyms

2D:	Two Dimensional
3D:	Three Dimensional
ECU:	Electronic Control Unit
FIS:	Fuzzy Inference System
FSM:	Finite State Machine
GPS:	Global Positioning System
LCD:	Liquid Crystal Display
LED:	Light Emitting Diodes
LSB:	Least Significant Bit
MSB:	Most Significant Bit
ODB:	On Board Diagnostics
QOE:	Quality of Experience
UI:	User Interface
UML:	Unified Modeling Language
USB:	Universal Serial Bus

Chapter 1

Introduction and Motivation

1.1 Introduction:

The automotive industry is one of the most important economic sectors of the world. With the advancement of this industry, many different types of automobiles have been developed and serve as a major means of transportation, especially for developed countries. With an increase in the number of vehicles on the road, safety regulations and driving protocols have become more regulated and enforced so as to increase passenger and driver safety as well as to ensure smooth operation on the road. These vehicles are equipped with certain types of driver/passenger comfort systems such as temperature control, entertainment, vehicle information and global positioning systems. Just as there are a number of vehicles on the roads, there are also a number of drivers. Each driver has his/her own ability to stay focused while driving and although it is not recommended many drivers do divide their attention between tasks while driving.

A well-known example in Ontario is the division of attention between driving and texting. It is now prohibited to drive while using any hand-held equipment, as not only is one utilizing the sense of vision that should be allocated to viewing the road but also the sense of touch that should be fixated on steering the vehicle and be prepared in case a quick response is needed. Many vehicles crash everyday due to a lack of focus and a division of attention while driving. Major highways require immense visual, physical and mental focus. With an increasing number of electronic devices in vehicles, focus can be shifted away from driving making it very dangerous [4].

Most current systems rely on visual interaction to operate convenience devices in the vehicle. Research shows that eye movement is relatively slower than physical movement in regards to response time [6]. Therefore, a combination of slow eye movement and interaction with devices while driving shifts our visual attention more to the task at hand while unknowingly neglecting the road and leading to a risky situation. There is a need to develop a safe system where a driver doesn't have to take his/her eyes off the road while operating these electronic systems.

The main objective is to fabricate a failsafe system that allows the user to operate the most commonly used electronics in the vehicle and also to alerts about any critically unsafe situations. For this kind of system to work, it is necessary that the feedback provided is distinct, identifiable and user friendly so as to ensure that the user is able to carry out the operation of the various devices smoothly yet still be able to distinguish and identify the critical warning feedback from the system. There are certain technologies that have been adopted to provide feedback to the users, usually ranging from visual/auditory and/or haptic responses. Visual feedback involves the installation of a screen in the car, which shows the current selected effects and the alternative control options for each specific device. Normally these screens are located in the center of the console. A view of the location of this screen is depicted in the picture below:

Fig. 1.1 Visual Display Terminal installed in the Console[1]

Another application of visual feedback is known as a “heads-up display”, which projects the desired information on a windscreen [5]. This small projector is fabricated inside the driver-side console and directly emits light on the screen making the image visible on the screen. The heads up display is shown in Figure 1.2.

Fig. 1.2 Heads up Display Projected on the Screen[1]

[1] http://www.bmw.ie/ie/en/newvehicles/6series/coupe/2004/allfacts/_shared/img/ergonomics_hud.jpg

Auditory feedback involves pre-programmed voice prompts which normally come from the vehicle's stereo system. Whenever there is a change in the controls and features of the vehicle and the devices within, a unique auditory prompt emerges. According to preference, accessibility and understanding, the user can usually customize the audio settings, language and other options of the audio prompts. Newer vehicles are equipped with intelligent auditory features that can be accessed by the user through voice commands; the systems also go as far as overseeing the driving circumstances by providing warnings and prompts based on speed and fuel [33]. The user can program a certain speed at which the car will either call out or beep to warn the driver. As of now, these features are limited to those that are also found in telephones. A user typically calls out the changes that he/she would like to see implemented relying exclusively on interaction with the system through "numbers". The program is heavily dependent on accurate speech recognition, which is adversely affected by background noise, language pronunciation and accent.

The third feedback technology is known as Haptics. Haptic technology is relatively new, providing a channel of communication between humans and an electronics boosted environment via touch. Although the technology is still under intensive research, it has been widely accepted as a responsive feedback providing system. This feedback technology relies on the sense of touch allowing the user to detect a specified pattern by stimulating the sense of touch attained through the user's fingers. Few cars have recently started using haptic technology as a feedback technology. An excellent example of haptic use in cars is found in BMW. Their feedback and navigation system for the features in the vehicle is provided by the "control jog" combined with the Visual Terminal Display installed in the console [8]. Below is the snap shot of a haptic based jog which can be found in the BMW cars known as I-Drive Jog:

Fig. 1.3 BMW I-drive Jog[2]

These different types of feedback technology have their own benefits and drawbacks which will be discussed thoroughly in the literature review.

1.2 Motivation:

With the implementation of new laws and stricter regulations in an effort to make driving a safer practice and experience, cellular use has been banned in most major countries. Some other laws regarding the operation of a motor vehicle while distracted are still under consideration. These laws are implemented to ensure public safety and a smooth transportation system. Major research is required to design these vehicular cockpits while ensuring public safety and operation. Current systems of interaction and feedback are underlined by an "eyes off the road" ideology. With upcoming safety laws, there is a need to develop a system that is acceptable under the driving regulations and the law as well as be safe enough to be operable and user-friendly. This research implements the following ideas to develop a haptic technology system that makes driving safer:

[2] http://www.bmw.com/com/en/newvehicles/z4/z4/2009/allfacts/ergonomics/_shared/img/idrive.jpg

- *A vehicle selection/warning system which provides feedback*
- *Non/Minimal use of Visual screens installed in vehicles*
- *Built on an "Hands on the Steering Wheel" while driving* view
- *Based on an "Eyes on the Road" while driving view*
- *A system which is flexible enough to be safe as defined by the law*
- *Minimum Driver distraction while driving*
- *Requires Easy installation*
- *User friendly*

1.2.1 Thesis Contribution

The main objective of this thesis is to propose solutions to reduce the driver's distractions and attention division while driving the car and operating other electronic devices within the car. This ensures that the conveniences and preferences of the user are not negotiated while being "safe". The proposed system can be operated by one or more fingers and provides complete user interface without requiring the user to engage his visual senses in the action, since a visual cue such as a screen will not be present but rather tactile cues that can be read by the fingers are provided. Based on this fact, the user can safely change the state of certain devices within the limits of new driving laws and can practice 'safe driving behaviour'.

Another major advantage of using this system is that the user won't have to take their hands off the steering wheel. These haptic buttons are to be installed on the steering wheel, which demands that the user's hands be on the steering wheel at all times.

Furthermore, the user will be able to get the feedback of the task performed by using the same buttons used to input changes. These buttons are equipped with haptic technology so the user won't have to confirm the validity by moving his hands around in an effort to locate an alternative button for feedback.

The proposed strategy is to first evaluate the effectiveness of haptics. It has been evaluated thoroughly by studying the responsiveness and interaction of the user with the system, the learning behaviour and the ability of developing distinguishable cues via haptic technology. All of this was evaluated and studied in a virtual environment. Based on the results of our user study, we developed a prototype haptic user interface**.** Furthermore, the system was evaluated for its practicality in the real world as much as in the virtual world. As per the results, both systems exhibited the same property that was carefully analyzed by the use of fuzzy logic. To further clarify the concept of user friendliness of the system, several aspects of the interaction between the user and the interface were monitored and recorded. Experiments were conducted evaluating the ability of users to detect the distinct feedback cues and how time (practice) affects the overall performance. Secondly we also analyzed the performance of the users as they interacted with the haptic technology while performing other tasks as well, this allowed us to understand the simplicity and effectiveness of the system in relation to the real world.

In analysis if the performance of the subjects as they interacted with the haptic technology, it was concluded that the simplicity of the haptic technology that has been proposed was effective enough to be "user friendly", so as to be mastered by the user with repeated use.

This research is not limited to controlling the devices but also focuses on enhancing the convenience of driving experience while providing maximum safety. The scope of this research can be further projected to give the user critical warnings which driving through tactile cues provided by the haptic technology system

1.2.2 Publications out of this work

A conference paper based on this research was presented in IEEE International conference in Guilin, China (ROBIO 2009).

- Fayez Asif, Janan Vinayakamoorthy, Jing Ren and Mark Green; "Haptic Controls in Cars for Making Driving more Safe," *Proceedings of IEEE International Conference on Robotics and Biomimetics, IEEE ROBIO 2009,* Guilin, China, 19-23 December, 2009.

1.3 Overview of Thesis

This thesis comprises of nine chapters. The first chapter includes a brief introduction of the problem statement, motivation and proposed technology that was undertaken for this research

The second chapter provides details on the different types of feedback technologies, related research work and analysis of the pros and cons.

The third chapter includes the general design methodology of haptic technology in cars. It demonstrates the driver control interface used for the input and output of feedback, the embedded control unit used to drive this system and the universal device interface.

The fourth chapter includes a software prototype that was developed to run the tests in the software mode. A virtual environment was created to run a few tests in different scenarios. The different tests conducted were assessed for their accuracy in portraying the scenarios and the results were evaluated for the effectiveness of the system and to develop a prototype.

The fifth chapter describes the hardware prototype and its divisions. The hardware is divided into touch buttons, vibrators, the touch control interface, embedded control unit for handling all inputs/outputs, the proximity sensing system and the observations.

The sixth chapter describes the evaluation of software simulation and hardware prototype using fuzzy logic and there comparison.

Last chapter entails a conclusion of my research and suggestions for future work.

Chapter 2

Survey of Literature

2.1 Visual display terminals:

Visual Display Terminals show visual demonstrations of the selected functions within Vehicles. Most major high end car companies are using these screens as the active part of their vehicle's GUI. The common placement of these screens is in the middle of the center console. All major companies give out this feature as optional and sometimes as a part of the vehicle. The uses of visual display terminals are mostly limited to GPS or entertainment systems. Only high end models give out a complete user interface for all possible outcomes.

The functions of such displays are controlled by buttons located at the side of the screen, a jog installed in the center of the driver and passenger seat and sometimes via touch screen technology requiring direct contact with the screen [19]. A lot of research is being conducted to enhance the interface of these screens in terms of their overall look, user friendliness, broadness, navigation, input/output speed and customization options. It is evident that their functionality has been drastically changed over the years yet safety concerns have also developed with the common use of these screens. New safety laws are a great hazard to the popularity of these screens and put everything at stake. For usage, the user must divert his/her eyes and attention off the road while driving, which can be quite risky and dangerous [21, 23]. As per the new law, drivers are not to use any visual/cellular devices while driving with the exception of GPS. With the new changes in driving regulations, it is quite difficult to improve these visual gadgets, as no matter what the case is, they cannot be used without diverting visual senses away from the road.

2.2 Heads up display:

The heads up display allows the user to select features displayed on the vehicle`s windshield. The heads up display was quite popular in Aeronautics but was introduced in the automotive industry within the last 10 years. Currently, there are very few models of vehicles on the road that come with this technology built in as it's quite expensive to administer.

The heads up display eliminates the need to turn your eyes away from the road. Basic information about the vehicle such as speed, engine Revolutions, fuel, temperature and sometimes a speed warning is displayed on the windshield. A small projector is installed in the driver's side console which directly emits a projection of this information on the inside of the windshield.

The user can customize the location (up to some extent), illumination and features to display. For non-built in models, an aftermarket heads up display[3] can be bought from certain manufacturers. Once connected to the vehicle's ODB connector, it will extract this information from the vehicle's ECU.

With all the advantages, this unit still has some drawbacks:

- Extended use of Heads up Display at night time puts a lot of strain on the eyes as the driver directly focuses on the windscreen [6].

[3] http://www.autosportcatalog.com/index.cfm/fa/p/pid/7055/sc/57260

- Based on an active study, Heads up display effects the analysis of background scenes and puts safety at risk and increases distortion [42]

Based on the above studies many drivers find that it overlaps with traffic, is distractive and divides and confuses focus.

2.3 Auditory Feedback:

Another type of feedback is auditory. Voice recognition has a long history in automotive research. To date, the use of voice recognition has been limited to pre-programmed voice prompts and a limited menu selection. The reasons for these limitations are certain noise related factors and different accents. Based on a study, many drivers found the audio interaction to be tedious and annoying after a while as repetitive input was required for the output to occur [33]. The user had to go through a specific audio menu to reach a certain task. Certain drivers suggest that they would prefer a human like audio interaction system which can simply take commands without confirming it every time. Furthermore, subjects wanted to interact with the system in a way they communicate with another passenger in the car e.g. with windows down, while the audio system is on etc. Audio interaction requires voice recognition that can never be 100% correct. Certain noise filtering techniques have been implemented with voice-activated devices but they need a lot more improvements when they are operated with windows down or with any other background noise. Hence its unfeasible to use the system with other interactive passengers in the car, with music on or with the windows down.

Most of the car models equipped with blue-tooth modules for wireless communication or In-dash GPS incorporate this sort of audio technology. Most of the systems require “adaptations” and habituation to the user's accent and voice either before installation or through repeated daily use.

2.4 Haptics:

The word haptics is a term is derived from the Greek verb "haptesthai", which refers to the sense of touch. Haptic technology encompasses the manual sensing and manipulation of surrounding objects and environments in such a way that one recognizes the changes through the sense of touch. The tactile cues and the environment can be made possible through a variety of procedures carried out through the actual presence of humans or through pre-programmed machines or through a combination of the two. Similar to the variation of the cues provided, the environment in which these cues exist can also be manipulation. The objects, feedback and surroundings can be present within the "real" world, created in a virtual reality or exist as a combination of both. The system can rely on other senses beyond the sense of touch, and often may incorporate visual and audio cues along with the tactile cues, so as to be stimulating more than one sensory system of humans. [48]

Haptic control is an emerging technology; it has been accepted by the automotive industry as a feedback technology for user interfaces. It gives the opportunity to utilize a sensory channel alternative to the visual sensory system, enhancing the user's experience in a multimodal environment. Eye movement is relatively slow in comparison to tactile receptors and hence adding a distraction or distortion in the visual field during driving leads to longer processing time and consequently longer reaction time of an individual. Studies have shown that the human ability to distinguish using the sense of touch doesn't impair as compared to sight or hearing with increasing age [17]. The best example lies in the aircraft technology, when the mechanical controls were replaced by electronic controls in 1980s. A haptic system was integrated to provide feedback for the gravitational forces experienced by the flaps and the tail during flight. This involves stiffing the controls, giving them certain vibrations like the old mechanical system to enhance a pilot's productivity and decision making during critical moments. Such presence of cues enhances the interactive experience and allows for a more accurate representation of the situation at hand.

Haptic technology functions when haptic interfaces are present with a system, such interface devices are capable of exchanging mechanical energy with users. A haptic device can have more than one input transducers or contact surfaces for the individual to interact with. As a returning output, the same medium is coupled with mechanical motors and solenoids to transform a virtual environment into reality. The haptic interfaces can be differentiated based on their degree of freedom or refresh rate. [49]

The use of haptics has been thoroughly investigated as they have been adapted by a wide range of applications to enhance user interface experience [7]. Examples include surgery, ceramic art, experimentation, simulation work and nano design projects.

Research studies have been conducted to improve the role of haptics in daily world computing. A study was conducted to improve the feel and overall understanding of haptics by designing a handshaking module using desktop Phantoms [2, 9]. The user was able to feel the difference between hand movements, body language and the general anatomy of other subject even though the subject was at a remote location.

Haptics have also been used to interact and communicate with visually impaired people [13]. The tactile cues that are provided to them are designed to help visually impaired people to judge a data visualization system and to identify the tactile representations as having a meaning. This research was a key motivator to research the different types of haptic designs present and how might they fulfill our objective.

In the Automotive Industry various types of input devices have already been placed on steering wheels, however they have not been combined with an output technology. A very simple example is the cruise control on the steering wheel, for which the driver doesn’t have to take his hands off yet he/she can control the acceleration/deceleration of the vehicle.

The use of haptics has been realized in high-end vehicles, and is scheduled to reach the broader auto market over the next few years. BMW is a leader in the field of utilizing haptic technology (I-Drive, Trademark of BMW) in their productions, yet the technology still is not popular as its often complex in design. Along with the complexity of the design of haptic technology systems, the user is also expected to “learn” the feedback in the system as representational of certain changes he/she has made. BMW’s I-Drive uses a jog, which is located on the center console. In order to control a specific function, the driver has to take one hand off the steering wheel to operate the jog. Therefore dividing the attention of the driver between the visual field and the car controls as hand-eye- coordination is required to locate the jog.

To navigate through different menus there is a screen installed which gives visual confirmation. To properly understand this system, one must examine the response time to do a certain task based on the distance between driver’s hand and jog. User has to look at the screen for confirmation. A similar haptic system has been introduced by AUDI & JAGUAR. All these systems are almost similar in nature as their control jogs are off the steering wheel and they use a screen. These systems are visual haptic systems. In terms of the cockpit control systems, these are high end but their design does not focus on driver's safety in a considerable manner [40].

Certain textures were developed for surgical simulations [10] to improve the manoeuvring of the device and to provide an enhanced feedback about the surfaces where surgery had been conducted. High end and low end phantoms were experimented and the differences between the overall haptics were recorded to predict a better module which is more versatile for different kind of haptic devices.

A research study [45] was conducted to use a haptic-based lane change guidance system, which could enforce strict lane changing behaviours. Haptics was used as an output medium to pass on to the user in case they run on any of the solid lines or if they are driving in a lane, in an improper manner. Certain tests were conducted to see the overall effectiveness and role of haptics; the results proved to be very positive.

The use of haptics in vehicular safety has been discussed in another study. This study proposes the design of a driver support system for the manual longitudinal control of a car during car-following. Haptics was chosen as medium to output tactile cues to the user. It was integrated with the gas pedal of the vehicle to generate certain stiffness levels and smooth pressing/depressing scenarios, based on the distance between the adjacent vehicles and the speed. The aim of this design was to develop a system that would cooperate with the driver in comfortably maintaining safe distant levels to adjacent vehicles yet the technology still "being green". [46]

A study comparable to the above showed the use of haptic technology in the driver's seat. This seat was capable of giving out tactile feedback based on the relative distance and velocity to objects outside the car. Evaluation showed that drivers perform best when the seat tilted according to the relative distance and velocity to the objects outside the car. Furthermore, this study also brought out the information that when visually and cognitively distracted drivers are using this system, they tend to perform better with the feedback as compared to the driver's performance with an ordinary non- haptic driving seat. This finding is a convincing factor that haptics does influence the safety and experience reading in the automotive field. [47]

Additional research [44] also worked upon the previous notion of using a car seat instrumented with tactile simulation elements but with the purpose to communicate directional information to a driver. A car seat was fitted with an 8 times 8 matrix of factors embedded in the seat pan. It was used to code different direction: four Cardinal and four Oblique directions. A field study was conducted under different road conditions. Directional accuracy and reaction time was recorded. The result shows that the tactile seat provided a promising and robust method of providing directional information. The percentage of correct directional responses was very high (about 92 %). This clearly indicates that haptic technology can prove to be promising also user convenience, comfort as well as a safety enhancer [44]

Another study discusses the use of haptic technology as a mechanism to decrease driver distraction while driving. As the portable entertainment and mobility technologies migrate into the car, driver distractions have now been acknowledged as major factors of road crashes. To help alert the drivers if they are distracted, active safety technologies such as lane departure warning systems and collision avoidance systems are now being implemented. The major issue with the implementation of Haptic technology is faced when one tries to tackle the concept of coordinating the other already present technologies in the car such as a mobile phone, navigation systems, stereo system, etc. These convenience technologies found within the car compete against the haptic system as the increase in these technological devices in the car means a more complex haptic system with many tactile cues. Haptic alerts are a method that may enable the system to short circuit the normal auditory or visual communication channels. This study presents a low cost haptic steering wheel controller that has been designed developed and tested and may be used as a communication device to indicate to the driver lane departures, collision avoidance, or other types of safety warnings [43]

The initial examination for haptic technology was examined more in depth in relation to its use in cars. Secondly, the dependability of haptic technology as a reliable feedback system was also examined. As the review has progressed, an assessment of the design style, advantages and draw backs of using haptics in cars as expressed in the research articles was done. Current haptic devices mainly focus on the aspect of selecting of controls based on viewing the system as well recognize the tactile properties of it. Studies suggest the use of haptics for force feedback skill learning, how they interact with the menu selection system. The user learning curve and the distinguishable haptic textures have been a major point in these research studies [11, 12, 15, 18]. Furthermore, user opinions and preferable haptic outcomes were discusses and examined as by Brunett [22]. Major test studies suggests the use of haptics as a new feedback technology as haptics and perception can jointly accomplish user judgement in daily world driving [28, 29, 31]

The potential design constraint that was proposed by Fitt's law suggests:

$$Movement\ Time = a + blog_2\left(\frac{Distance}{Size} + 1\right)$$

Eq. 2.1 Fitt's Law[4]

[4] Human-Computer Interaction Third Edition iSBN: 978-81-317-1703-5

Where ‘a; and ‘b’ are constants. As per the fitt’s law, for every user interface a response time can be calculated. In the current systems where control knobs and buttons are located away from the steering wheel compel the user to look away and increase movement time. For every single task to be operated, there will be a forward and backward movement from the steering wheel to the knob resulting in even more increase in movement time. As a result, the point that arises is based on Fitt’s law yet lacks focus of the task completion time.

As a result of the understanding of the importance of time as a determinant in the safety of the driver and passengers, the designers are compelled to design a system that will decrease the time its takes the driver to make a decision and to complete a task. Therefore, it only seems suitable to integrate the system in a location that is close to the driver, does not require visual attention and provides reliable feedback.

The proposed idea is to integrate this specially designed haptic system onto the steering wheel. This ensures driver’s hand stay on the steering wheel. The suggested system can take inputs based on touch and can also produce haptic outputs (Unique vibrations) based on the selection conducted by the user.

Chapter 3

General Design Methodology for Haptics in Cars

This system lays emphasis on driver safety and ease of use, developing an approach based on tactile cues as output. Since it is not using any auditory or visual means; the driver has to "feel" it through the means of haptic feedback. The user has to recognize the vibrations from specific haptic buttons and can self-learn to identify the specific vibrations as representations of output cues. The most unique feature of the system lies in its capability of generating haptic textures or vibrations specific to the driver, which will greatly reduce or eliminate the need of visual confirmation.

The proposed design for this system is as follows:

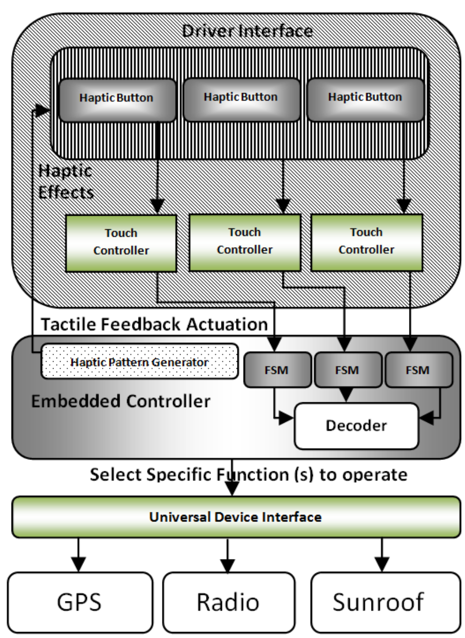

Fig. 3.1 Overall System Diagram

The main system is divided into three separate components:

- Driver control interface
- Embedded Control Unit
- Universal Device Interface

3.1 Driver Control Interface:

This unit consists of three haptic/touch buttons. These buttons are capable of generating pulses based on the user's tapping nature and communicate with the next abstracted layer (Embedded Control Unit). These buttons can generate haptic output based on vibrations which can be felt simultaneously when the user is interacting with the button.

