University of New Hampshire
University of New Hampshire Scholars' Repository

Master's Theses and Capstones | Student Scholarship

Winter 2008

Effects of different push-to-talk solutions on driving performance

Oskar Palinko
University of New Hampshire, Durham

EFFECTS OF DIFFERENT PUSH-TO-TALK SOLUTIONS

ON DRIVING PERFORMANCE

By

OSKAR PALINKO

B.S., University of Novi Sad, 2004

THESIS

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements for the Degree of

Master of Science

in

Electrical Engineering

December, 2008

This thesis has been examined and approved.

Thesis Director, Dr. Andrew L. Kun
Associate Professor of Electrical Engineering

Dr. W. Thomas Miller, III
Professor of Electrical Engineering

Dr. William H. Lenharth
Research Associate Professor of Electrical Engineering

Dr. Tim Paek
Researcher, Machine Learning and Applied Statistics, Microsoft Research

8/29/08

Date

ACKNOWLEDGEMENTS

First of all, I would like to thank my thesis advisor Dr. Andrew L. Kun for his constant support, insight and guidance throughout the course of my research.

I would also like to thank Dr. Andrew L. Kun and Dr. Neda Pekarić-Nađ for giving me the opportunity to obtain my Master's degree at the University of New Hampshire.

I would like to thank Dr. W. Thomas Miller, III, Dr. William H. Lenhart and Dr. Tim Paek for their help and advices during my studies and for serving on my thesis committee.

I would like to thank my parents Dezső and Margit and my sister Lilla for the love and support that they have given me during my many years of education.

I thank my loving wife, Danijela, for constantly helping and supporting me during good and bad times.

Thanks also go out to all my fellow Project54 colleagues who have helped me in many ways during my studies, but especially to Owen Derby for his work on data analysis and Željko Medenica for his advice on setting up the experiment.

The work reported here was supported by the U.S. Department of Justice under grants 2005CKWX0426 and 2006DDBXK099.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

3D	Three Dimensional
AASHTO	American Association of State Highway and Transportation Officials
ACT-R	Adaptive Control of Thought - Rational
AFG	Ambient Fixed Glove order
ANOVA	Analysis of Variance
CAD/CAM	Computer Aided Design / Computer Aided Manufacturing
DF	Degree of Freedom
FGA	Fixed Glove Ambient order
FPGA	Field Programmable Gate Array
GAF	Glove Ambient Fixed order
GPS	Global Positioning System
GUI	Graphical User Interface
HCID	Handware Computer Input Device
IQR	Interquartile Range
LAN	Local Area Network
MIT	Massachusetts Institute of Technology
OS	Operating System
P54	Project54
PDA	Personal Digital Assistant
PERCLOS	Percentage of Eye Closure
PHR	Push Hold Release

PR	Push Release
PTT	Push To Talk
RF	Radio Frequency
SAPI	Speech Application Programming Interface
SDK	Software Development Kit
SUI	Speech User Interface
UI	User Interface
UNH	University of New Hampshire
USB	Universal Serial Bus
VR	Virtual Reality

ABSTRACT

EFFECTS OF DIFFERENT PUSH-TO-TALK SOLUTIONS ON DRIVING PERFORMANCE

by

Oskar Palinko

University of New Hampshire, December, 2008

Police officers have been using the Project54 system in their vehicles for a number of years. They have also started using the handheld version of Project54 outside their vehicles recently. There is a need to connect these two instances of the system into a continuous user interface. On the other hand, research has shown that the PTT button location affects driving performance. This thesis investigates the difference between the old, fixed PTT button and a new wireless PTT glove, that could be used in and outside of the car. The thesis describes the design of the glove and the driving simulator experiment that was conducted to investigate the glove's merit. The main results show that the glove allows more freedom of operation, appears to be easier and more efficient to operate and it reduces the visual distraction of the drivers.