"Haptic buttons" are buttons that can receive touch inputs and can also provide a cue to the user about the current state by outputting distinguishable haptic feedback such as haptic textures. Since the haptic button functions as a complete input/output driver interface, we can completely eliminate the need of visual interaction. The inputs of touch buttons are recognized by a touch control unit that converts them into digital format, which can then be fed to the next, layer i.e. the microcontroller.

3.2 Embedded Control Unit:

This abstracted layer is responsible for controlling all the functions of the system. Based on the user's input, we associate each input with a state machine. These states machines are defined as Finite State Machines (FSM). Once a particular state has been reached, they are sent to the decoder which decodes each state and controls a specific function of an in-vehicle device such as volume adjustment or on/off. Each state corresponds to a specific haptic effect which confirms the selection to the user. The different haptic effects can be created by varying the amplitude and frequency of the wave pattern, which is then fed to the haptic button. This unit also communicates with the third layer which is our Universal Device Interface.

3.3 Universal Device Interface:

This layer is a universal communication system, which is capable of communicating to different devices. A smart communication technology will be incorporated in the system with an embedded protocol that will allow a simple plug and play operation just like a USB (not implemented yet) and all the devices will be able to communicate with the system.

This design is a demonstration of an actual haptic control system that can be constructed based on the above scheme. To examine the above-proposed system, we conducted a few tests in the simulation to examine the user learning curve, texture recognition curve, overall system user friendliness and system functionality. The same model was constructed in a 2D environment. Tests were conducted to study the possible outcome and whether a physical model can be developed. After a careful study and analysis of the results, a prototype was developed which successfully worked in the manner outlined.

Chapter 4

Software Prototype & Evaluation

4.1 Software Prototype

The first task for this research was to test the usability of the system and the nature of haptic technology. We have developed a 2D model of the system on a computer using the Phantom Device which mimics the model in virtual reality and stimulates an output similar to the proposed haptic technology design discussed above. The user is able to select between three different buttons using the stylus attached to the Phantom device. The stylus allows the user to distinguish between the textures of the buttons that we have allocated in the virtual reality [11, 12].

For our research we have selected and used the PHANTOM® Desktop™ Haptic Device[5]. It is a portable haptic device which has 6 degree-of-freedom and a high fidelity force-feedback output.

[5] Phantom Desktop Ghost: www.sensable.com

Figure 4.1 Phantom Desktop[6]

This simulation was created to evaluate the behaviour of haptics in automotive vehicles. The proposed idea is to investigate effectiveness of haptics, user's preferences, learning behaviour, distinguishing nature of haptics. The results from this study will be used to develop a hardware prototype which will exhibit the same properties as per the software simulation.

4.1.1 Virtual Environment:

The virtual environment involves the use of four virtual buttons in a 2D environment. These buttons look and feel distinct from each other and their virtual textures can be distinguished by users via the Phantom device. The first button has metallic properties and is made to resemble a piece of aluminum which possesses a minute amount of kinetic and static friction. Once the stylus of the phantom device "touches" the aluminum button in the virtual reality, it moves with little resistance as a fingertip would on a piece of aluminum metal resembling a smooth and shiny surface. The second button was chosen to resemble a piece of rubber in texture. It has kinetic and static friction of this surface was modified to be quite high in

[6] http://www.sensable.com/documents/images/PhantomDesktop_Large.jpg

the virtual reality software. All buttons are made in the shape of a cube, while the dimensions and surface friction assigned in the Virtual world is made to "feel" the same way as it would in the real world. The third virtual button is made to resemble an ice cube. On the screen it appears to look similar to an ice cube with seem less kinetic and static friction assigned to it in the virtual reality resembling a very slippery and frictionless surface. The fourth button is placed above the three test buttons for the purpose of guiding the user towards the three test buttons when the eyes are closed, so that all cues other than "tactile cues" in the Virtual world are removed. The forth button is as large as all the other three buttons combined and has metallic properties similar to that of the first aluminum button. The placement of this large button in the 2D environment encourages easy calibration and handling

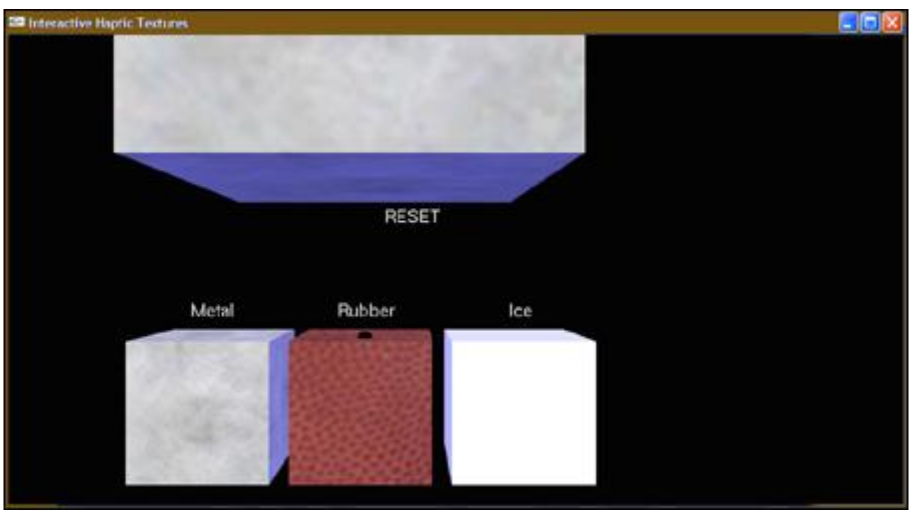

Fig. 4.2 Virtual Haptic Simulation Screen shot

4.1.2 Working Scenario:

After the creation of a virtual environment, the next step was to emulate the functionality of the proposed haptic system into the Virtual Environment. We created a scenario involving a State Machine model. The task within the Virtual Environment via Phantom stylus, projected to incorporate the essence in reality of changing the volume of the speakers and browsing the music tracks in the car[7]. In the initial stage where the button has not made any changes, the aluminum virtual button is denoted as the primary selection button. By denoting it as the primary selection button, we are establishing that this button is responsible for the offline/online status of a specific system and the other buttons in the 2D environment. The user is able to change the state by touching and pressing down the Phantom Stylus onto the aluminum button. As a confirmation for the user that a selection has been made, the aluminum button's texture changes into a rubber material. This then directs the button to an alternative phase, stage two of the "state machine", playing the first musical track on the CD. At the current stage the other two buttons, rubber and ice, are irrelevant as they have been purposely turned offline.

For the next stage, the user has to keep the cursor against the first button and has to press the stylus button; it will bring the second and third buttons online. Both of the second and third buttons are responsible for the volume control function. The second button allows an increase of volume and the third allows the user to decrease the volume. For buttons two and three to be online the primary selection button has been selected by the user again and is now in stage three, where the conformational texture is that of ice.

The user can press the cursor of the haptic device against the first button and once the stylus button is pressed, it will change the first virtual button back into stage two, where it will

[7] Phantom Desktop Ghost: www.sensable.com

look and feel like a rubber button again. Once this change occurs, the track and volume controls become offline.

This simple program can be reset at any time by pressing the stylus against the top metallic large button.

In investigation, along with the development of a prototype, a User Learning Curve, Texture Recognition Curve, and a Usability curve were recorded and analyzed.

4.2 Evaluation

To assess the effectiveness of a haptic interface it is important to use human test subjects. We conducted 5 different types of tests with a group of 25 people aged 21-30. These participants had diverse backgrounds and comprised of students from different departments, professors, construction workers, pizza delivery drivers, etc. We divided people into three groups based on their knowledge and familiarity with the haptic systems. The beginner group included people who did not have knowledge of haptic systems. Intermediate users were well aware of haptic systems but had never used it. Advanced users were completely aware of the system and had also used it before. All these tests were conducted in the research lab. The apparatus that was used was a computer with our Haptic Simulator Software along with a desktop Phantom. For the proximity sensing system, proximity hardware was configured with our custom haptic buttons. All test subjects were classified according to the above division of familiarity and no subject repeated the test, therefore removing any chance of having participants who had “pre-learned” the procedure.

4.2.1 Usability Test:

This test was conducted to determine the usability of the system and how user friendly it was. This test included 7 beginners, 7 intermediates and 3 advanced users. Manuals were provided to subjects so that they could understand what a haptic system was and how they could use it. Subjects had to determine on their own what the system was and how it worked. Demonstration of the apparatus was shown to the test subjects so that they could correctly utilize the device. Subjects were monitored while interacting with the system and were asked if the program was effectively and intuitively allowing control. The following graph demonstrates the average time taken for all three groups.

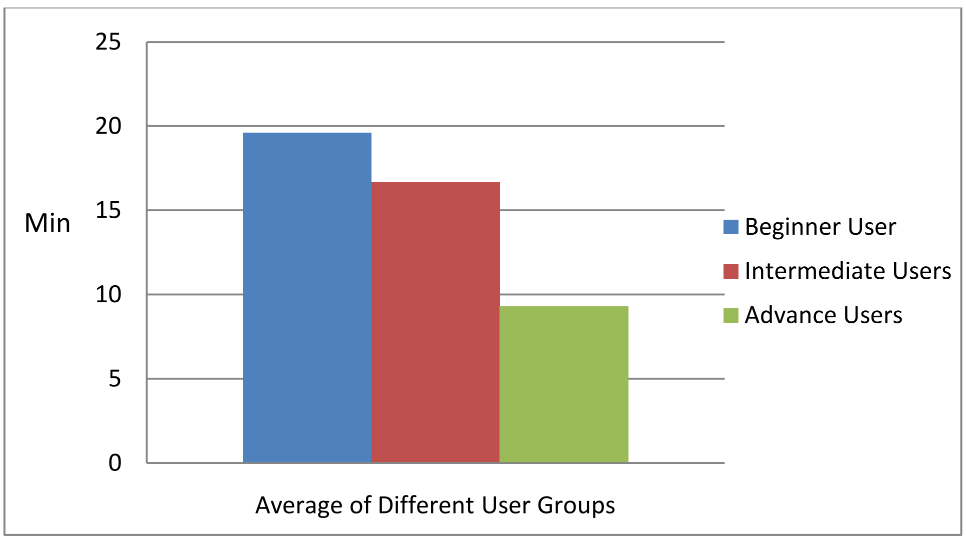

Fig. 4.3 Usability Test w.r.t Time

The above graph represents the relation between different types of classified users. In this test we can see a major difference in terms of time i.e. an advance user takes less time than an intermediate user who takes less time than a beginner user. This clarifies that the more you use the haptic system, the less time it will take a user to interact with it.

4.2.2 Distinguish Texture Recognition Test:

This test was conducted to check the user`s ability to distinguish between the textures of the buttons within the Virtual Environment based on the tactile cues experienced through the Phantom device. This second test was a haptic distinguishing test. This test included 7 beginners, 7 intermediate and 3 advanced users. For this test, each subject was blind folded. The stylus was moved to a random position and they were asked to hold the haptic device's stylus. We placed the stylus in their hand, on to a haptic button and asked if they can recognize the type of texture based on Ice, Metal and Rubber. For this test, the user had to give out an answer regardless of accuracy. A total of ten questions were asked. Their responses along with the time taken to distinguish between textures were recorded. The following graph demonstrates average time taken for each group to distinguish between different haptic textures:

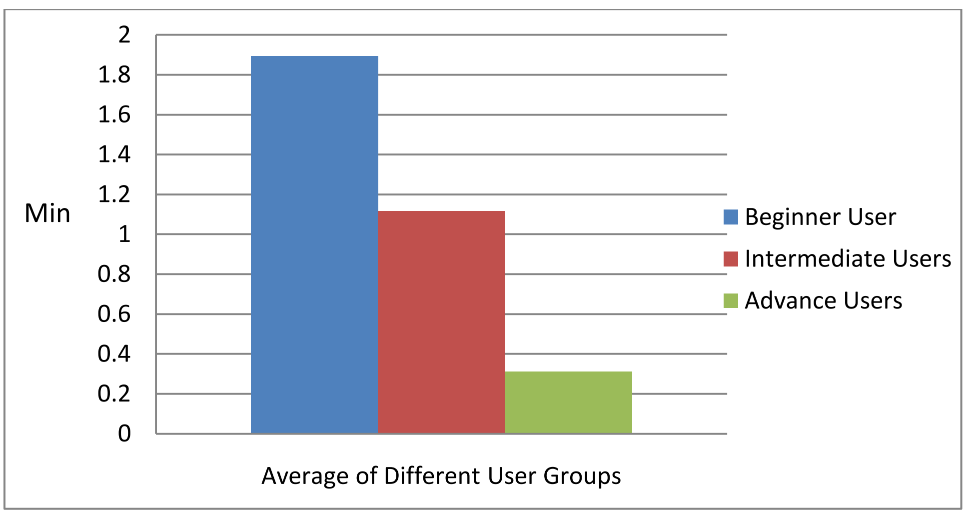

Fig. 4.4 Distinguish Texture Recognition Test w.r.t Time

The above graph demonstrates the relation between different categories of users. From this test, we see a major disparity among the users based on the time it takes to interpret and identify the textured surfaces and the level of familiarity with haptic technology. In regards to time, advance users take less time than intermediate users which takes less time than beginner users. This clarifies that by practice and repeated use of a haptic system, a user's judgment skills can be improved drastically.

This next graph represents the success rate of the subjects for using the haptic system:

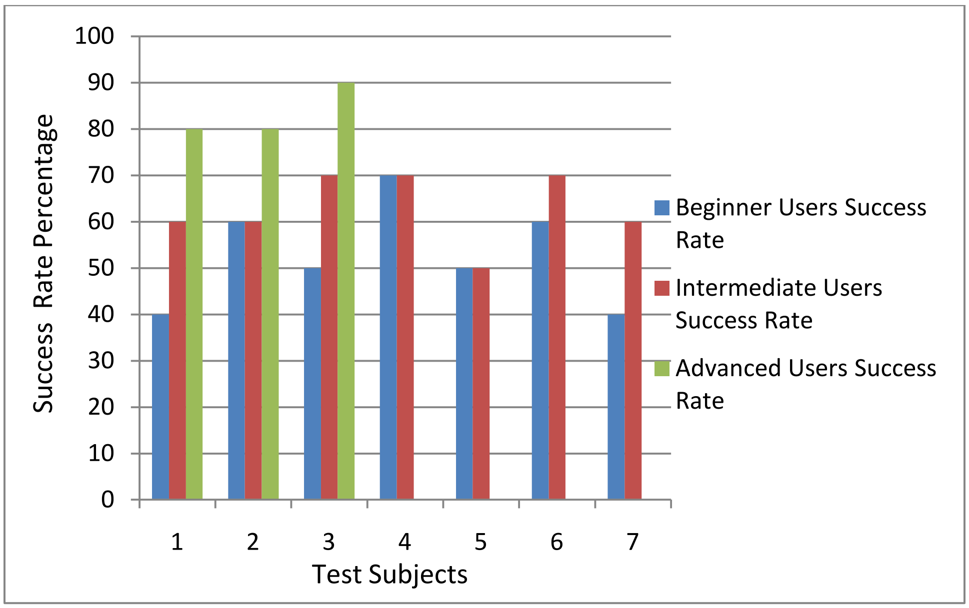

Fig. 4.5 Distinguish Texture Recognition Test (Success Rate)

This above graph defines a max-min percentage rate. For a beginner user, the success rate falls between 40~70%, while for an intermediate user it is between 50~70% and for an advanced user it is 80~90%.

4.2.3 Single Texture Recognition Test:

This test was conducted to determine if users can remember a specific haptic texture and if they can recognize and attribute the texture to the function whenever they encounter the same haptic feedback. This third test was similar to the previous test but subjects were not allowed to move from one button to another in an attempt to help discover which button they were on. This test included 7 beginners, 7 intermediate and 3 advance users. For this test they were asked ten questions. Following is a graph demonstrating the results we gathered from our test subjects

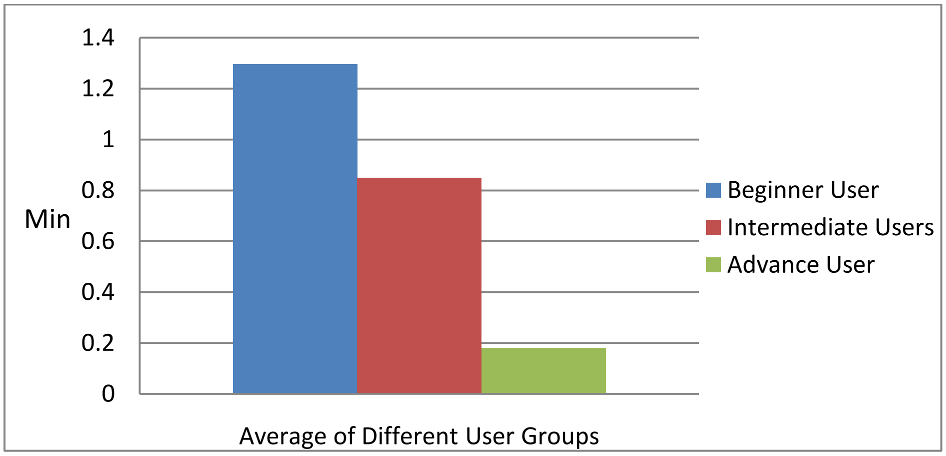

Fig. 4.6 Single Texture Recognition Test w.r.t Time

As per this graph, it took less time by the test subjects (in all three groups) to differentiate between different textures.. This time they were allowed to compare different textures, hence this clearly represents that there is a significant change when subjects are exposed to different textures which can increase their judgment capabilities in terms of time.

The following graph represents the success rate of subjects for using the haptic system:

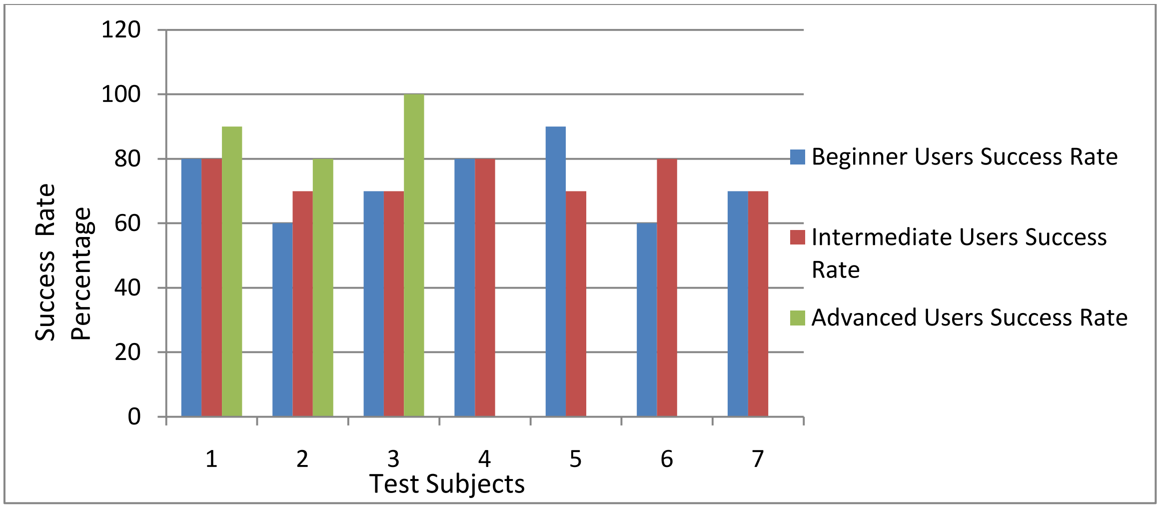

Fig. 4.7 Single Texture Recognition Test (Success Rate)

In this graph, there is a significant difference between the success rate if we compare it to the last graph where test subjects were not allowed to move between the different textures. For this graph the max-min percentage rate for a beginner user is 60~90%, for an intermediate user; 70~80% whereas for an advanced user it is 80~100%. Hence this clearly represents that there is a significant change when subjects are exposed to different textures which can increase their judgment capabilities in terms of the success rate

4.2.4 Concentrated Focus Usability Test:

This test was conducted to analyze complete system usability and a user's ability to keep his focus and eyes on the screen while manipulating certain devices using haptic controls. For this final test, a 5 minute video clip was played. Subjects were asked to keep their eyes on the video clip. While the video was played, they were asked 20 random questions about the video for several seconds following the video. While viewing the video, subjects were asked to hold the stylus of the phantom and to do 6 tasks i.e. to un-mute the sound of the computer through our haptic control system, reset the system, click on the icy structure, mute the sound which was being played in the background etc. A series of control tasks were required to complete these major tasks and they were given manuals and prior training for completing the tasks. Subjects were asked to control the haptic interface and perform this task while viewing the video clip. Each test subject was asked the same series of questions and they were asked to perform the same haptic device control task. The following graph demonstrates the usability of the system based on the time taken to do it:

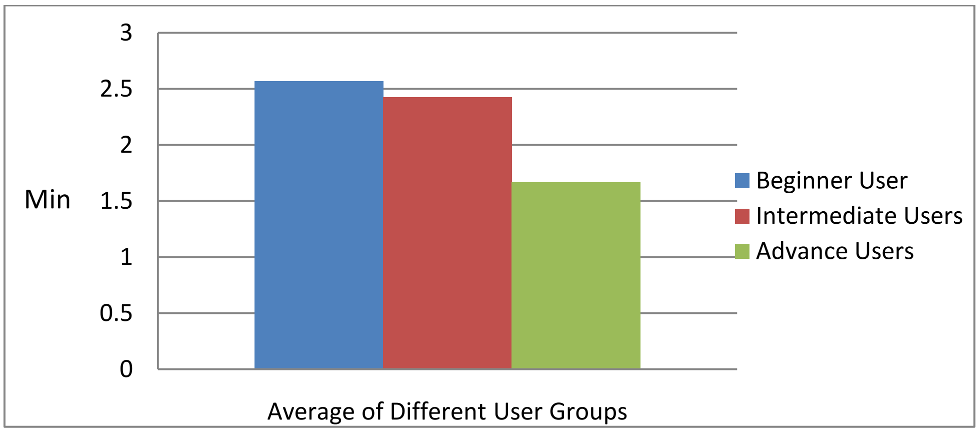

Fig. 4.8 Concentrated Focus Usability Test

In the above graph, the subjects were exposed to an environment where they had to focus on their screen while using a haptic system to perform different tasks. This graph demonstrates that for a beginner user it took more time to complete the task, while for an advanced user it took the least amount of time.

This graph represents the success rate of the subjects while using the haptic system:

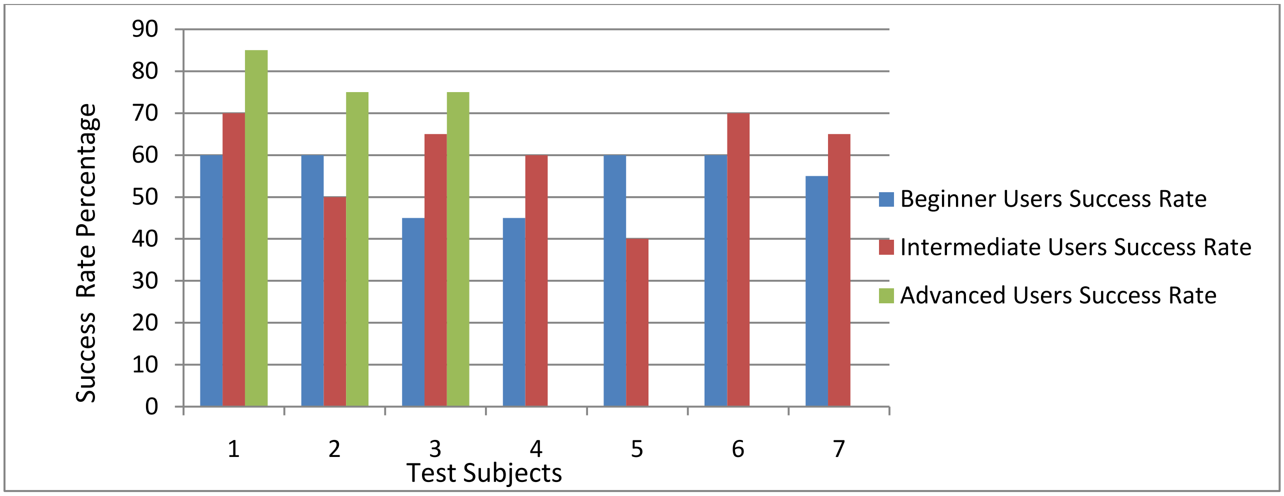

Fig. 4.9 Concentrated Focus Usability Test

This above graph represents different test subjects from classified groups and their performance when exposed to a scenario where they have to use a haptic system while viewing a video. Overall, there is quite a variation between the beginner users, in terms of their judgment skills, and how focused they are while using the system. For the intermediate and advanced users, there is less variation. Again, this can be improved by exposing subjects to haptic systems on a daily basis which will improve their skills.

These important test results were crucial for the development of an actual prototype. They gave us a brief idea about what was lacking in the current design and how can it could be improved. It also helped us to asses the opinions of the test subjects about the overall implications of our proposed system, and whether they have any suggestions to further include or exclude anything.

4.2.5 Proximity Sensing System Test:

A test was conducted in order to recognize the effectiveness of the proximity sensing. The system generates a consistent vibration whenever an obstacle is closer than 1.5 feet to the detector. Subjects were trained about the specific pattern for this sensing system. We conducted the test between 7 beginners, 2 intermediate and 2 advance users. Subjects were asked to analyze if they could recognize that particular feedback out of all the other vibration patterns. They were questioned 5 times. Following is a graph demonstrating the success rate of the proximity sensing system:

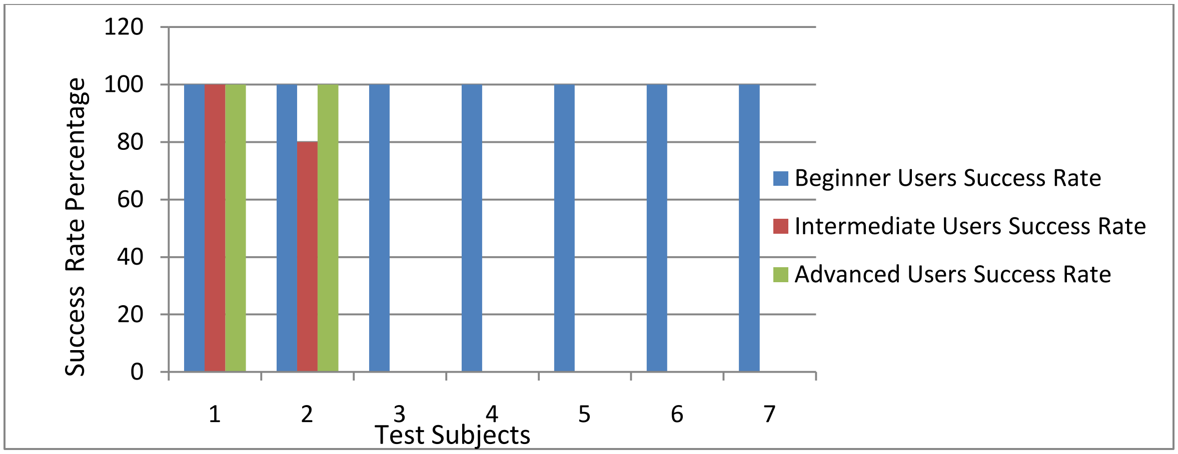

Fig. 4.10 Proximity Sensing Effectiveness (Success Rate)

For this test all the test subjects from every domain were almost 100% correct (except one intermediate user) due to the immense amplitude and consistent nature of the vibration pattern. These vibration patterns are consistent and entirely different from the other fluctuating patterns which vary in relation to time.

4.2.6 Observations

After running a few tests, we observed great improvement in the beginner users' skills and ability to use tactile cues to identify and recognize as required in haptic technology. Most recent test results can be analyzed to understand the user learning curve. The graph shows improvements among beginner users.

Another major factor that needed to be observed was time. Due to the nature of this research, task completion is not as important as the driving itself. Regardless, it contributes to a major part of the success as a particular task has to be completed. For the first few tests, there was a major time problem that we faced, but later on, we saw quite an improvement among all categories of users. Hence, we concluded that the user learning curve is directly proportional to the use of the system. In regards to the development and implementation of our haptic technology this meant that the subjects were able to acclimatize to system and learn the tactile cues that acted as identifiers for certain actions. Using the understanding that subject's performance improves with time allowed us to be confident in using an array of cues for feedback and variation in the proposed haptic system.

These experimental results were the complete motivation that haptic technology can be used to differentiate between different selections. As mentioned in Section 1.2.1, the ability of the users to easily interact with the system with substantial performance improvements as time passed further verifies the point that users are able to distinguish between the distinct tactile cues provided. Along with being able to distinguish, the user's performance also improves with increased interaction, which strongly suggests that once the haptic system is put into practice it will be able to function effectively in the real world.

The existing systems lack unique identifiable cues for separate devices, whereas the pilot study provided a clear indication that haptic technology can be used to provide such distinct response cues and that these cues can be learnt and distinguished by users without interfering with the use of their other sense systems. This confirms that haptic technology developed based on our proposed haptic system will be user friendly and efficient.

Chapter 5

Hardware Prototype

Based on the the pilot experimental results and keeping the simple fact in mind that a driver needs to keep his hands on the steering wheel, a different design was considered which can be used to navigate the system.

The initial ideas was to mount a rotary jog on the steering wheel. Due to the rotary nature of the jog, the user had to suspend his hands from the actual steering wheel to use the jog which doesn't fulfill the key focus of this thesis.

A second option was to use haptic buttons. They can be mounted on the steering wheel or they can be embedded within it for a sleeker design but still allowing the user to keep his hands fixated on the steering wheel of the vehicle. The driver can simply slide his grip over the wheel to jump between different buttons just like an ordinary cruise control selector. Based on this fact, haptic buttons were created. These buttons can simply take an input by a gentle tap and at the same time the user can feel the feedback. Wires can be run from these small controllers to the central control unit which is located off the steering wheel underneath the hood.

For this system to work, it is developed using a PIC development board called HP268ST from Microchip[8].

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[8]Pic Microcontroller Development Board

http://microcontrollershop.com/product_info.php?products_id=2365&osCsid=8f20e91a2d30b401dba58e4e13b35e3e

The hardware prototype consists of four main components which are as follows:

- Haptic Buttons
- Touch Control Interface
- Proximity Sensing System
- Embedded controller

5.1 Haptic Button:

Our haptic buttons comprised of two operating circumstances i.e. input/output. For the input state, we used the touch interface and for output we used vibrations as the haptic feedback. Below is the detailed discussion about both input/output circumstances. Size and cost were major factors of concern during the fabrication stage. These buttons were to be small enough so they could be installed on the steering wheel. Very tiny project boxes were selected to fulfill the size requirements.

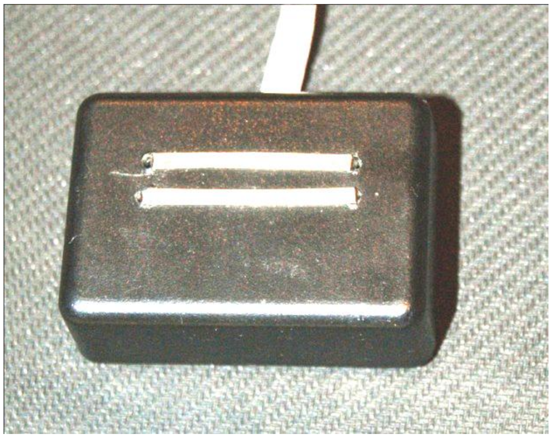

Fig. 5.1 Haptic Button

5.1.1 Touch—Input:

For the touch input, two metallic wires are pasted on the top of each button and are connected to the touch controller. Once these two wires are touched by a finger, they send the signal to the touch controller which translates the signal into a digital format. Below is the location of Touch Plates for the Touch Sensor on the button.

Fig. 5.2 Touch Plates Connected to the wires for Touch Sensors (Back of Haptic Button)

5.1.2 Vibration—Output:

The simplest haptic devices such as vibrations are used in cell phones. For the actual prototype, the idea was to generate different patterns of waves based on different devices. For this purpose, vibrators were used to test different set of operable waves and for which they could give a recognizable haptic feedback, The vibrators[9] that we used were electromagnetic vibrators

[9] LG Innotek Co.# TA09-T3001459AA / Spec MVMF-A346T3. Mini-pancake vibrator motor

manufactured by LG. Due to their small size (10mm diameter X 3mm Thick) they can be installed at the back of our touch buttons. An important consideration was the cost. These vibrators turned out to be quite low cost and effective. Below is a snapshot of the haptic button`s back which displays the vibrators for feedback.

Fig. 5.3 Vibrators for Feedback (Back of Haptic Button)

5.2 Touch Control Interface:

The touch controllers are non-latch circuits. Since the touch acts like a pulse for the system, every time the user touches these buttons; it generates a pulse which is further translated by the touch controller interface into the digital data for the next layer.

5.3 Proximity Sensing System:

To further enhance the system's efficiency and tackle safety concerns, another sensor was integrated with the system known as an ultra sonic sensor which acted as a proximity sensing device for the vehicle. If the distance with the adjacent vehicle is not safe, the system will generate a haptic feedback with the maximum amplitude to warn the driver about the possible collision.

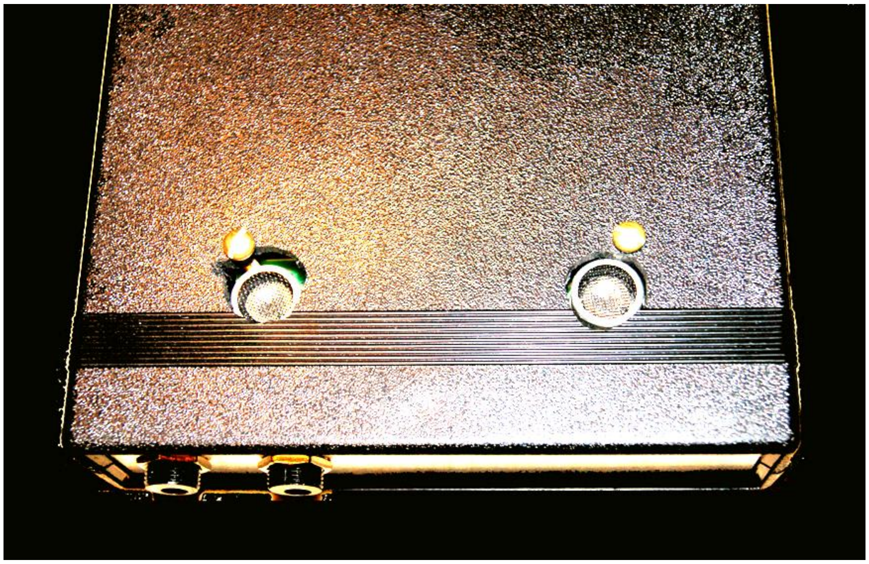

Fig. 5.4 Ultra Sonic Sensors for Proximity Sensing System

5.4 Embedded Controller:

The controller that we have used is a PIC16F877A[10] and is responsible for controlling all the inputs and generating the outputs.

[10] Pic Microcontroller Development Board
http://microcontrollershop.com/product_info.php?products_id=2365&osCsid=8f20e91a2d30b401dba58e4e13b35e3e

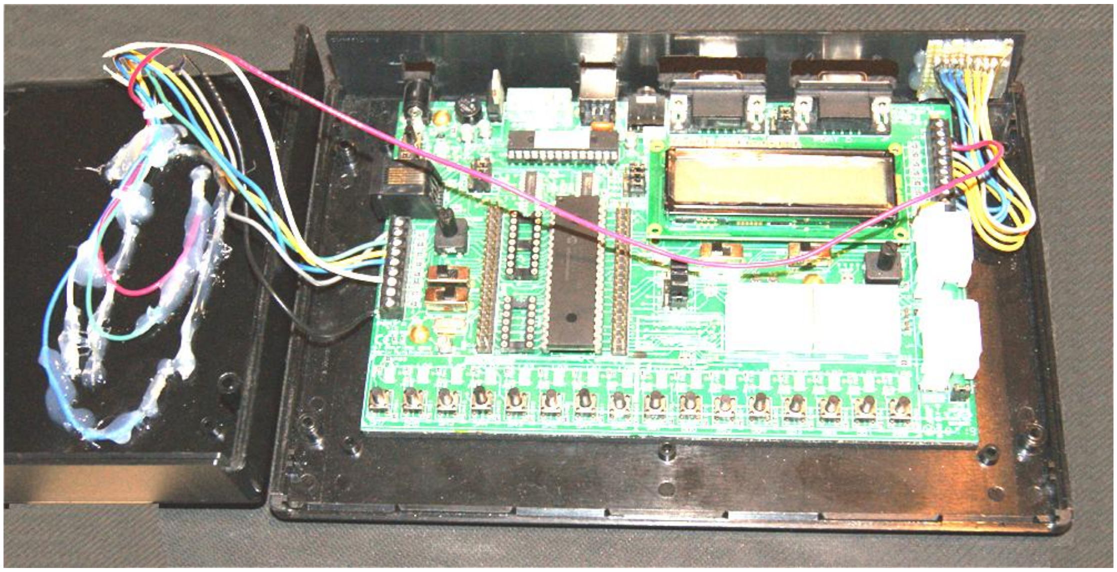

Fig. 5.5 Embedded Control Unit

Once this circuit is fed with power, it starts looping and waiting for the user input and monitors the proximity sensing system. In case the vehicle is running too close to the adjacent vehicle, the system will generate a strong haptic feedback with maximum amplitude to alert the driver. In the normal operating mode, the unit waits for the user's tap and based on the taps, it selects the appropriate device and acknowledges it in the form of haptic feedback. This control unit delivers distinguishable wave patterns to the haptic buttons to provide the user with feedback. A long and short fluctuating wave was used to distinguish the two functions for each device.

5.5 Haptic Feedback Fall back:

A major problem faced while integrating the vibrator with the system was that these vibrators when tested can only work with a square/sin/triangular/saw tooth wave which is less than 5Hz. If it goes beyond 5Hz, the user won't be able to feel the difference as these vibrators cannot truly reflect them. The second problem is that if you input a square/sin/triangular or a saw tooth wave, a very minor difference is observed which may not be noticeable by an ordinanry user but can only be analyzed by an expert haptic user. This requires a user to be trained enough on a daily basis, so that he/she can detect the minor difference.

5.6 Evaluation:

To evaluate the hardware prototype, five new test subjects were invited with three of the old test subjects. Previous test subjects were either in different states and cities and were unable to come to the test study. The evaluation was conducted with the help of a driving simulator known as STISIM [11]. A free version was downloaded from their website for the use of educational and testing purposes only.

A force feed-back based steering wheel was connected along with acceleration and brake pedals. Force feed-back was used to formulate the exact driving environment which a normal power steering wheel gives out. It was customized automatically by the simulator software.

Test subjects ranged from an age of 21 to 39 years out of which 5 were male and 3 were female. All these test subjects were graduated driving license holders with the experience of at least 2 years. 2 of these test subjects were advance, 2 were intermediate users and the rest of them were beginners in regards to their familiarity of haptic systems.

The LCD screen was used to simulate the driving experience. The inside view of the car was projected on the screen with the addition of standard gauges. Haptic buttons were installed on the steering wheel to give out the exact in-vehicle scenario. This prototype was not connected directly with any hardware other than the on board lights to show a visual confirmation just for the references. This visual confirmation was not visible to the subject.

[11] http://www.stisimdrive.com/

Every subject was provided with a practical demonstration of the prototype to show them how it works and how you can navigate through the menus and turn a feature on/off. They were introduced to different vibration patterns and what they represented. Every user was given 10 minutes to practise using the system before the actual test.

A camera was installed on top of the LCD screen to keep track of the user's eye if they look down at the steering wheel. A consent form was signed by each of the subjects prior to the test. Test subjects were told to follow all the traffic signs and duplicate a realistic driving scenario. Eye tracking behaviour was recorded with a time line to reconfirm their eye movement adjacent to a particular task. Test subjects were not recommended any suggestions as to where to look and to focus except for the driving task.

A total of three tasks were given to the user while driving:

1. Select the first device and turn it on.
2. Return to the main menu.
3. Select the third device correctly.

A manual trigger was used to enable the proximity sensing system as the simulator doesn't allow the direct connectivity. It was triggered manually whenever a driver was running too close to the adjacent vehicle.

Each test lasted till the tasks were completed. The first task was requested at the 3rd minute of the test, just to familiarize the subject with the driving environment. Every time a task was requested, time was marked to synchronize the eye tracking behaviour of the test subject and it was marked again at the completion of the task.

Below is a snapshot of the testing environment:

Fig. 5.6 Testing Environment for Hardware Prototype

These tests were further analyzed to evaluate the accuracy, completion time, and eye behaviour and user learning curve. Below are the graphs which were evaluated after a careful analysis of the test results:

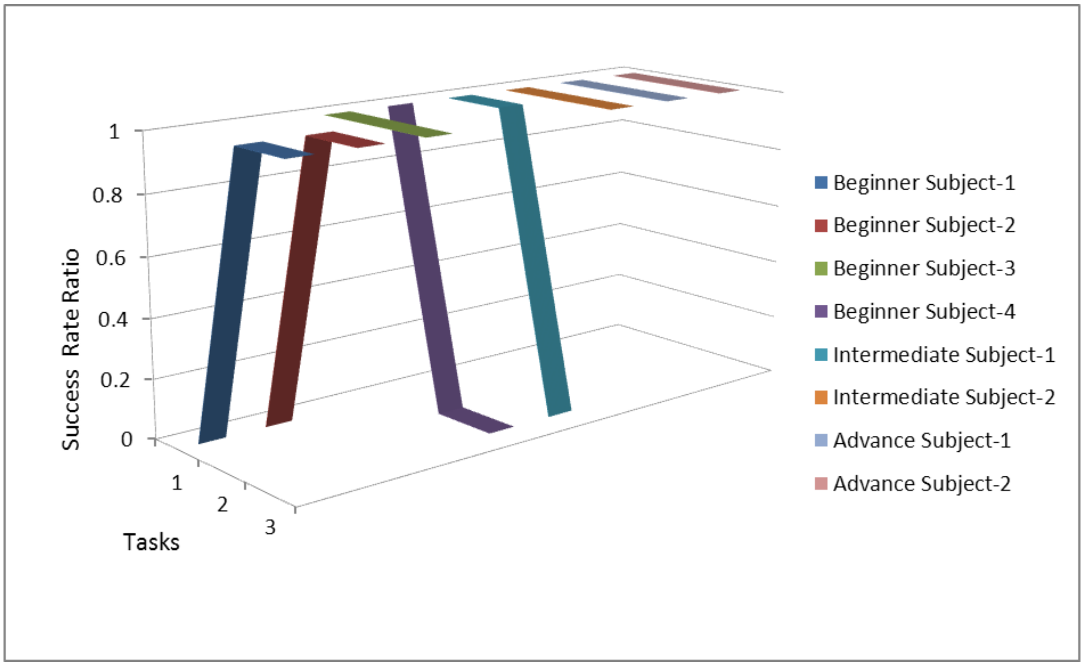

Fig. 5.7 Success Rate Ratio w.r.t Accuracy (Detailed View)

This test demonstrates the user learning curve and accuracy for each of the tasks performed by beginner, intermediate and advanced users. Based on the above graph, it can be observed that the overall performance of subjects for using the system was quite accurate. An interview was conducted with each test subject about why they scored in a particular way and if they had any recommendations about the functionality of the system.

The outcome of the interview by most of the subjects recommended that if more time was provided, it could have been much better as they were having difficulties locating the buttons on the steering wheel. Practice would have helped them achieve a better score. As per the fact, it can be concluded that exposing the subjects to this system on a daily basis would help them learn the locations of these buttons and memorize them for daily use.