CHAPTER I

INTRODUCTION

Problem statement

Speech interaction is becoming a widely used technology in vehicles. Speech user interfaces hold the promise of providing safe driving conditions by allowing drivers to keep their hands on the wheel and eyes on the road [1]. Ambient recognizer systems, which listen to the operator all the time, may not deliver very high recognition accuracy, because they have the additional task to determine whether the driver is trying to issue a command, just talking to another person or if there are other noise sources in the vehicle (radio, entertainment system, etc.). To overcome this problem, push-to-talk (PTT) buttons are used to trigger the speech recognizer to start and stop listening to driver utterances.

Today, the automotive industry uses push-buttons for speech input and various other purposes (radio activation, volume control, cruise control, etc.). These buttons are usually located on the steering wheel. The Project54 (P54) system developed by our laboratory integrates all electronic devices in a police cruiser into a single system that allows voice control of in-car devices. The P54 system uses a steering wheel based PTT button for its speech user interface (SUI) activation.

Speech user interfaces, partly due to their small form factor [2], allow us to create systems that provide a continuous experience between multiple locations such as the inside of a cruiser and the world outside the cruiser. However, a fixed, steering wheel-based PTT button does not allow users of the P54 system to issue speech commands to the system from outside the cruiser. In general, a fixed PTT button will not allow using the same speech user interface both inside and outside a vehicle. This is the problem that motivates the research described in this thesis.

Goals

The first and main goal of our research is to create a prototype PTT solution that would contribute to providing a seamless experience for users in interacting with a speech user interface both inside and outside a vehicle. This new solution would be in contrast to a solution which may employ a fixed button inside the vehicle and perhaps another fixed button on a handheld device used outside the vehicle.

The second goal of this thesis is to evaluate the impact of using the new PTT solution on driving performance. The evaluation should indicate how using the PTT solution compares to using a fixed PTT button and how it compares to using ambient recognition, that is a speech interface that does not require the user to indicate either the beginning or the end of an utterance. Comparison to the fixed PTT button is important since all currently available in-car PTT buttons (including the ones used in the Project54 system) are fixed. Comparison to ambient recognition is relevant since ambient recognition should provide a best-case baseline for using an in-car speech user interface: the cognitive load of using the interface is present but the cognitive (and physical) load of using a PTT button is not. The evaluation should also provide information about the interactions between PTT type and other factors that may influence driving performance.

We will place several constraints on the second goal of this thesis. First, we will evaluate the new PTT solution only on one type of road: a two-lane, curvy, rural road with limited traffic. Second, we will only evaluate the PTT solution in daytime driving. Finally, the performance of the PTT solution will only be evaluated on one speech interaction task. This will be the police radio task we used in [3].

Hypotheses

The first major hypothesis of our research is that a wireless PTT glove could be used to indicate to the recognizer the beginning and end of user utterances, both from inside and from outside the vehicle. This thesis will examine the operation of such a PTT glove inside the vehicle.

Our second major hypothesis can be stated in very general terms as follows: driving performance will be affected by multiple factors related to the characteristics of the speech user interface, the type of road traveled and the psychological state of the driver. In this thesis we will explore secondary hypotheses related to the second major hypothesis.

Secondary Hypotheses

H1. In a recent study on PTT usage [3] we found that using a fixed PTT button negatively affected driving performance when the speech recognition accuracy of the in-car speech user interface was low. We hypothesize that driving performance will be better when using the ambient recognizer (no PTT button) compared to the use of the glove PTT button. On the other hand it is expected that the glove PTT button will perform better than the fixed.