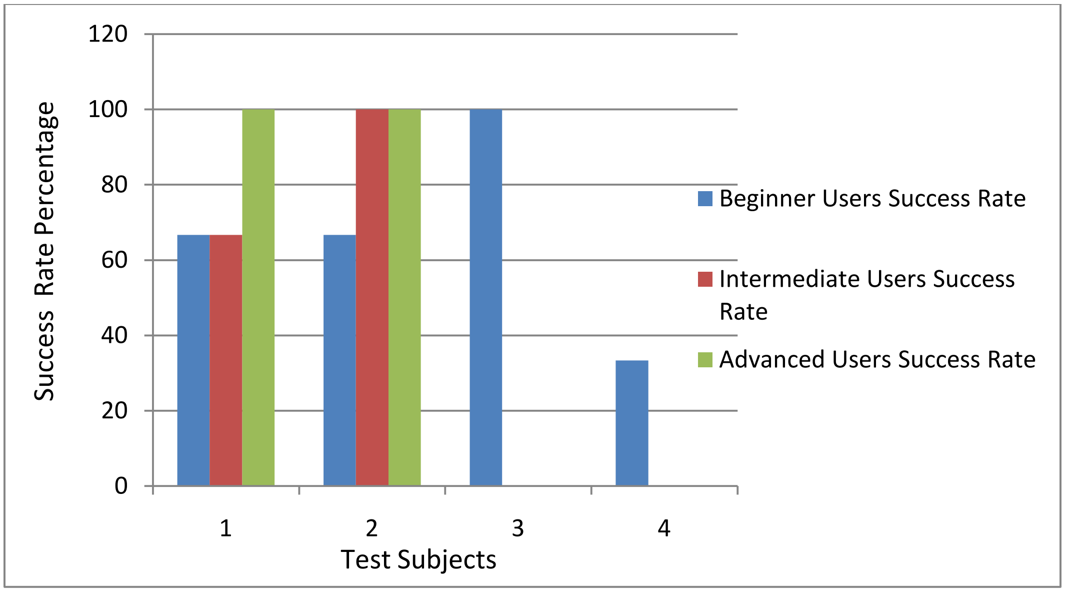

Fig. 5.8 Success Rate Ratio w.r.t Accuracy (Overall Average)

This test shows an overall view of how accurate the subjects were. Only one intermediate user scored less than 50% and most of them reside in the 65~100% range

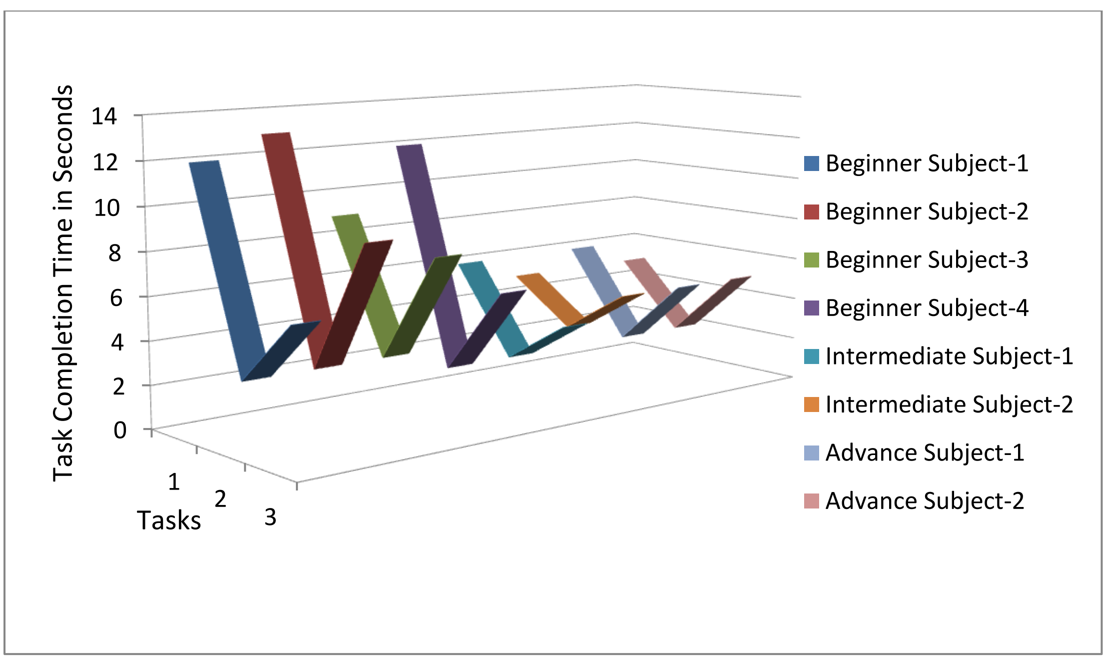

Fig. 5.9 Task Completion w.r.t Time (Detailed View)

This graph represents a detailed view of task completion time. It can be observed that there is a significant difference between the completion time of beginner users to the intermediate and advanced users. Most of the users have high completion times for the first task. The second task was fairly easy and required a double tap at the first button and all of them did well in that task. The third task is a replica of the first task. However, a different device was chosen in this task. Subjects had an initial idea about doing the first task and they did well in the third task.

When the test subjects were asked why they took a longer time to complete the first task, they stated that the only problem was entering the code to activate the first device as they failed to remember the encoding. It should be noted that this answer was given out by the beginner users as they had no knowledge of binary encoding schemes. As per the intermediate users, they focused more on analyzing the feedback which resulted in a higher task completion time. The user can always request the feedback as many times as they want by single tapping the first button once a device has been selected.

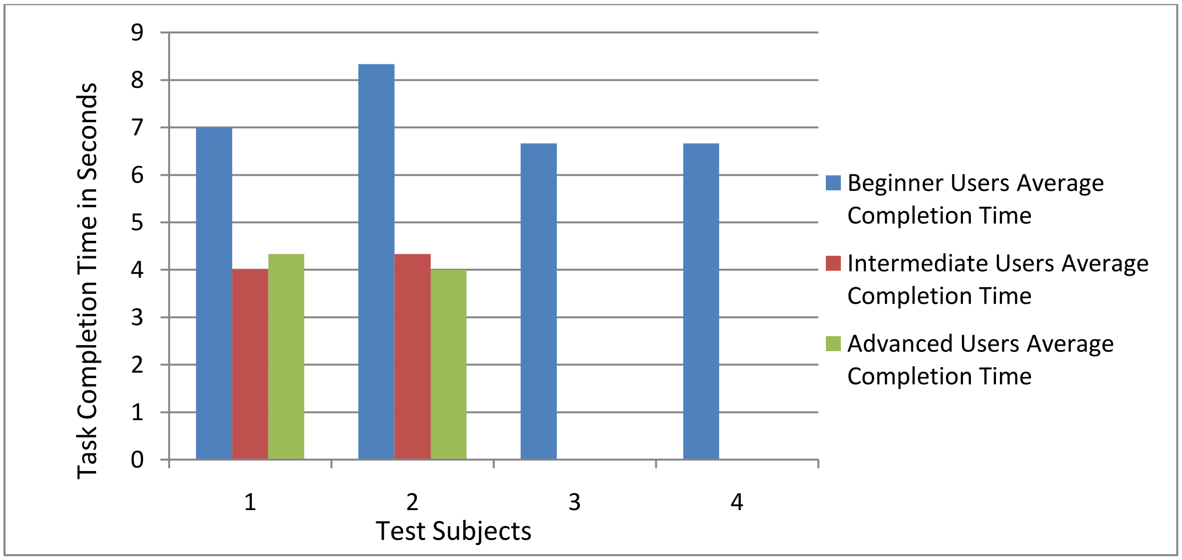

Fig. 5.10 Task Completion w.r.t Time (Overall Average)

Figure 5.11 depicts the overall average from the different range of users and their timings. The beginner users took a fairly long time as compared to intermediate and advanced users. It can be concluded that by providing more training, test subjects can fall in the intermediate and advanced user groups with lower task completion times.

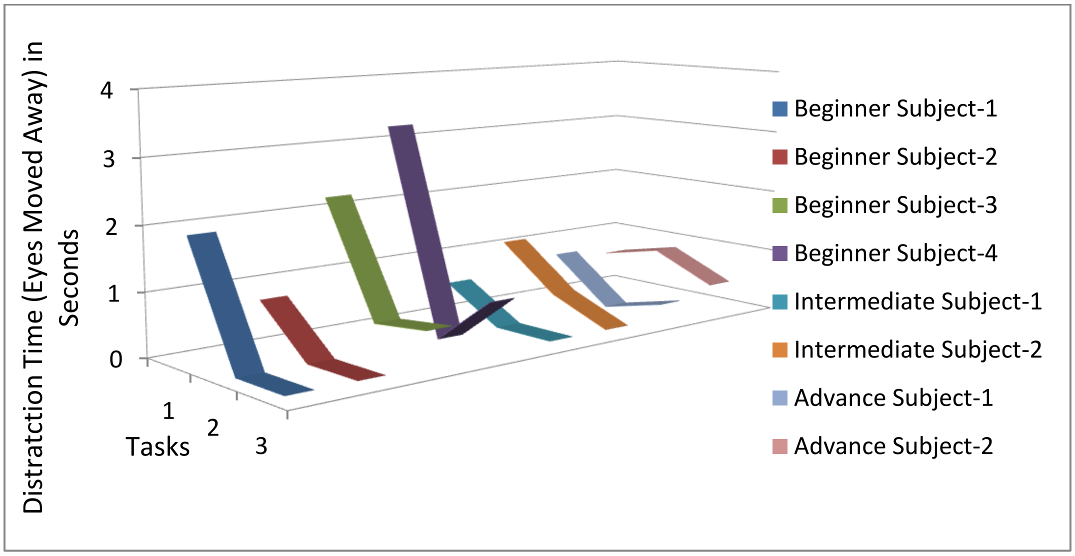

Fig. 5.11 Eye Tracking Behaviour w.r.t Time

This figure plays a very vital role in the completion of this thesis. For each subject, the task start time and end time was marked using video footage. By using the slow motion feature, the behaviour of the subject's eyes was analyzed. The time illustrates a sum of all instances when a user was looking down at the steering wheel while doing the task. Some test subjects looked more than once to complete a particular task such as Beginner Subject 3 and 4. However at the final task which is a replica of the first task except for the selection of a different device, a very minor change in the movements of eyes was recorded. It suggests that more training and daily use can reduce the general behaviour of the test subjects drastically.

A manual trigger for the proximity sensing system was configured to be triggered manually as the driving simulator software has no interface for driving over the lane except the visual data. It was suppose to be triggered manually whenever a subject was running very close to the adjacent vehicle but none of the above mentioned driving behaviour was recorded. No data was collected for the proximity sensing systems test

The general outcome of the interview about this scenario was almost the same as the task completion time. Most of the test subjects were looking for the buttons in the first task. After using the system for some time, they were able to memorize the locations of these haptic buttons.

Most of the test subjects gave positive feedback about the system. One test subject found the system to be a bit frustrating as the subject was having difficulties locating the keys on the steering wheel.

Chapter 6

Comparison of Software Simulation & Hardware Prototype using Fuzzy Logic

To better understand the behaviour characteristics and Quality of experience of software simulation and hardware prototype, it is necessary to compute the User Interface effectiveness of both systems. As they use different forms of haptic devices, it is necessary to use subjective data to come up with a model that can completely predict the working effectiveness of these models and the relation between them.

To achieve a better understanding of User Interface Effectiveness, fuzzy logic is used to compute a common ground of behaviour between the two User Interfaces. Since fuzzy logic has the capability of using subjective data to non-crisp data values. It can be analyzed that if both systems lie in the same performance matrix or not?

With the help of fuzzy logic, a 3D surface was generated for both user interfaces. This surface demonstrates User Interface effectiveness based on subjective data and relations between them can be analyzed and studied.

For the evaluation fuzzy logic toolbox from MATLAB[12] has been used. MATLAB uses Mandani fuzzy system [50]. The results typically demonstrated the essential difference between the two systems and their effectiveness through the use of 3D graphs.

[12] Fuzzy logic toolbox for use with MATLAB®, Math Works Inc 2009

Each QOE model consisted of two inputs and one output Fuzzy Inference System. The inputs were diversified in ways that catered to all the possible data values from the previous evaluation results.

6.1 Software Simulation User Interface Effectiveness

To evaluate the User Interface (UI) effectiveness, data values from the single texture recognition test, the distinguished texture recognition test and the concentrated focus usability test were used.

For the QOEs, success rate data and task completion time from the previous evaluations was used. These were the two inputs (for each graph) that were further divided into three membership functions each. These membership functions had values under the categories Excellent, Average and Poor (success rate and task completion time). The help of three membership functions, which defined the UI effectiveness as Excellent, Average and Poor, also analyzed the output.

For all the inputs, a trapezoidal function was used, as the values were crisp. For the outputs a triangular function was used to generate the precise values [51].

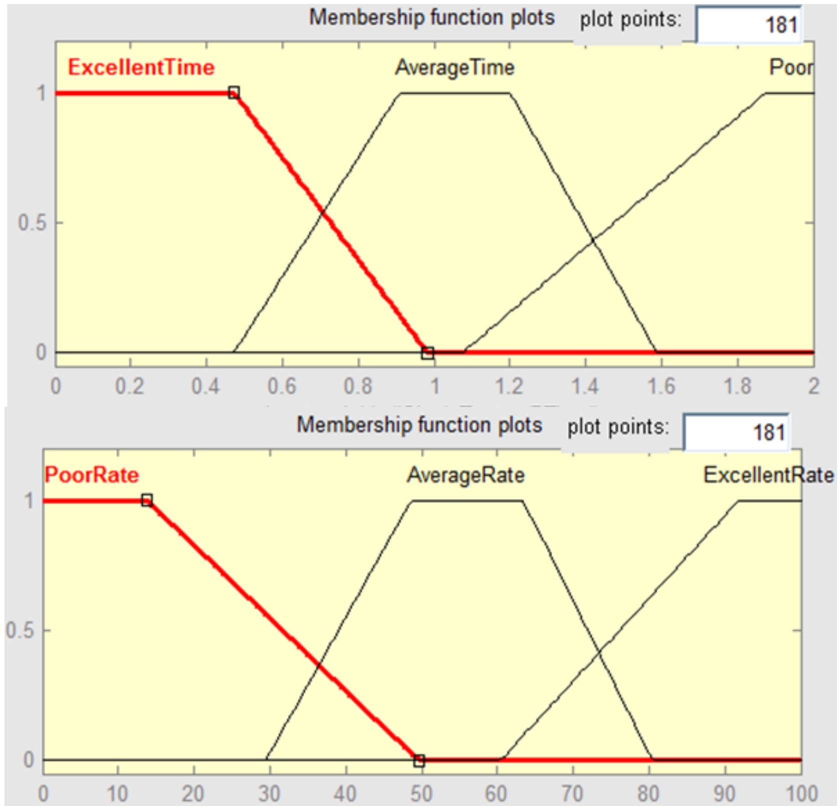

Fig. 6.1 Membership functions for inputs of 1st QOE

The values for first input function (Single Texture Recognition Time) ranged from 0-2, as the time for beginner, intermediate and advance subjects also lay between this range. Secondly, input ranges from 0-100 demonstrated the success rate of subjects.

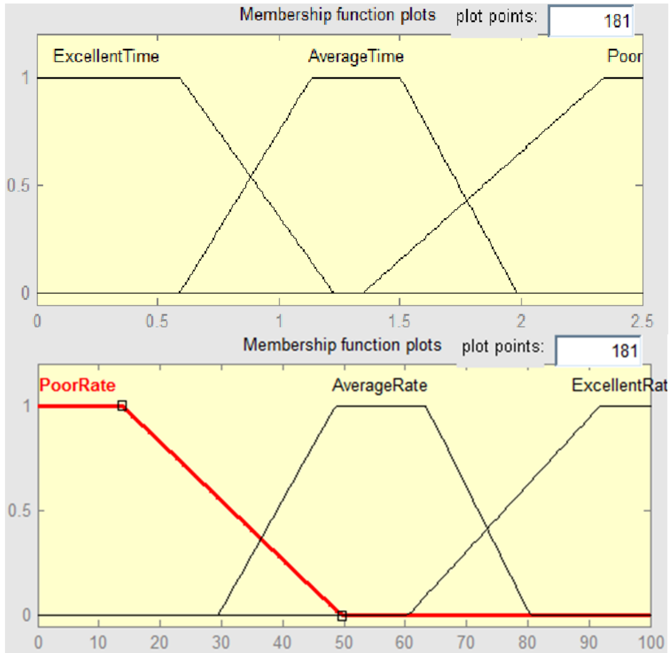

Fig. 6.2 Membership functions for inputs of 2nd QOE

For the second QOE, inputs ranges from 0-2.5 for the task completion time and 0-100 for the success rate based on the initial test data.

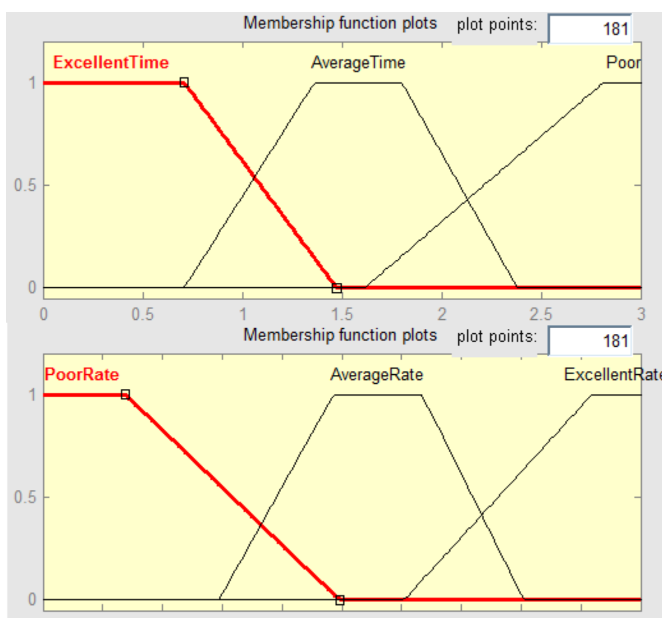

Fig. 6.3 Membership functions for inputs of 3rd QOE

For the third QOE, inputs ranges from 0-3 existed for the task completion time and 0-100 for the success rate, as based on the initial test data.

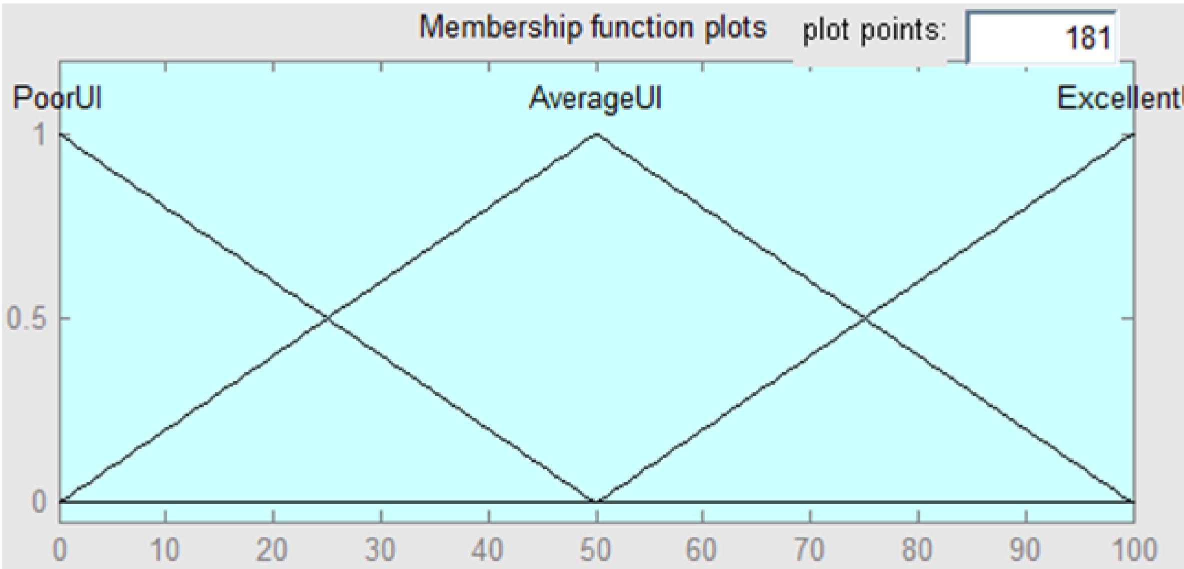

Fig. 6.4 Membership functions for Outputs of all QOEs

The output range was from 0-100, as based on the User Interface Effectiveness. Same range was also used for all of the other graphs so as to stay consistent and to allow easy understanding of the evaluation system. The three Fuzzy inference systems from all three graphs generated three different graphs based on their different behaviours. All the three mamdani based FIS are shown below in the figure 6.5.

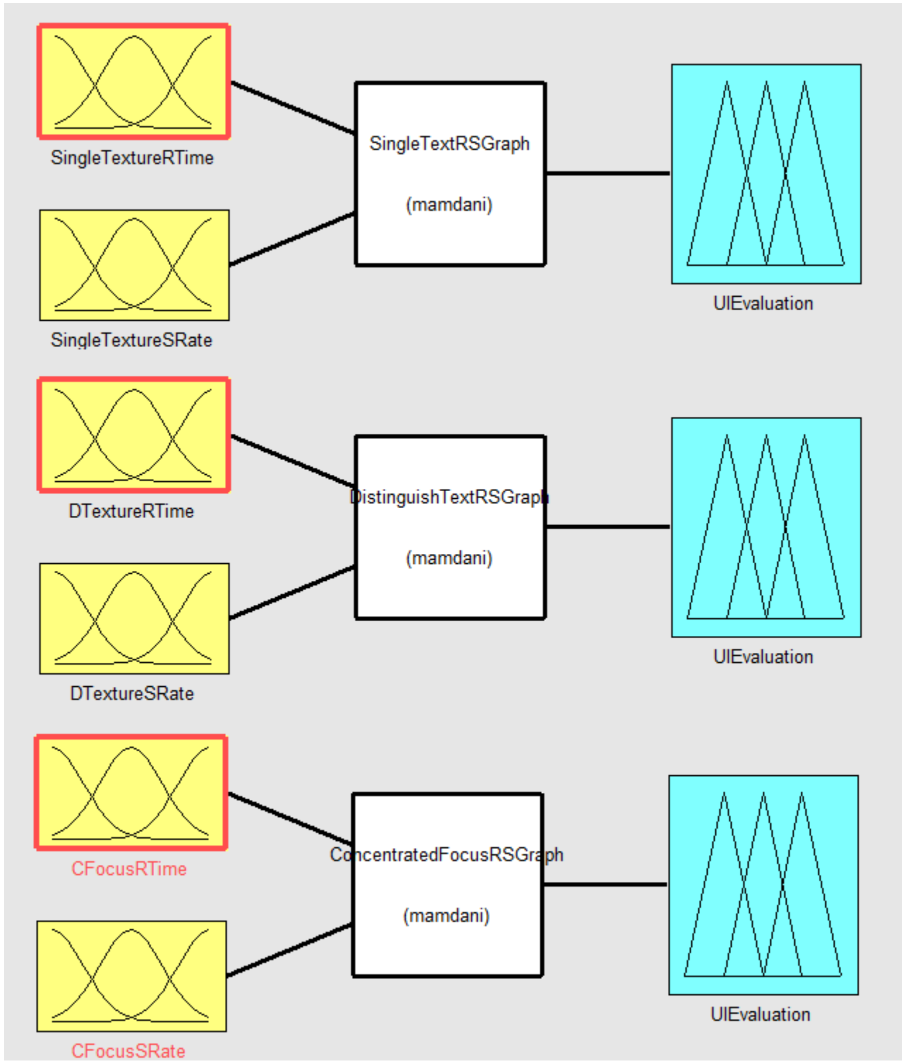

Fig. 6.5 FIS using Mamdani

Mamdani FIS was used as it applied the technique of defuzzification of a fuzzy output [50]. It is noted that mamdani is a standard fuzzy inference system, which is a part of the MATLAB fuzzy toolbox.

For this system to work, nine rules were enforced based on the membership functions, which classified the data as excellent, average and poor. These rules were selected due to the working scenario under which the simulation took place and of which safety was a major concern and the time spent on the operation was a minor concern.

Rules			
AND	Excellent Success Rate	Average Success Rate	Poor Success Rate
Excellent Time	Excellent UI	Average UI	Poor UI
Average Time	Excellent UI	Average UI	Poor UI
Poor Time	Average UI	Average UI	Poor UI

Table. 6.1 Rules

These same rules were also applied to the Hardware Prototype so as to maintain the simplicity and consistency of the evaluation.

To test the system, visual testing was selected. Visual testing involved running the MATLAB fuzzy logic toolbox called the ‘rule viewer’. The “rule viewer” portrays a visual concept of selecting and “activating” a particular rule. Selecting the “red line” and dragging it over to different graph sections can alter the inputs present in the input value. Certain rules can be fired based on the movement of the “red line” and hence it is quite easy to test the system as whole [50].

As we used three different tests results to compute three different QOEs, the following are the three rule viewers from the Single Texture Recognition Test, the Distinguished Texture Recognition test and the concentrated focus usability test.

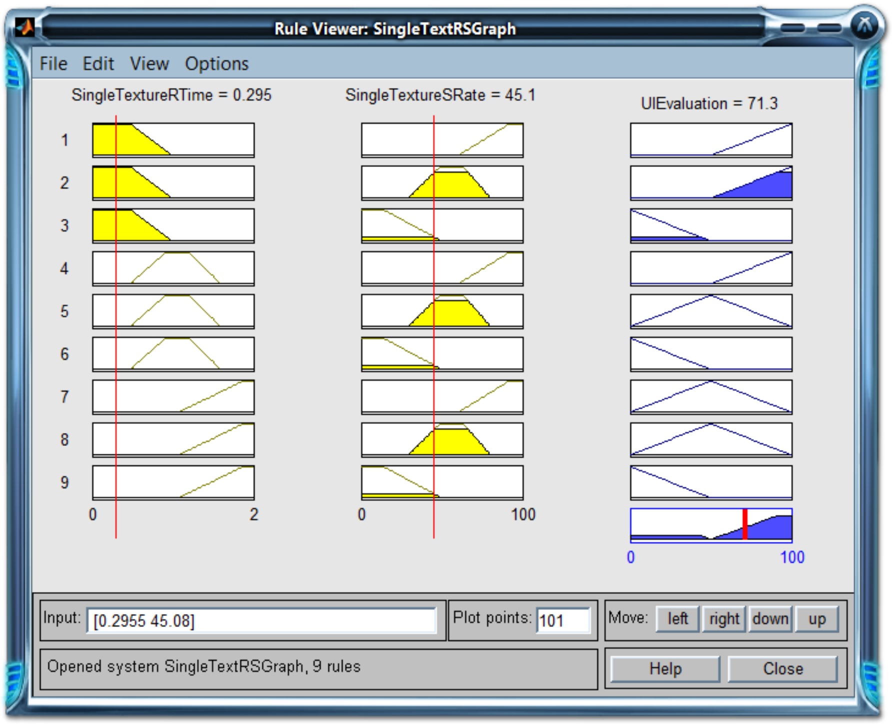

Fig. 6.6 Rule Viewer QOE-1

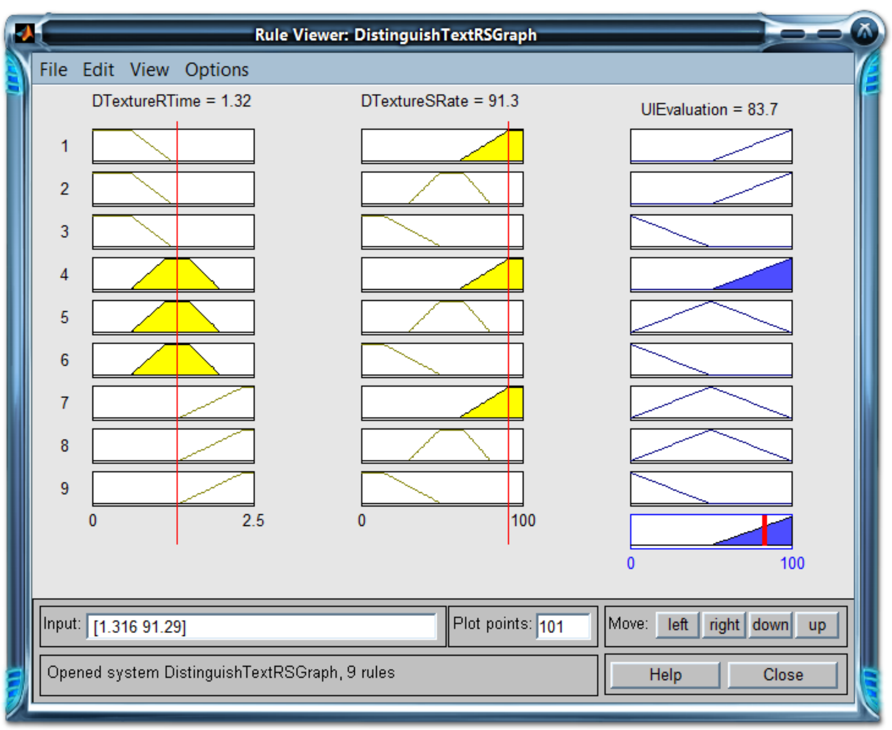

Fig. 6.7 Rule Viewer QOE-2

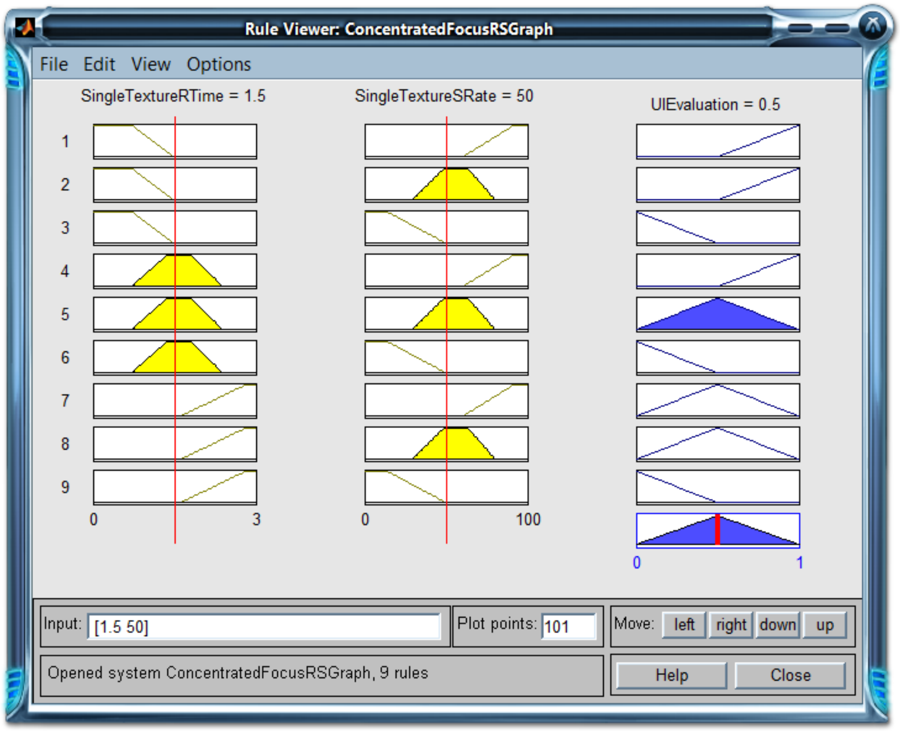

Fig. 6.8 Rule Viewer QOE-3

After running these tests, three graphs were generated. Each graph represented a unique QOE based on test results for each test.

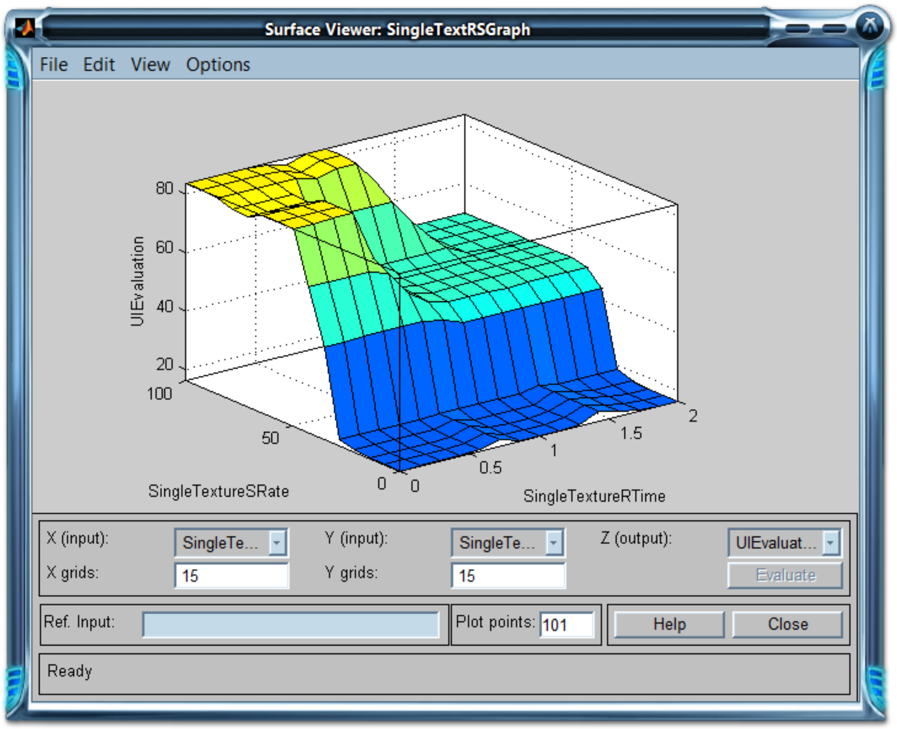

Fig. 6.9 QOE-1 Surface Viewer

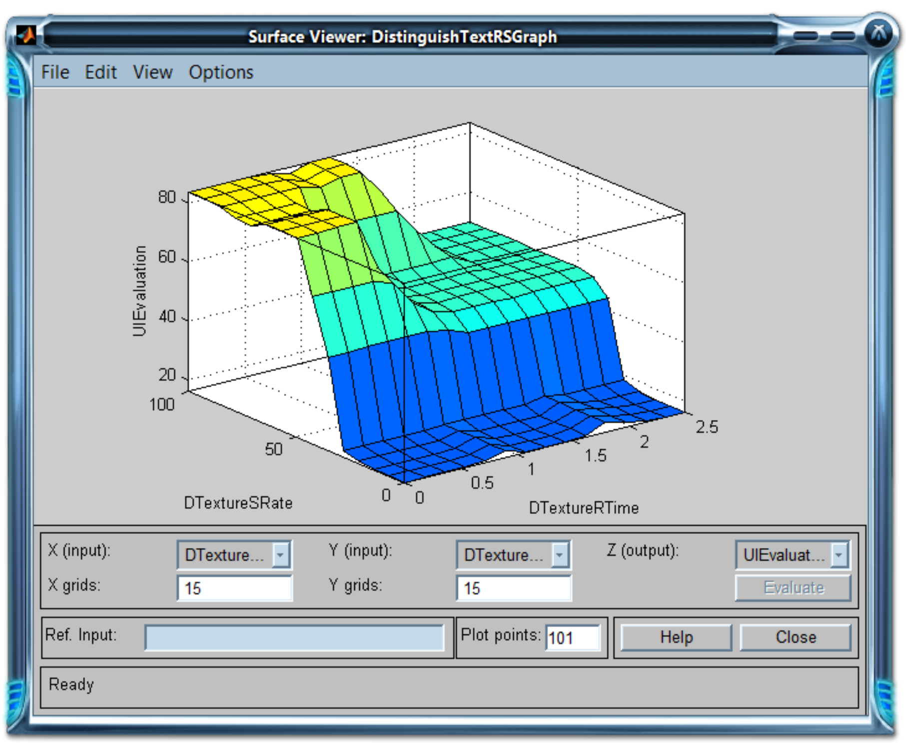

Fig. 6.10 QOE-2 Surface Viewer

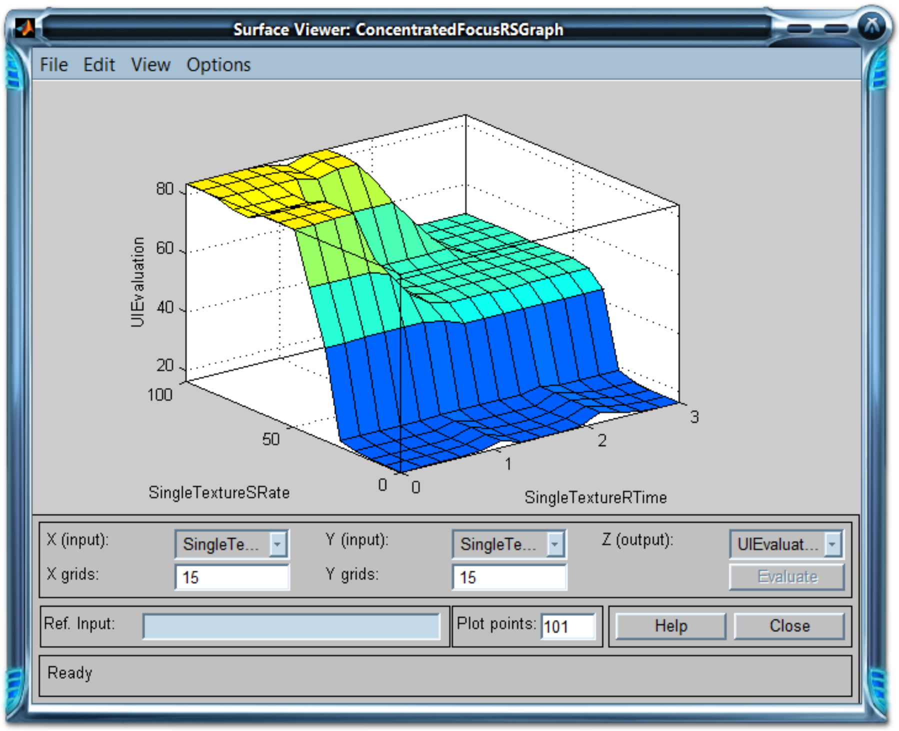

Fig. 6.11 QOE-3 Surface Viewer

It can be said that all QOEs have a similar nature of behaviour in regards to their effectiveness. A very minor difference can be noticed based on the change of the ranges, however if the success rate and task completion time fell between the average ratio and tends to be towards "excellent", the system drastically improves overall UI Effectiveness. This system only exhibited poor UI Effectiveness when success rate dropped along with the usability time.

6.2 Hardware Prototype User Interface Effectiveness

To evaluate the UI effectiveness of the hardware prototype, likewise software prototype UI effectiveness, the data from the previous test results was used.

For the QOE of this prototype, there were two inputs and one output. Inputs were classified using the same membership functions; Excellent, average and poor. Output was also analyzed using the membership functions, which sorted out the values on a classification matrix of excellent, average and poor.

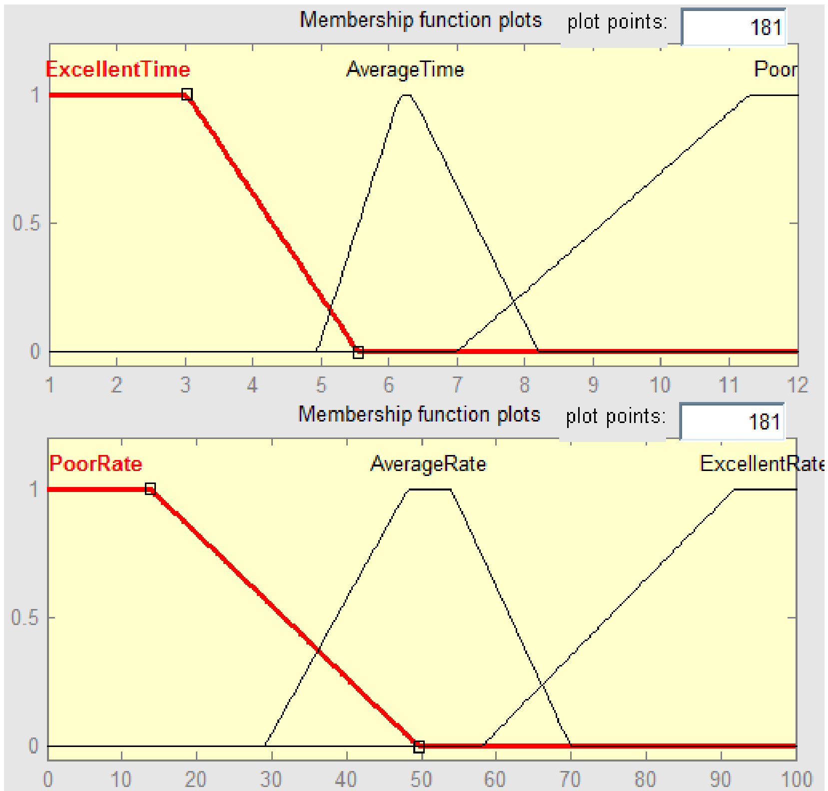

Fig. 6.12 Membership function for QOE Hardware Prototype

The values for first input function (Task completion time) ranged between 1-12, as the time it took the beginner, the intermediate and the advanced subjects lay within this range. The second inputs ranged from 0-100 to demonstrate the success rate of subjects.

For the output, the same membership function was used, which was previously discussed in regards to Fig.6.4. By using the same membership function, both surfaces could easily be compared, evaluated and analyzed in regards to and their behaviour regardless of the different mediums they encompassed.

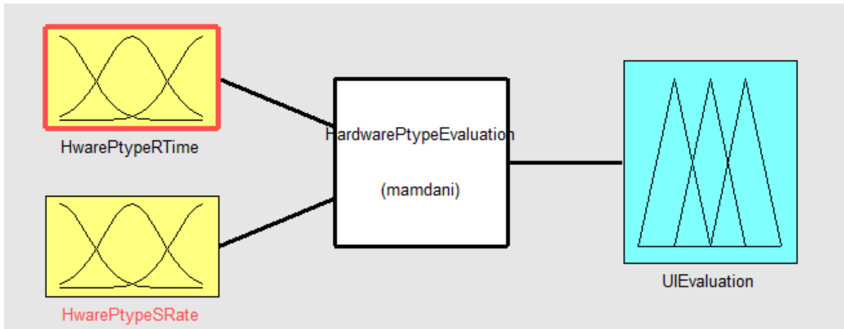

Fig. 6.13 FIS for hardware Prototype using Mamdani

The rules were selected from the same matrix as presented in Table 6.1. The hardware prototype included only one FIS since all three of the tasks were similar in nature, whereas the three tasks in the software prototype were different and required separate FIS.

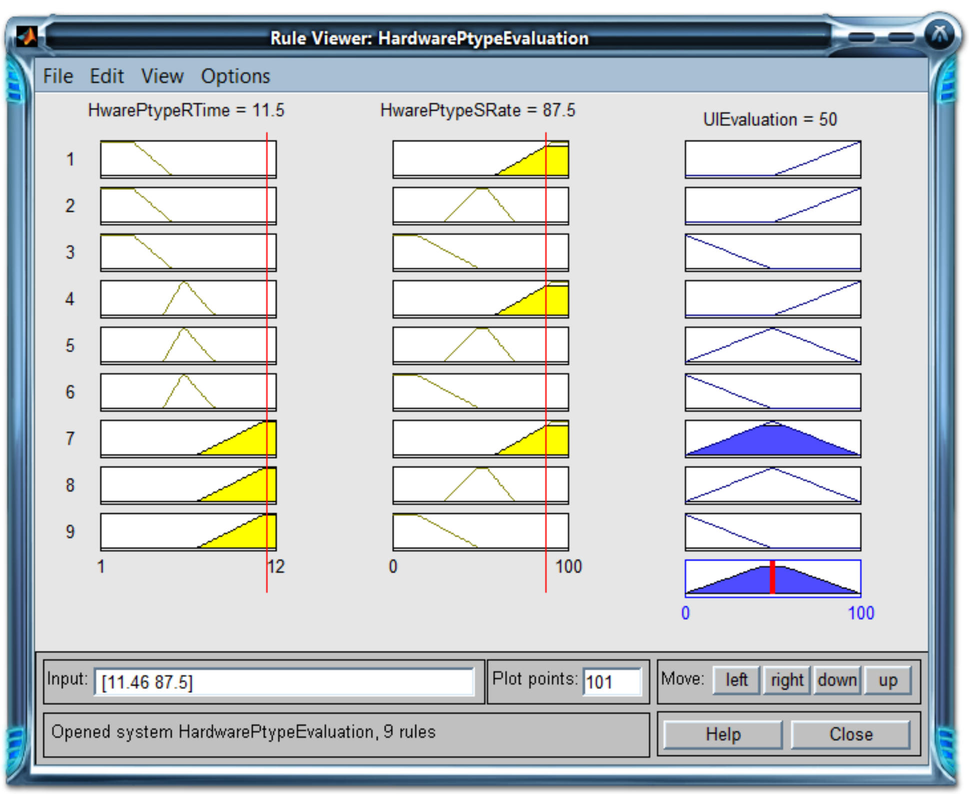

Fig. 6.14 Rule Viewer for Prototype QOE

The visual testing method was the same as the one used for generating the surface. The hardware system was tested based on different values of task completion time and success rate and the behaviour on how it affects the User Interface effectiveness was recorded. If the data was manipulated in such a way that the success rate was close to 100% and the task competition time was close to 1 second, than the FIS calculated the UI Effectiveness to be 93.6

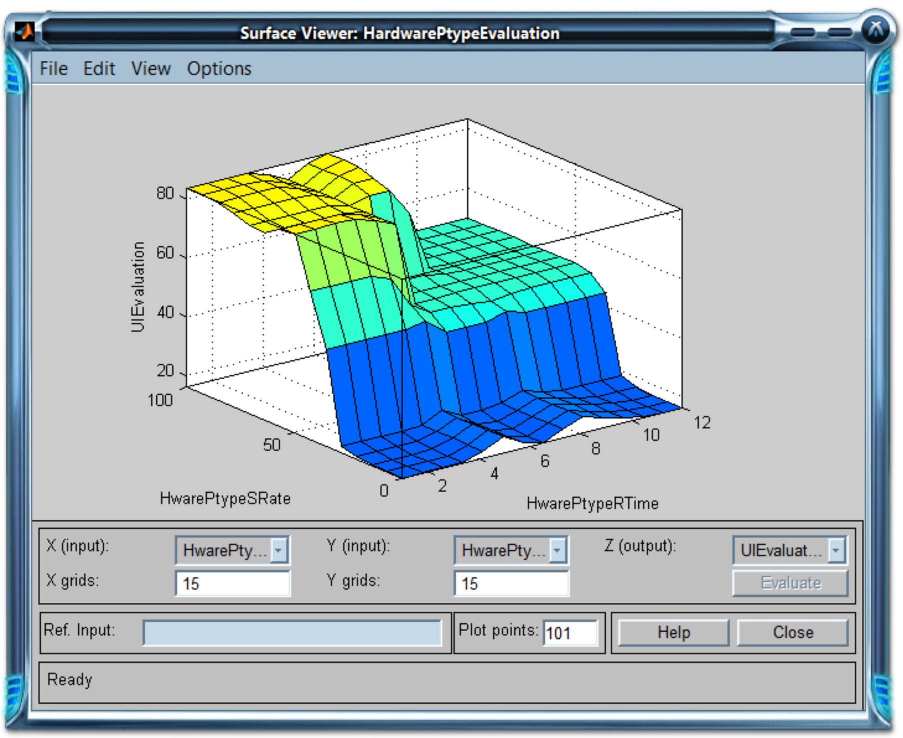

Fig. 6.15 QOE Surface Viewer for Prototype

By comparing Fig 6.15 to Fig. 6.9, 6.10, 6.11, it can be said that although both these platforms are different in nature based on their different interaction scheme, functionality and medium, however both systems comes up very close in terms of performance matrices. It can be noted the surface values of software prototype is similar in nature as compared to the hardware prototype except the grid values. Furthermore, overall UI Effectiveness turns out to be very close, except for a few minor differences. Hence it's inferred that both these system exhibits the same nature of behaviour, nature of haptics and UI effectiveness. It can be concluded that Quality of Experience can be improved drastically if a subject is exposed to more training and daily use.