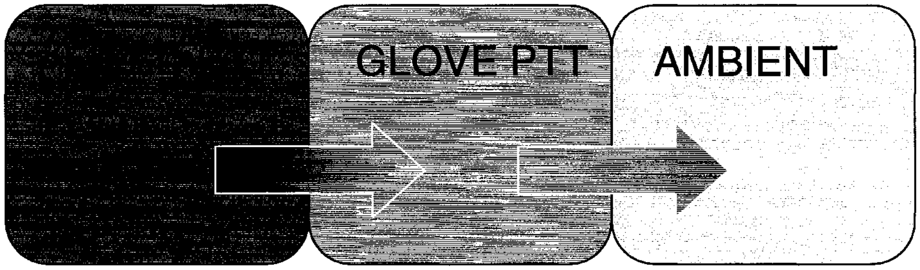

Figure 1 PTT input methods vs. driving performance

Figure 1 visualizes this hypothesis. The arrows are directed toward expected better driving performance. Also, lighter shades of grey represent presumably easier methods to use. Driving performance is measured by the variance of lane position, steering wheel angle and velocity. Large variances in lane position are a prominent sign of poor driving performance, since they indicate that the drivers weaved in their lane. Steering wheel angle variance is not by itself a sign of weak driving performance, because for example the wheel has to be rotated to take a turn. However, it can be used as a relative measure of performance when comparing variances of multiple participants driving the same road. A higher variance is an indication of increased effort expended by a driver to remain in his/her lane. Variance in velocity does not have to indicate unsafe driving. Nonetheless, drivers often reduce speed when they are concerned about safety or when distracted. We expect that, since ambient recognition does not involve an additional manual task, it will impact driving performance less than either the glove or the fixed PTT buttons. Operating the glove PTT button does not require finding the fixed PTT button on the steering wheel – the user can press down anywhere on the wheel to initiate speech interaction. Thus, we expect that the glove PTT button will impact driving performance less than operating the fixed PTT button.

H2. There are three types of interactions with in-vehicle PTT buttons. In what we can call the push-hold-release (PHR) type of interaction the user pushes the PTT button to indicate the beginning of the utterance, holds the PTT button depressed during the utterance, and releases the button to indicate the end of the utterance. In the push-release (PR) type of interaction the user pushes the PTT button to indicate the beginning of the utterance and the end point of the utterance is determined by the speech recognizer. We hypothesize that the push-release PTT operation will influence driving performance less than the push-hold-release sequence. In the no-push (NP) type of interaction the ambient recognizer is used, which cannot be classified either as a PHR or PR.

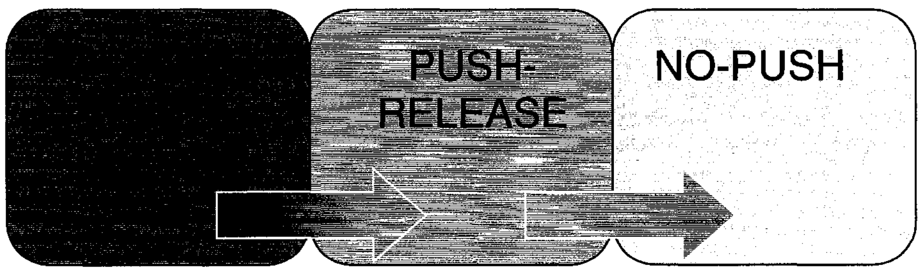

Figure 2 PTT input modalities vs. driving performance

Push-hold-release operation requires the user to hold down the PTT button for a relatively long period of time, while push-release operation only requires a quick click. We expect that PR operation is less of a distraction when driving and will thus result in better driving performance than PHR operation. The NP (ambient) recognition should provide better driving performance than the other two.

H3. In our recent study on PTT usage [3] our findings indicated that PTT button usage negatively affected driving performance when the speech recognition accuracy of the in-car speech user interface was low. This brings us to the third, and rather broad, hypothesis: interactions between PTT glove usage, PTT interaction type, speech recognizer accuracy, different road types and various other factors, affect driving performance in different ways. For example, driving in the city demands more attention than driving on a rural highway [4], thus using the PTT glove in a city environment may affect driving performance differently than using the PTT glove on a rural highway. Figure 3 shows the H3 graphically. The PTT interaction types (push-hold-release vs. push-release) are shown in two parallel planes. Columns represent types of PTT input: fixed button, PTT glove and ambient recognition. Rows represent recognizer accuracy: high and low. It is supposed that the easiest task (with the best driving performance) would be when using ambient recognition and highly accurate speech recognition, while the worst performance is expected for fixed PTT with PHR interaction type and low accuracy.