Chapter 7

Conclusion of Thesis

This research demonstrates the use of haptics for automotive vehicle use. A study was first conducted to evaluate the effectiveness of haptics. By the help of Volunteer test subjects, certain tests were conducted in the virtual simulation environment. Results were evaluated thoroughly to study user's preferences, learning behaviour and the distinguishing nature of haptics. Based on the evaluation study, a prototype model was developed which uses haptics for the user interface. This prototype was further tested by subject testing. Volunteer test subjects helped to evaluate success rate, response time, usability time, user learning curve, non-distractive nature of haptics. Furthermore it was tested to be as practical as the virtual environment through fuzzy logic evaluation. As per the results, both systems exhibit the same Quality of Experience and User Interface Effectiveness which was carefully analyzed by the use of fuzzy logic.

The outcomes of this thesis are as follows:

1. This study proposes a haptic based user interface for safe driving practices so that the focus of the driver is not shared by other electronic devices operating in the vehicle while driving.
2. This design does not rely on visual gadgets. However it imposes a design functionality which can only be felt using the same interaction interface by means of a haptic feedback.
3. This system is capable of working with multiple devices at a time and enforces an "eyes on the road" philosophy while driving.

4. This system can be enhanced to control the vehicle's internal mechanical configurations and as it currently works with the critical warning systems i.e. proximity sensing system.
5. This work illustrates a true "hands on the steering wheel" philosophy
6. The proposed system is designed in such a way that it can work with any sort of automatic vehicle

7.1 Future Work

As of now, this system is capable of working with limited devices due to the limitations of vibrating patterns. To introduce the haptic control of more devices, another form of the haptic button is under research. This button is capable of projecting different shapes based on the selected device. As you can see in Fig. 9.1 there are 16 individual knobs forming a matrix.

Certain different fixed or fluctuating patterns can be generated. With this kind of technology, more devices can be integrated as it will provide a chance for increased feedback options to the user based on textures rather than just vibrations

The goal for the fabrication of this new haptic button is that using one single button; inputs can be entered and at the same time, outputs can be felt by the fluctuating/fixed pattern. Due to the metallic nature of the pins it is suggested that touch sensors should be connected to each pin individually or collectively. This new button can be connected to the same control unit used in this research as it was carefully designed keeping in mind the backward compatibility. Tiny solenoids have been used to raise the pins to reduce the overall size of this new button. A total of sixteen small sized solenoids have been used to form different relatively rich patterns as compared to the last haptic buttons.

For the test purposes this model is fabricated which seems quite big in size. For the final design careful consideration and research is required to minimize size and weight as much as possible. Due to the touch nature, solenoids have to be strong enough to withhold the pressure exerted by the finger while feeling the pattern [12]. This is one major concern for which extensive research needs to be done as it will leverage the feeling of the texture [28, 29]. This design is still under research and requires extensive testing before it can be used as a new haptic medium.

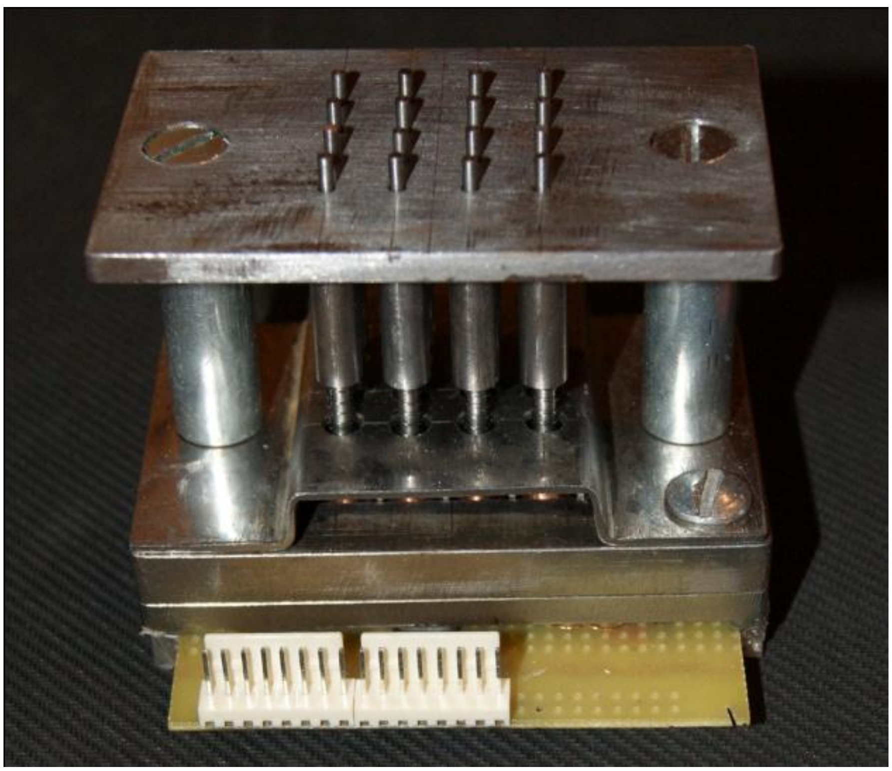

Fig. 7.1 New Haptic Button

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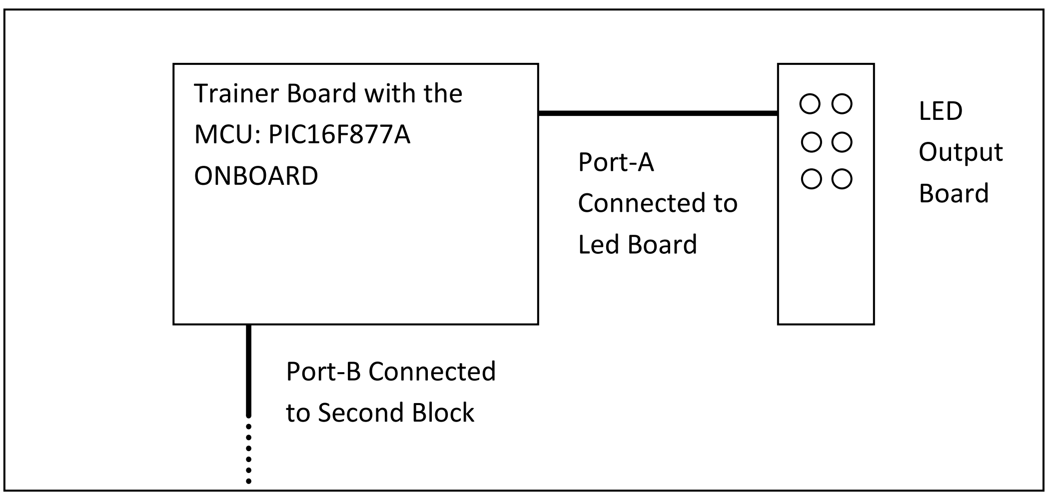
Appendix A: Design Details & Input/output Scheme

Design Details:

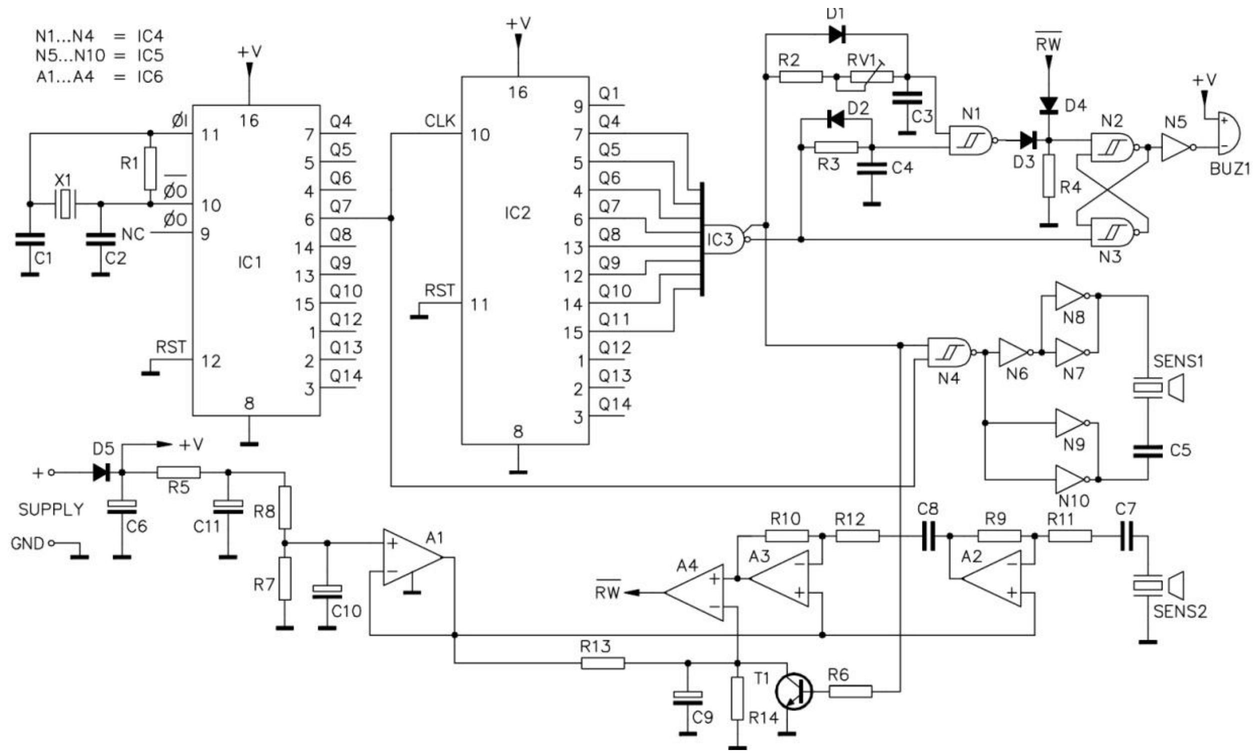
This whole hardware prototype can be operated on a +12 Volts DC Supply. It draws up to 1.2A at the peak where all the devices are active. On a normal basis, this unit takes about 450~500mA. The hardware prototype consists of three main blocks. The first block includes the Embedded Controller and Output LEDs. For this prototype, the PIC Microchip HP268ST Trainer Board has been used. Below is a Block Diagram of the trainer board and how it is connected to the Output LEDs and Second Block.



Block Diagram of Trainer Board and Output Unit (First Block)

Port-A has 8 wires and 1 Ground Wire. Out of these eight wires, LSB 6 Wires have been used for the LED output board. 2 MSB wires are not used. For the Port B, 7 LSB Wires are used and the 1 MSB Wire is unused. This unit can be reprogrammed by the help of supplied USB cord. One power unit is required for this unit as individual power supplies have been used.

The Second Block consists of proximity sensing system and touch controllers. The proximity sensing unit was bought as a package from a local electronic retail store. This unit is fabricated by Velleman Inc[13] and the details about this particular circuit can be found from their website. Detailed circuit drawings for these circuits are shown below.



Circuit Diagram: Proximity Sensing System

Second circuit in the same circuit block belongs to the Touch controllers. This circuit was also bought from a Retail Circuit and was customized based on our custom needs. This circuit is called as Smart Kit 1005[14]. The original design was built to work as a Toggle switch as the main

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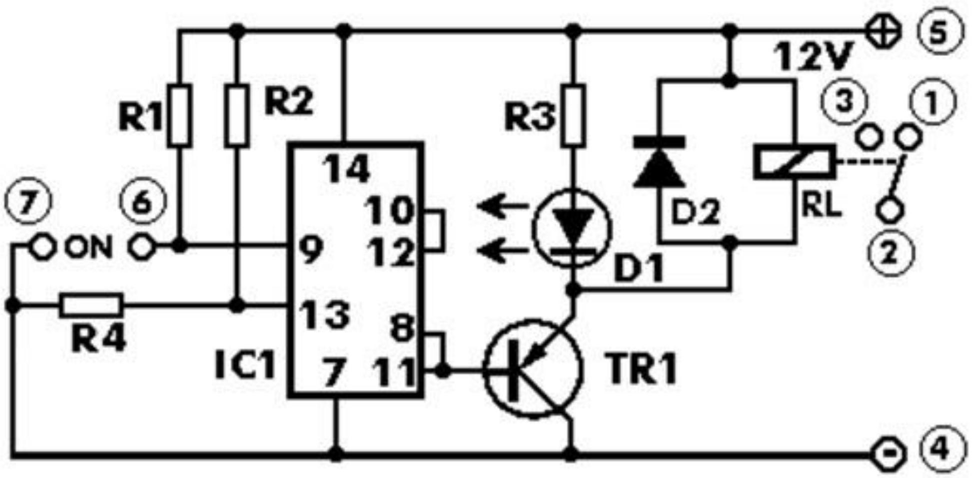
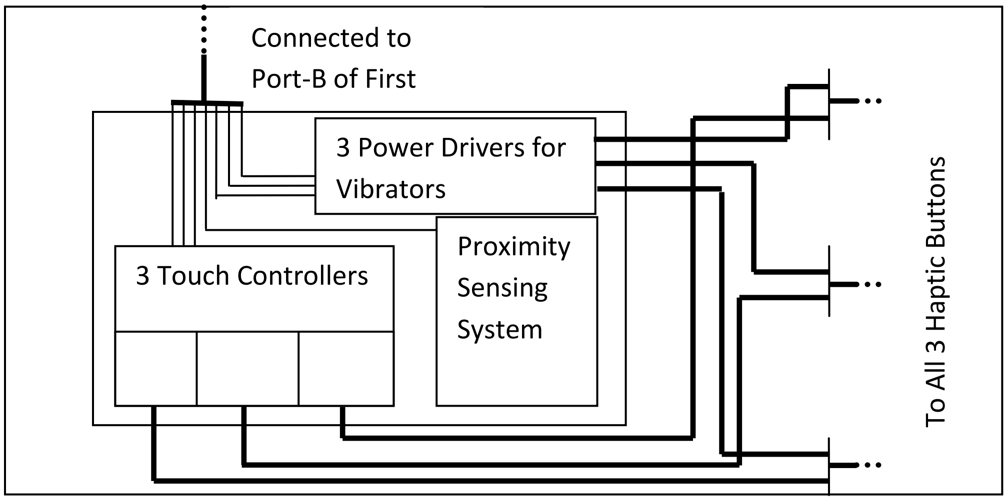
[14] Touch Controller, Smart Kit 1005: http://english.cxem.net/guard/guard2.php

flip flop 'Sets' and 'Resets' based on the minor resistance change provided by the finger. A Resistance equalling the human body was introduced for the Set region that changes the operation of this circuit from a toggle switch to a permanent touch non-latching button. The value for this introduced Resistance was 2.2 KΩ which is labelled as R4. Rest of the values can be found from the Reference website for this circuit.



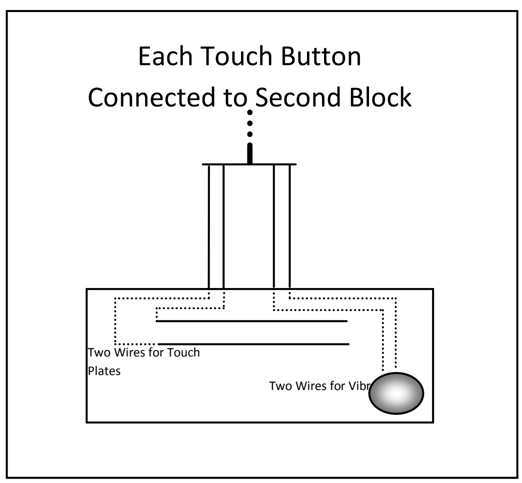
Touch Controller

There are three haptic buttons, for each button there is one touch controller. We used 3 touch controllers and 1 proximity sensing system. There are three power driver circuits for the vibrators installed in all 3 haptic buttons. The following block diagram represents the connection of these circuits with each other and the rest of the circuitry.



Block Diagram of Proximity & Touch Controllers (Second Block)

The third block consists of haptic buttons and the following diagram demonstrates their wiring configuration.



Wiring Details of a Haptic Button (Third Block)

Each haptic button is connected to the second block. All the haptic buttons have the same wiring configuration and thus can be interchanged. Each takes a set of four wires. The first two wires are designated for the touch plates used for touch controllers while the last two wires are connected to the supplied vibrator and they deliver power to vibrator.

Out of four wires, two wires are input wires and two of them are output wires.

Input Scheme:

This system has the ability to be controlled by touch. Single tap, multi tap, long press, or short press can be adopted as a method of interaction with the system. We tried to adapt the simplest input scheme to keep things less complex. There are three buttons which can be used to select a specified device. The following table represents how binary coding has been used to differentiate between different devices. This system starts in demo mode and to take it out of the demo mode, the user can press and hold all three keys. Once out of the demo mode, the following chart represents possible inputs.

1st Key	2nd Key	3rd Key	Device Selected
0	0	0	Not Used
0	0	1	1st Device
0	1	0	2nd Device
0	1	1	3rd Device
1	0	0	Not Used
1	0	1	Not Used
1	1	0	Not Used
1	1	1	Demo Mode On/Off

Binary Input Schemes

The Not Used states in this system could be used to handle more devices. However for testing purposes, only three devices have been integrated with the system. Once a device is selected, the user can use the 2nd and 3rd key to change the state of the device.

For the control, the 2nd and 3rd keys are programmed in a way that they work with latched or non latched devices. These keys can control simple toggle switches i.e. the power button of the GPS or they can be used to control linear devices such as the sun roof. As long as the user keeps their finger on the key, they keep sending the command signal to the prior selected device.

After the selection of a device, the first key is reserved to reset the system, or to grab the feedback for the selected device. Once pressed, this key will give you unique feedback for the selected device. If the button is double tapped; it will reset the system to the initial state, where another device can be selected again.

Feedback Scheme:

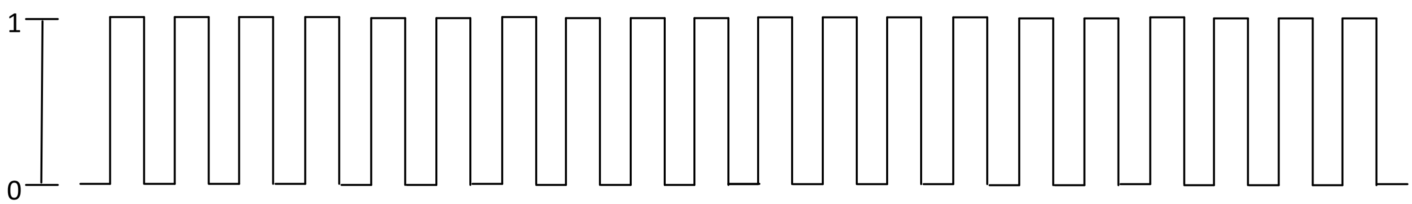
To help the user identify a particular device, a unique haptic feedback has been generated for each selected device. Whenever a device is selected, this feedback is fed out to the vibrator installed in the haptic button. As the system does not time out, the user can recall this feedback by single tapping the 1st key as long as he/she wants.

A differentiable feedback is provided when the user changes the state of a device while using the 2nd and 3rd key. This feedback can be felt at the time of the input (From the time when the finger will touch the sensors till the lift up).

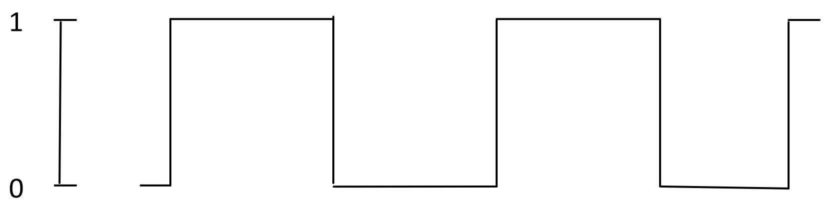
A consistent vibration is generated which overrides the system functionality whenever anything is detected near the proximity sensing system. The nature of the proximity sensing system is quite important as it measures the adjacent distance to the next running vehicle. Based on that, it triggers a hard stop on the system activity and alerts the user at maximum frequency till the vehicle has been moved to a safe distance. Once it is back to a safe distance, the system will resume normal functionality and the user can interact with all the connected devices again.

Vibration Patterns:

Each vibrator is controlled by a control signal generated by the microcontroller which initates the 20 Hz vibrator to vibrate as per the control signals. The Vibrating pattern of the vibrator is shown and are followed by the control signals:

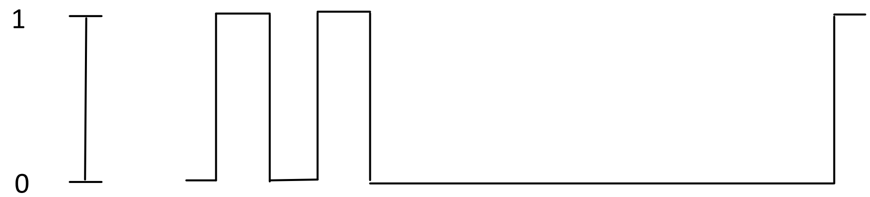


Vibration Pattern over 1 Second (20 Hz)



1st Control Signal (Each Second)

2^{nd} Control Signal (Each Second)



3^{rd} Control Signal (Each Second)

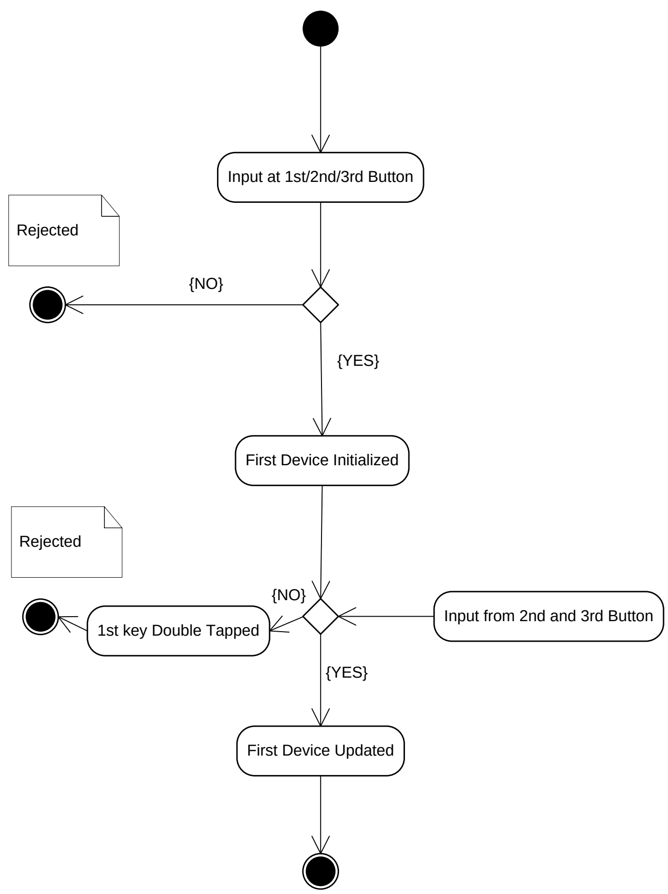
4^{th} Control Signal (Each Second)

It is to be noted that vibrator operated at a rate of 20 Hz, hence it is quite a challenge to generate different patterns that are easily recognized by a test subject. Any pattern less than 5 Hz can only be felt by an expert user. User can only differentiate on and off states of a vibrator regardless. When it comes to comparing each control signal there should be enough idle state room in the states to be judged.

Appendix B: UML Design Files

Activity Diagram:

Three buttons are designated specially for the input allowing the user to switch between three different devices. For all three devices, the activity diagram is shown below:

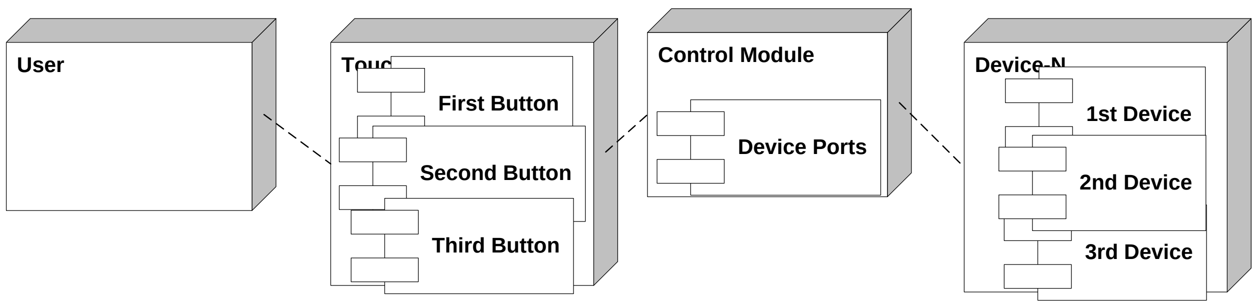


Activity Diagram for selected Device

The user can input at first/second and third buttons as only three devices are defined. Only the selected input code will be accepted and the rest will be rejected. Once the code has been accepted, the selected device (out of first, second or third) will be initialized by outputting the specified feedback pattern. At this stage, the user can change the state of the selected device by using the 2nd and 3rd keys or the user can also opt out by double tapping the first key.

Physical View:

The physical view defines the physical objects involved in the system. In this case we have four physical objects interacting with our system which are as follows:



Physical View

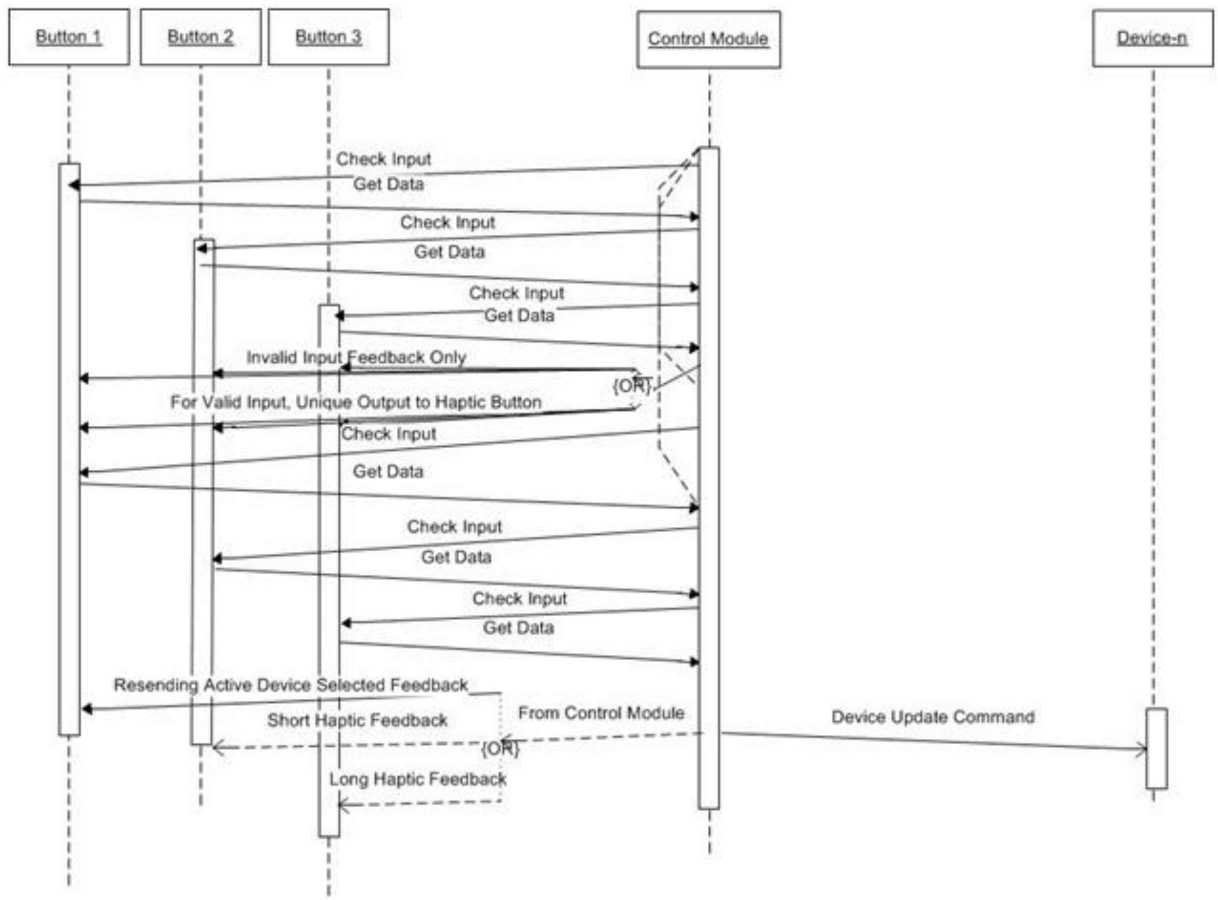
The user will be the first physical body interacting with the system. The second physical object will be our three touch buttons. The third object involves our control module which will handle all the possible outcomes and will compute all inputs/outputs. The last physical object of the system is the actual device which will be updated using this system.

Sequence Diagram:

Sequence diagram represents the flow of control with respect to time. The system will be in the waiting state at start. At this point, it will be keep looping to check any input values at the three buttons. Once a change has been found it will generate a haptic code based on the validity of the input. If the input code is valid it will further check the input values, otherwise it will revert back to the initial stage.

For the valid input code, it will check the state of all three buttons one more time. If the first key is tapped twice, it will revert back to the initial stage.

If the first key is tapped once, or the 2nd and 3rd keys are tapped, it will generate the appropriate haptic code and will update the device based on the encoding scheme.

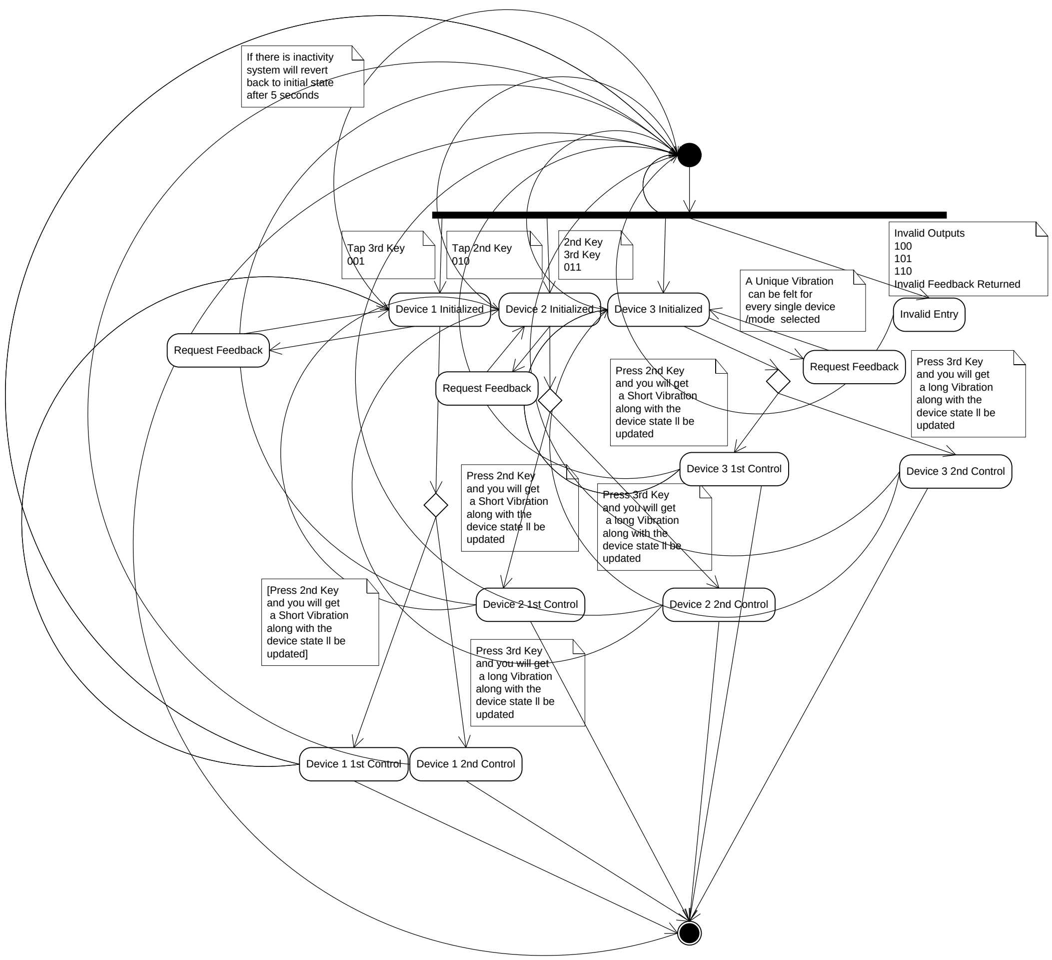


Sequence Diagram

State Machine:

The state machine diagram defines all possible states of the system. The user can select a certain device by using a binary input scheme. Once selected, the user can request feedback one more time by single tapping the 1st key.

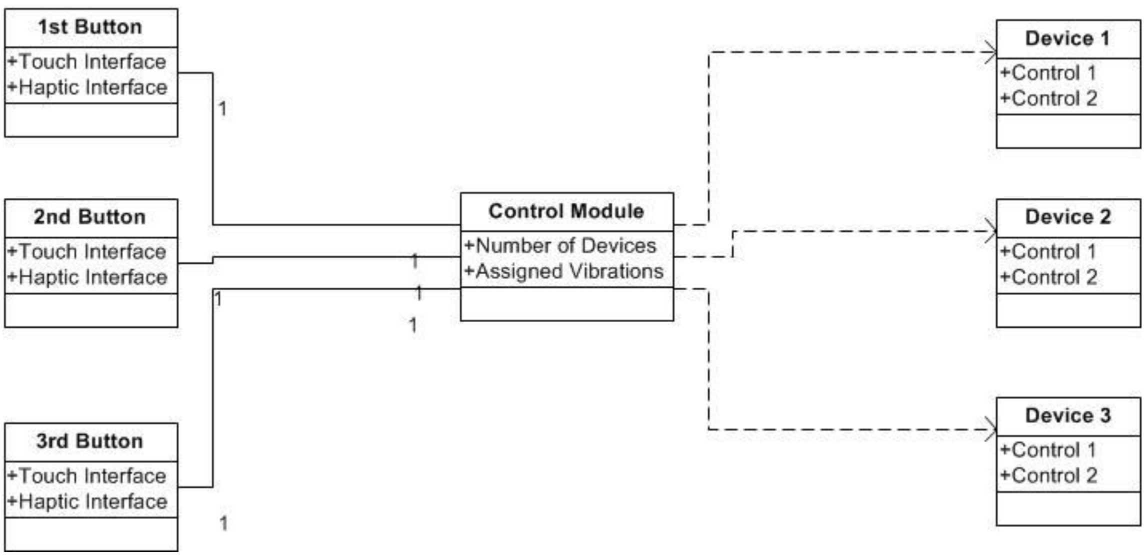
The user can also update the state of the selected device by using the 2nd and 3rd key. At this time, a unique haptic feedback will be provided to ensure completion of the task. The user can go back to the initial stage at any time by double tapping the 1st key



State Machine

Static View:

This diagram illustrates relations between the keys/control modules and the devices. The possible hierarchy defines a "one to one" and a "one to many" relationship between these entities. For each specified input, only one device is specified. For each specified device there is only one vibration pattern. For each selected device there are two controls (This defines a one to many relationships).



Static View

Appendix C: Software Simulation CPP Code

```
//Part A

/*******************************************************************************
 Checks the state of the gimbal button and gets the position of the device.
*******************************************************************************/
HDCallbackCode HDCALLBACK updateDeviceCallback(void *pUserData)
{
   int nButtons = 0;

   hdBeginFrame(hdGetCurrentDevice());

   /* Retrieve the current button(s). */
   hdGetIntegerv(HD_CURRENT_BUTTONS, &nButtons);

   /* In order to get the specific button 1 state, we use a bitmask to
     test for the HD_DEVICE_BUTTON_1 bit. */
   gServoDeviceData.m_buttonState =
      (nButtons & HD_DEVICE_BUTTON_1) ? TRUE : FALSE;

   /* Get the current location of the device (HD_GET_CURRENT_POSITION)
     We declare a vector of three doubles since hdGetDoublev returns
     the information in a vector of size 3. */
   hdGetDoublev(HD_CURRENT_POSITION, gServoDeviceData.m_devicePosition);

   /* Copy the position into our device_data tructure. */
   hdEndFrame(hdGetCurrentDevice());

   return HD_CALLBACK_CONTINUE;
}
/*******************************************************************************
 Checks the state of the gimbal button and gets the position of the device.
*******************************************************************************/


//Part B
/*******************************************************************************
 Creates the objects that can be seen, felt and dragged around.
*******************************************************************************/
void createDraggableObjects()
{
   // Create a bunch of shapes and add them to the draggable object vector.
```

```
DraggableObject dro_d;

        dro_d.hap_stiffness = 1.0;
    dro_d.hap_damping = 0.0;
    dro_d.hap_static_friction = 0.0908;
    dro_d.hap_dynamic_friction = 0.03774;

    // former Dodecahedron.
    dro_d.shapeId = hlGenShapes(1);
    dro_d.transform = hduMatrix::createTranslation(-2.2,-1.5,0);
    dro_d.displayList = glGenLists(1);
    glNewList(dro_d.displayList, GL_COMPILE);

        glEnable(GL_TEXTURE_2D);
        glBindTexture(GL_TEXTURE_2D, _textureId);
        glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
        glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);

        glBegin(GL_QUADS);

        //Front face
        glNormal3f(0.0, 0.0f, 1.0f);
        glTexCoord2f(0.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, -BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(1.0f, 0.0f);
        glVertex3f(BOX_SIZE / 2, -BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(1.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(0.0f, 1.0f);
        glVertex3f(-BOX_SIZE / 2, BOX_SIZE / 2, BOX_SIZE / 2);

        //Top face
        glNormal3f(0.0, 1.0f, 0.0f);
        glTexCoord2f(0.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(1.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(1.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(0.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, BOX_SIZE / 2, -BOX_SIZE / 2);

        //Bottom face
        glNormal3f(0.0, -1.0f, 0.0f);
        glTexCoord2f(0.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, -BOX_SIZE / 2, -BOX_SIZE / 2);
```

```
        glTexCoord2f(1.0f, 0.0f);
        glVertex3f(BOX_SIZE / 2, -BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(1.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, -BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(0.0f, 1.0f);
        glVertex3f(-BOX_SIZE / 2, -BOX_SIZE / 2, BOX_SIZE / 2);

        //Left face
        glNormal3f(-1.0, 0.0f, 0.0f);
        glTexCoord2f(0.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, -BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(1.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, -BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(1.0f, 1.0f);
        glVertex3f(-BOX_SIZE / 2, BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(0.0f, 1.0f);
        glVertex3f(-BOX_SIZE / 2, BOX_SIZE / 2, -BOX_SIZE / 2);

        //Right face
        glNormal3f(1.0, 0.0f, 0.0f);
        glTexCoord2f(0.0f, 0.0f);
        glVertex3f(BOX_SIZE / 2, -BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(1.0f, 0.0f);
        glVertex3f(BOX_SIZE / 2, BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(1.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, BOX_SIZE / 2, BOX_SIZE / 2);
        glTexCoord2f(0.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, -BOX_SIZE / 2, BOX_SIZE / 2);

        //Back face
        glNormal3f(0.0, 0.0f, -1.0f);
        glTexCoord2f(0.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, -BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(1.0f, 0.0f);
        glVertex3f(-BOX_SIZE / 2, BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(1.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, BOX_SIZE / 2, -BOX_SIZE / 2);
        glTexCoord2f(0.0f, 1.0f);
        glVertex3f(BOX_SIZE / 2, -BOX_SIZE / 2, -BOX_SIZE / 2);

        glEnd();

    glEndList();

    draggableObjects.push_back(dro_d);
```

```
        glDisable(GL_TEXTURE_2D);
}

//Part C
/*******************************************************************************
 Draws the objects that can be seen, felt and dragged around.
*******************************************************************************/
void drawDraggableObjects()
{
  hlTouchModel(HL_CONTACT);
  hlTouchableFace(HL_FRONT);

  for (int i = 0; i < draggableObjects.size()-3; ++i)
  {
    const DraggableObject& obj = draggableObjects[i];

    // Position and orient the object.
    glPushMatrix();

    glMultMatrixd(obj.transform);

                //glCallList(draggableObjects[0].displayList);

    // Draw the object graphically.

                  glCallList(obj.displayList);

    // Draw the object haptically (but not if it is being dragged).
    if (i != gCurrentDragObj)
    {
      hlBeginShape(HL_SHAPE_FEEDBACK_BUFFER, obj.shapeId);

      hlMaterialf(HL_FRONT_AND_BACK, HL_STIFFNESS, obj.hap_stiffness);
      hlMaterialf(HL_FRONT, HL_DAMPING, obj.hap_damping);
      hlMaterialf(HL_FRONT, HL_STATIC_FRICTION, obj.hap_static_friction);
      hlMaterialf(HL_FRONT, HL_DYNAMIC_FRICTION, obj.hap_dynamic_friction);

      glCallList(obj.displayList);


      hlEndShape();
    }

    glPopMatrix();
  }
```

```
//Part D
          ///////////Stage 1
          if(button==1)
          {

stage1=true;
const DraggableObject& obj = draggableObjects[4];

    glPushMatrix();

      glMultMatrixd(obj.transform);

                    glCallList(obj.displayList);

                    //haptics

                    if (i != gCurrentDragObj)
      {
          hlBeginShape(HL_SHAPE_FEEDBACK_BUFFER, obj.shapeId);
          hlMaterialf(HL_FRONT_AND_BACK, HL_STIFFNESS, obj.hap_stiffness);
          hlMaterialf(HL_FRONT, HL_DAMPING, obj.hap_damping);
          hlMaterialf(HL_FRONT, HL_STATIC_FRICTION, obj.hap_static_friction);
          hlMaterialf(HL_FRONT, HL_DYNAMIC_FRICTION, obj.hap_dynamic_friction);

          glCallList(obj.displayList);

          hlEndShape();
      }
      glPopMatrix();
          }

//Part E
/////////////////////////////////////stage 2

          if(button==1 && stage1==true && stage1release == true && stage2==true)
          {
                   //glutSolidDodecahedron();
const DraggableObject& obj = draggableObjects[5];

    glPushMatrix();
      glMultMatrixd(obj.transform);
                    glCallList(obj.displayList);
                    //haptics
                    if (i != gCurrentDragObj)
      {
```

```
        hlBeginShape(HL_SHAPE_FEEDBACK_BUFFER, obj.shapeId);
        hlMaterialf(HL_FRONT_AND_BACK, HL_STIFFNESS, obj.hap_stiffness);
        hlMaterialf(HL_FRONT, HL_DAMPING, obj.hap_damping);
        hlMaterialf(HL_FRONT, HL_STATIC_FRICTION, obj.hap_static_friction);
        hlMaterialf(HL_FRONT, HL_DYNAMIC_FRICTION, obj.hap_dynamic_friction);

        glCallList(obj.displayList);
        hlEndShape();
      }
      glPopMatrix();
        }

//Part F
///////////////////////////stage 3///////////
        if(button==1 && stage2==true && stage2release == true && stage3==true)
        {
        //glutSolidDodecahedron();
const DraggableObject& obj = draggableObjects[6];
    glPushMatrix();
      glMultMatrixd(obj.transform);
                glCallList(obj.displayList);
                //haptics
                if (i != gCurrentDragObj)
      {
        hlBeginShape(HL_SHAPE_FEEDBACK_BUFFER, obj.shapeId);
        hlMaterialf(HL_FRONT_AND_BACK, HL_STIFFNESS, obj.hap_stiffness);
        hlMaterialf(HL_FRONT, HL_DAMPING, obj.hap_damping);
        hlMaterialf(HL_FRONT, HL_STATIC_FRICTION, obj.hap_static_friction);
        hlMaterialf(HL_FRONT, HL_DYNAMIC_FRICTION, obj.hap_dynamic_friction);

        glCallList(obj.displayList);
        hlEndShape();
      }
      glPopMatrix();
        }
}

//Part G
// "Drag" the current drag object, if one is current.
      if (gCurrentDragObj != -1)
      {
                        if(currentData.m_devicePosition[0]<-50 &&
currentData.m_devicePosition[0]>-100 && currentData.m_devicePosition[1]<-3 &&
currentData.m_devicePosition[1]>-56 && currentData.m_devicePosition[2]>-18 &&
currentData.m_devicePosition[2]<33)
                        {
```

```
                                    button = 1;
                                    //stage_position=stage_position+1;
                                    //fprintf(stdout, "Current position: (%g, %g)\n",
        //&button,
        //stage_position);

                                            // load a media file
//soundt=mediaNum;

                    if(sound_on==false)
                    {
                            if(soundloaded==false)
                            {
                                    unsigned int mediaNum = MediaLoad("3.wav");
                                    unsigned int mediaNum2 = MediaLoad("RL.wav");
                            soundloaded=true;
                                    soundt=mediaNum;
                                    soundt2=mediaNum2;
                            }
            MediaPlay(soundt);
            sound_on=true;
                    }
                            }
                            /////////////////////////////Sound ON
                            if(currentData.m_devicePosition[0]<-25 &&
currentData.m_devicePosition[0]>-50 && currentData.m_devicePosition[1]<87 &&
currentData.m_devicePosition[1]>64/* && currentData.m_devicePosition[2]>-18 &&
currentData.m_devicePosition[2]<33*/)

                            {
                                    button = 4;
                                    //stage_position=stage_position+1;
                                    //fprintf(stdout, "Current position: (%g, %g)\n",
        //&button,
        //stage_position);
                            }
                            if(button==1 && stage1 ==true &&stage1release==true &&
currentData.m_devicePosition[0]<-50 && currentData.m_devicePosition[0]>-100 &&
currentData.m_devicePosition[1]<-3 && currentData.m_devicePosition[1]>-56 &&
currentData.m_devicePosition[2]>-18 && currentData.m_devicePosition[2]<33)
                            {
                                    stage2=true;
                                    //glutSolidDodecahedron();
                            }
                            if(button==4)
                            {
```

```
					stage = 0;
					sound_on=false;
stage_position=0;
button=0;
stage1=false;
stage2=false;
stage3=false;
stage1release=false;
stage2release=false;
stage3release=false;
					//glutSolidDodecahedron();
				}
				if(button==1 && stage2 ==true &&stage2release==true &&
currentData.m_devicePosition[0]<-50 && currentData.m_devicePosition[0]>-100 &&
currentData.m_devicePosition[1]<-3 && currentData.m_devicePosition[1]>-56 &&
currentData.m_devicePosition[2]>-18 && currentData.m_devicePosition[2]<33)
				{
					 stage3=true;
					//glutSolidDodecahedron();
					MediaPlay(soundt2);
				}
				//needs to happen when pressed not on state check
				if(button==2 && stage2 ==true && stage3 == false)
				{
					//glutSolidDodecahedron();
//unsigned int mediaNum = MediaLoad("3.wav");
					//volume controls
					volume=volume+10;
					MediaSetVolume(soundt,volume);
				}
				if(button==3 && stage2 ==true && stage3 == false)
				{
//unsigned int mediaNum = MediaLoad("3.wav");
					//volume controls
					volume=volume-10;
					MediaSetVolume(soundt,volume);
				}

				if(button==1 && stage3 ==true &&stage3release==true &&
currentData.m_devicePosition[0]<-50 && currentData.m_devicePosition[0]>-100 &&
currentData.m_devicePosition[1]<-3 && currentData.m_devicePosition[1]>-56 &&
currentData.m_devicePosition[2]>-18 && currentData.m_devicePosition[2]<33)
				{
					// stageresetready=true;
					//glutSolidDodecahedron();
				}
```

```
			if(currentData.m_devicePosition[0]>-40 &&
currentData.m_devicePosition[0]<7  && currentData.m_devicePosition[1]<-3 &&
currentData.m_devicePosition[1]>-56 && currentData.m_devicePosition[2]>-18 &&
currentData.m_devicePosition[2]<33)
			{
				button = 2;
			}
			if(currentData.m_devicePosition[0]>18 &&
currentData.m_devicePosition[0]<65 && currentData.m_devicePosition[1]<-3 &&
currentData.m_devicePosition[1]>-56 && currentData.m_devicePosition[2]>-18 &&
currentData.m_devicePosition[2]<33)
			{
				button = 3;
				//glutSolidCube(0.5);
}

//Part H
	//	stage_position=2;
   //  glutDisplayFunc(glutDisplay);

if (button==1 &&(currentData.m_devicePosition[0]>-45 || currentData.m_devicePosition[0]<-
105 || currentData.m_devicePosition[1]>2 || currentData.m_devicePosition[1]<-61 ||
currentData.m_devicePosition[2]<-23
	|| currentData.m_devicePosition[2]>38))
{
//glutSolidDodecahedron();
stage1release=true;
}

if (button==1 && stage2==true && (currentData.m_devicePosition[0]>-45 ||
currentData.m_devicePosition[0]<-105 || currentData.m_devicePosition[1]>2 ||
currentData.m_devicePosition[1]<-61 || currentData.m_devicePosition[2]<-23
	|| currentData.m_devicePosition[2]>38))
{
//glutSolidDodecahedron();
stage2release=true;
}
if (button==1 && stage3==true && (currentData.m_devicePosition[0]>-45 ||
currentData.m_devicePosition[0]<-105 || currentData.m_devicePosition[1]>2 ||
currentData.m_devicePosition[1]<-61 || currentData.m_devicePosition[2]<-23
	|| currentData.m_devicePosition[2]>38))
{
//glutSolidDodecahedron();
stage3release=true;
}
```

/*

Part A

The phantom haptics device is used as input in this code. The position of the phantom device is taken and implemented in a 3D environment.

Part B

The haptic feedback code can be found here. The objects are created with their respective haptic feedback properties. The object's stiffness, damping, static friction and dynamic friction properties are determined here. A numerical value is assigned. An image of the particular object is then used as to represent its texture and is bound to all sides of the object. OpenGL code creates the sides and binds the texture to the object.

Part C

These objects that were created get drawn on to the screen in this section of code.

Part D

The stages of the state machine are implemented here. Depending on the state, the volume controls come online and the sound track can be changed.

Part E

Stage 2 of the state machine and the properties of this stage are coded in this section.

Part F

Code determining stage 3 of the machine is found here. The flags used to determine the situation of the state machine are set and checked everywhere and an example of that can be seen at the bottom of this section of code.

Part G

Stages and flags are checked here. Depending on the state of the machine the appropriate action is taken. From playing a track to changing the track and changing the volume is done in this code. The files are also loaded in this code. The co-ordinate location of the phantom device is also checked to determine which object is being pointed to.

Part H

This is an example of code where the position of the phantom device and the status of flags are checked to set other flags. This is done to determine what state the state machine is in.

*/

Appendix D: Embedded Control Unit C Code

```
//==========Initialization and Program Code=======
// Haptics in Cars Code Version-1 (Recoded after the chip was fried :(   )
// This code includes different vibration patterns to confrim the output
// Written by Fayez Asif, Email- fayezasif@gmail.com
// This code gives out 4 Different Feedbacks for the 3 Connected Devices 1 Error Feedback
// Demo Run Included
// To Get out of the Demo Run, Press any Key for 3 Seconds
// To Get Back to the Demo Run, Press All Three Keys for 1 Second in the Main Menu

#include <system.h>

int check_press();
void lvibra();
void svibra();

void main ()
{
   trisb.0 = 1;
            // set First 7 bits of PORTB for input
   trisb.1 = 1;
    trisb.2 = 1;
    trisb.3 = 0;
    trisb.4 = 0;
    trisb.5 = 0;
    trisb.6 = 1;
    trisb.7 = 0;
            // Set 8th bit of PORTB for Output
```

```
    trisa.0 = 0;
            // set First 7 bits of PORTB for input
   trisa.1 = 0;
    trisa.2 = 0;
    trisa.3 = 0;
    trisa.4 = 0;
    trisa.5 = 0;
    trisa.6 = 1;
    trisa.7 = 1;
            // Set First 6 bits of PORTA for output

   porta = 0x00 ;
            // Zero Garbage Values
   portb = 0x00 ;
            // Zero Garbage Values

    int i,j, setval=0,setval2=0,setval3=0,tvalue1=0,tvalue2=0;
            // Global Interger for Loop Declaration

//====================Demo Run=====================

while(portb==0)
{
    demo:
    //Light Testing
//======================
    portb = 0x80;
            // Testing Controls for Device 1
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    portb = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
```

```
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
    porta = 0x01;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    porta = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
//=======================
    porta = 0x02;
            // Testing Controls for Device 2
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    porta = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
    porta = 0x04;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    porta = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
//=======================
```

```
      porta = 0x08;
              // Testing Controls for Device 3
      for ( i=0 ; i < 30000 ; i= i + 1 ) ;
      porta = 0x00;
      for ( i=0 ; i < 30000 ; i= i + 1 ) ;
      if ( portb!= 0)
              // Key Interrupt from Demo Run
              {
              while(portb!=0)
                      {
                      }
              goto V2;
              }
      porta = 0x20;
      for ( i=0 ; i < 30000 ; i= i + 1 ) ;
      porta = 0x00;
      for ( i=0 ; i < 30000 ; i= i + 1 ) ;
//=======================

      // Haptic Testing

///=======================
      for (j = 0; j < 3; j= j + 1)
      // Test Vibration No 1
              {
              portb = 0x38;
              for ( i=0 ; i < 32000 ; i= i + 1 ) ;
              for ( i=0 ; i < 4000 ; i= i + 1 ) ;
              portb = 0x00;
              for ( i=0 ; i < 4000 ; i= i + 1 ) ;
              }
```

```
    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
//========================
    for (j = 0; j < 3; j= j + 1)
    // Test Vibration No 2
            {
            portb = 0x38;
            for ( i=0 ; i < 16000 ; i= i + 1 ) ;
            portb = 0x00;
            for ( i=0 ; i < 32000 ; i= i + 1 ) ;
            }
    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
//========================
    for (j = 0; j < 4; j= j + 1)
    // Test Vibration No 3
            {
```

```
            portb = 0x38;
            for ( i=0 ; i < 8000 ; i= i + 1 ) ;
            portb = 0x00;
            for ( i=0 ; i < 8000 ; i= i + 1 ) ;
            }
    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
//=======================
    for (j = 0; j < 3; j= j + 1)
    // Test Vibration No 4
            {
            portb = 0x38;
            for ( i=0 ; i < 3000 ; i= i + 1 ) ;
            portb = 0x00;
            for ( i=0 ; i < 32000 ; i= i + 1 ) ;
            }
    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
```

```
            }
//========================

    // Lights With Haptic Testing

//========Feedback========
    for (j = 0; j < 3; j= j + 1)
    // Test Vibration No 1
            {
            portb = 0x38;
            for ( i=0 ; i < 32000 ; i= i + 1 ) ;
            for ( i=0 ; i < 4000 ; i= i + 1 ) ;
            portb = 0x00;
            for ( i=0 ; i < 4000 ; i= i + 1 ) ;
            }
    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
//=========Lights=========
    portb = 0x80;
            // Testing Controls for Device 1
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    portb = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
```

```
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
    porta = 0x01;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    porta = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
//========Feedback========
    for (j = 0; j < 3; j= j + 1)
    // Test Vibration No 2
            {
            portb = 0x38;
            for ( i=0 ; i < 16000 ; i= i + 1 ) ;
            portb = 0x00;
            for ( i=0 ; i < 32000 ; i= i + 1 ) ;
            }
    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
```

```
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
//=========Lights=========
    porta = 0x02;
            // Testing Controls for Device 2
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    porta = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
                    }
            goto V2;
            }
    porta = 0x04;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    porta = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                    {
```

```
                }
            goto V2;
            }
//========Feedback========
    for (j = 0; j < 4; j= j + 1)
    // Test Vibration No 3
            {
            portb = 0x38;
            for ( i=0 ; i < 8000 ; i= i + 1 ) ;
            portb = 0x00;
            for ( i=0 ; i < 8000 ; i= i + 1 ) ;
            }
    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                {
                }
            goto V2;
            }
//=========Lights=========
    porta = 0x08;
            // Testing Controls for Device 3
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    porta = 0x00;
    for ( i=0 ; i < 30000 ; i= i + 1 ) ;
    if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
```

```
                {
                }
            goto V2;
            }
        porta = 0x20;
        for ( i=0 ; i < 30000 ; i= i + 1 ) ;
        porta = 0x00;
        for ( i=0 ; i < 30000 ; i= i + 1 ) ;
        if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
                {
                }
            goto V2;
            }
    //========Feedback========
        for (j = 0; j < 3; j= j + 1)
        // Test Vibration No 4
            {
            portb = 0x38;
            for ( i=0 ; i < 3000 ; i= i + 1 ) ;
            portb = 0x00;
            for ( i=0 ; i < 32000 ; i= i + 1 ) ;
            }
        for ( i=0 ; i < 32000 ; i= i + 1 ) ;
        if ( portb!= 0)
            // Key Interrupt from Demo Run
            {
            while(portb!=0)
            {
```

```
                }
                goto V2;
                }
}
//==================Main Program===================

   while ( 1 )
                        // Loop Forever
                {
                V2:
       if (portb!=0x00)
     // check the input on PORTB by detecting non zero value
                        {
                        for(i=0;i<555;i++)
                // Debouncing delay to avoid Noisy Data
                                {
                                }
                        if(portb!=0x00)
                        // Again check the Value for the Correct Input
                                {
                                setval=portb;
                // Assign the value from PortB to Setval
                                while (portb!=0)
                // Wait for the User to remove the finger from the touch sensor
                                        {
                                        if (portb==0x7)
                                                {
                                                while (portb!=0)
                                                        {
                                                        }
                                                goto demo;
```

```
                    }
                }
            if (setval == 0x01)
// If code 001 entered make the necessary outputs
                {
                for ( i=0 ; i < 32000 ; i= i + 1 );
                for ( i=0 ; i < 32000 ; i= i + 1 );
                // Output Data for 001
                V1:
            // Label for Goto
                for (j = 0; j < 3; j= j + 1)
                    {
            // Vibration Output for First Input
                    portb = 0x38;

                    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
                    for ( i=0 ; i < 4000 ; i= i + 1 ) ;
                    portb = 0x00;
                    for ( i=0 ; i < 4000 ; i= i + 1 ) ;
                    }
                while(1)
                    {

                    if(portb == 0x02)
// Checking Input for First Control
                        {
                        porta = 0x01 ;
// Outputing Lights based on above control
                        lvibra();
        // Outputting Long Haptic Vibration to confirm Selection
                        }
```

```
porta = 0x00;
// Turning Off Controls

if(portb == 0x01)
// Checking Input for Second Control
{
portb = 0x88;
// Outputting Lights and Vibrations as Using same port [not calling svibra here]
for ( i=0 ; i < 8000 ; i= i + 1 ) ;
portb = 0x80;
for ( i=0 ; i < 8000 ; i= i + 1 ) ;
}
portb = 0x00;
// Turning Off Controls
//==========Reconfirmation & Reset Code=============
if (portb==0x04)
// Getting Back to Start and Requesting the Active Selected Device
{
for(i=0;i<555;i++)
    {
    }
if(portb==0x04)
    {
    while(portb!=0x00)
        {
        }
    tvalue2=check_press();

    if(tvalue2==0x04)
        {
        portb = 0x00;
```

```
                                        goto V2;
                //Double Tap...Start Program from Start
                                        }
                                    else if (tvalue2==0x00)
                                        {
                                        portb = 0x00;
                                        goto V1;
                // Single Tap, go back to Feedback for this condition
                                        }
                                    }
                                }
//==================================================
                            }
                        }
                    else if (setval == 0x02)
    // If code 01* entered Check the Value of *
                        {
                        setval2=check_press();
            // Check the Value of 01* by Calling Check Press Function

                        if (setval2==0)
            // If Data Entered is 010 then Output Following Stuff
                            {
                            //Output Data for 010
                            V3:
                            for (j = 0; j < 3; j= j + 1)
                                {
                    // Vibration Output for Second Input
                                portb = 0x38;

                                for ( i=0 ; i < 16000 ; i= i + 1 ) ;
```

```
                    portb = 0x00;
                    for ( i=0 ; i < 32000 ; i= i + 1 ) ;
                    }
                while(1)
                    {
                    if(portb == 0x02)
        // Checking Input for First Control
                        {
                        porta = 0x04 ;
        // Outputing Lights based on above control
                        lvibra();
            // Outputting Long Haptic Vibration to confirm Selection
                        }
                    porta = 0x00;

                    if(portb == 0x01)
        // Checking Input for Second Control
                        {
                        porta = 0x02;
        // Outputing Lights based on above control
                        svibra();
            //Vibration Output for second input
                        }
                    porta = 0x00;
        // Turning Off Controls
//==========Reconfirmation & Reset Code=============
                    if (portb==0x04)
            // Getting Back to Start and Requesting the Active Selected Device
                        {
                        for(i=0;i<555;i++)
                            {
```

```
                    }
                if(portb==0x04)
                    {
                    while(portb!=0x00)
                        {
                        }
                    tvalue2=check_press();

                    if(tvalue2==0x04)
                        {
                        portb = 0x00;
                        goto V2;
//Double Tap...Start Program from Start
                        }
                    else if (tvalue2==0x00)
                        {
                        portb = 0x00;
                        goto V3;
// Single Tap, go back to Feedback for this condition
                        }
                    }
                }
//=====================================================
            }
        }
    else
        {
        for ( i=0 ; i < 32000 ; i= i + 1 );
        for ( i=0 ; i < 32000 ; i= i + 1 );
        //Output Data for 011
        V4:
```

```
                    for (j = 0; j < 3; j= j + 1)
// Vibration Output for Second Input
                        {
                        portb = 0x38;

                        for ( i=0 ; i < 8000 ; i= i + 1 ) ;
                        portb = 0x00;
                        for ( i=0 ; i < 8000 ; i= i + 1 ) ;
                        }
                    while(1)
                        {
                        if(portb == 0x02)
        // Checking Input for First Control
                            {
                            porta = 0x20 ;
        // Outputting Lights based on above control
                            lvibra();
            // Outputting Long Haptic Vibration to confirm Selection
                            }
                        porta = 0x00;
                        if(portb == 0x01)
        // Checking Input for Second Control
                            {
                            porta = 0x08;
        // Outputing Lights based on above control
                            svibra();
            //Vibration Output for second input
                            }
                        porta = 0x00;
        // Turning Off Controls
//==========Reconfirmation & Reset Code============
```

```
                    if (portb==0x04)
// Getting Back to Start and Requesting the Active Selected Device
                        {
                        for(i=0;i<555;i++)
                            {
                            }
                        if(portb==0x04)
                            {
                            while(portb!=0x00)
                                {
                                }
                            tvalue2=check_press();

                            if(tvalue2==0x04)
                                {
                                portb = 0x00;
                                goto V2;
    // Double Tap...Start Program from Start
                                }
                            else if (tvalue2==0x00)
                                {
                                portb = 0x00;
                                goto V4;
    // Single Tap, go back to Feedback for this condition
                                }
                            }
                        }
//==================================================
                    }
                }
            }
```

```
                    else if (setval == 0x04)
        // If code 1** entered Check the Value of *
                        {
                        setval2=check_press();
            // Check the Value of 10* by Calling Check Press Function

                        if (setval2==1)
            // If Data Entered is 101 then Output Following Stuff
                            {
                            for ( i=0 ; i < 32000 ; i= i + 1 );
                            for ( i=0 ; i < 32000 ; i= i + 1 );
                            //Output Data for 101
                            for (j = 0; j < 3; j= j + 1)
                                {
                                portb = 0x38;
                                for ( i=0 ; i < 3000 ; i= i + 1 ) ;
// Invalid Input as No Device is Connected
                                portb = 0x00;
                                for ( i=0 ; i < 32000 ; i= i + 1 ) ;
                                }
                            }
                        else if(setval2==0)
            // If Data Entered is 100 then Output Following Stuff
                            {
                            //Output Data for 100
                            for (j = 0; j < 3; j= j + 1)
                                {
                                portb = 0x38;
                                for ( i=0 ; i < 3000 ; i= i + 1 ) ;
// Invalid Input as No Device is Connected
                                portb = 0x00;
```

```
                                        for ( i=0 ; i < 32000 ; i= i + 1 ) ;
                                        }
                                }
                        else if(setval2==2)
                // If code 11* entered Check the Value of *
                                {
                                setval3=check_press();
                // Check the Value of 11* by Calling Check Press Function

                                if (setval3==0)
                // If Data Entered is 110 then Output Following Stuff
                                        {
                                        //Output Data for 110
                                        for (j = 0; j < 3; j= j + 1)
                                                {
                                                portb = 0x38;
                                                for ( i=0 ; i < 3000 ; i= i + 1 ) ;
        // Invalid Input as No Device is Connected
                                                portb = 0x00;
                                                for ( i=0 ; i < 32000 ; i= i + 1 ) ;
                                                }
                                        }
                                else if (setval3==1)
            // If code 11* entered Check the Value of *
                                        {
                        // If Data Entered is 111 then Output Following Stuff
                                        for ( i=0 ; i < 32000 ; i= i + 1 );
                                        for ( i=0 ; i < 32000 ; i= i + 1 );
                                        //Output Data for 111
                                        for (j = 0; j < 3; j= j + 1)
                                                {
```

```
                                        portb = 0x38;
                                        for ( i=0 ; i < 3000 ; i= i + 1 ) ;
  // Invalud Input as No Device is Connected
                                        portb = 0x00;
                                        for ( i=0 ; i < 32000 ; i= i + 1 ) ;
                                        }
                                    }
                                }
                            }
                        portb = 0x00 ;
                        }
                    }
                }
}



//================End of Main Program==============
//===============Function Declaration==============



//================Long Vibrations Func=============
void lvibra(void)
{
int i,j;
portb = 0x10;
                        // Vibration Output for First Control Function
for ( i=0 ; i < 20000 ; i= i + 1 ) ;
portb = 0x00;
for ( i=0 ; i < 20000 ; i= i + 1 ) ;
}
//================================================
```

```
//===============Short Vibration Func==============
void svibra(void)
{
int i,j;
portb = 0x08;
                                    // Vibration Output for Second Control Function
for ( i=0 ; i < 8000 ; i= i + 1 ) ;
portb = 0x00;
for ( i=0 ; i < 8000 ; i= i + 1 ) ;
}
//================================================



//=================Key Press Func==================
int check_press(void)
                         // Function Check Press for debouncing and grabbing the second and third
inputs
{
int i,j,set=0;

for ( j=0 ; j < 3 ; j= j + 1 )
     // Increase 3 to Increase 2nd Input Time
     {
     for ( i=0 ; i < 32000 ; i= i + 1 )
               {
               if (portb!=0x00)
                         {
                         for(i=0;i<555;i++)
                         {
                         }
```

```
                    if (portb!=0x00)
                    {
                    set=portb;
                    break;
                    }
                    }
            }
            if (set!=0)
            break;
    }
    while (portb!=0)
            {
            }
return set;
}
//==================================================
```

Appendix E: Consent Form

CONSENT FORM

University of Ontario Institute of Technology

2000 Simcoe St N, Oshawa Canada L1H7K4

CONSENT TO PARTICIPATE IN RESEARCH

Haptic Controls in Cars for Safer Driving

You are asked to participate in a research study conducted by [*Mr. Fayez Asif*]**, from the** [*Faculty of Engineering and Applied Sciences*] **at the University of Ontario Institute of Technology.** [*The results of this research will be contributed towards a dissertation*].

If you have any questions or concerns about the research, please feel free to contact [Mr. Fayez Asif at +1-647-866-7207 or by e-mail fayezasif@gmail.com]

PURPOSE OF THE STUDY

This study will help to learn user learning behaviour for haptic based user interface systems in cars. The results will be used to improve the existing designs and towards the betterment of current interface systems.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:

You will be asked to complete simple tasks e.g. (Turn on a device using our haptic system) using under research haptic system. You will complete these tasks while watching a video. Training will be provided for how to use the system and the brief introduction of a haptic system.

Total time for participating in this study will last no more than an hour, You can request your copy of trial at the end of the study for your reference

POTENTIAL RISKS AND DISCOMFORTS

There are no physical/mental or psychological hazards for using this system.

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

By the help of this study, existing user interfaces in the cars can be improved by the use of haptics. This study will provide a new testimonial for the use of haptics in automotive technology

PAYMENT FOR PARTICIPATION

There will be no payments associated with this study.

CONFIDENTIALITY

Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study.

The contents of tests and audio/video feed will be strictly used to identify potential improvements for this research. These contents will be used only for educational purposes only and the results out of the video feed will be released without any connection the nomenclature of the subject. Subjects are ranked as Beginner, Intermediate and advanced based on there experience level. Only these tags will be released to identify subject type and there result. After calculating the results, these audio/video feeds will be deleted.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study.

____

SIGNATURE OF RESEARCH PARTICIPANT

I have read the information provided for the study "[*Haptic Control in Cars for Safer Driving*]**" as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.**

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Name of Participant (please print)

______________________________________ ______________

Signature of Participant Date

SIGNATURE OF WITNESS

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Name of Witness (please print)

______________________________________ _______________

Signature of Witness Date