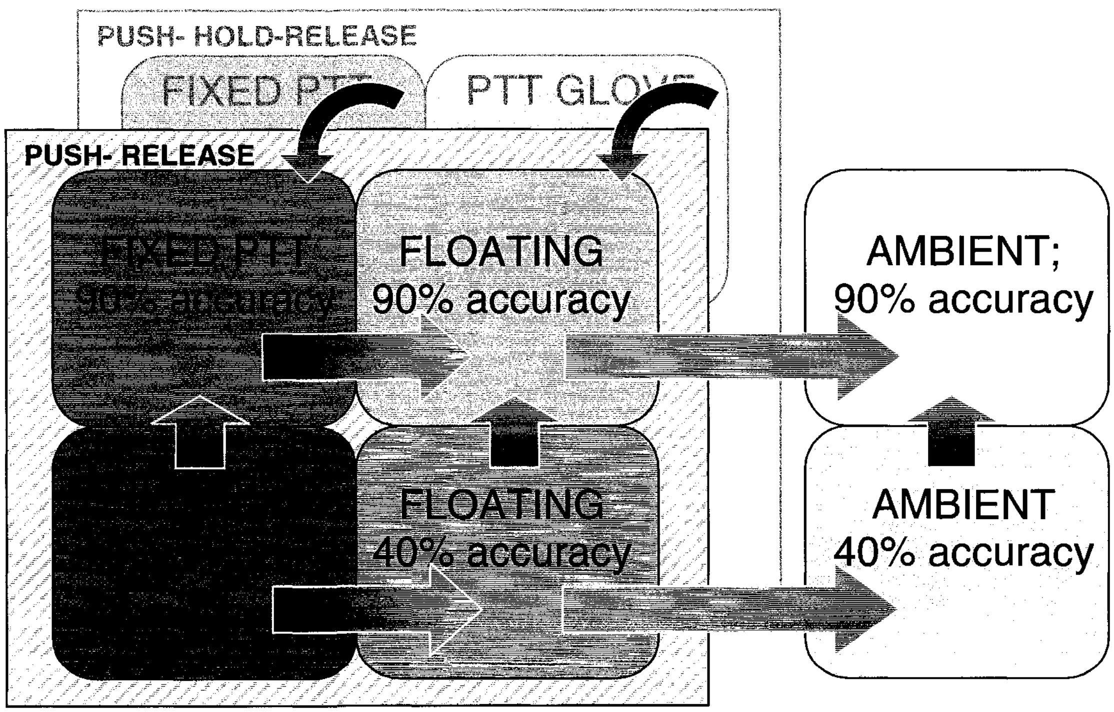

Figure 3 Various PTT factors vs. driving performance

Approach

The main method in this research would be the experimental approach. The research will be performed according to the following steps:

1) Design and implement a prototype wireless push-to-talk glove
2) Perform a pilot study to validate the usability of such a solution
3) If successful, perform a full experiment using the glove
4) Analyze the collected data
5) Compile future steps for possible follow-up experiments

These steps will be followed and referenced to throughout the structure of this document.

Thesis Overview

The thesis is organized into seven chapters.

Chapter I Introduction - gives an introduction to the topic that is being covered by the thesis. It overviews the problems that are addressed. Then it gives the goals that are being pursued. The third part proposes hypotheses that will focus the research to solving the defined problems. The fourth part gives a brief explanation of the approach of the thesis. Finally this part gives an overview of the thesis.

Chapter II Background – summarizes the background research and knowledge that this thesis is built upon. The first part discusses uses of gloves in human-computer interaction tasks. It compares the existing solutions with our glove solution. The second part overviews research done in the field of in-car speech user interfaces. Our glove PTT solution is used in conjunction with the speech user interface, which are both reviewed here.

Chapter III Hardware Implementation – gives design and testing methods for the implementation of our wireless PTT glove. The first part talks about the actual process of how the glove was built. The second part describes the pilot study that was conducted to verify the hardware design.

Chapter IV Experiment Design – discusses how the experiment was designed and executed. First, the used research equipment is described. Then the independent and dependent experimental variables are explained. Next, the simulator scenario is described. In the fourth part, the secondary, speech tasks is presented. Then, the process of subject recruitment is overviewed and the population's basic characteristics are given. Finally, the timeline and order of the elements of the experiment are presented.

Chapter V Results and Discussion – presents the results of the performed experiment, which are divided into four subsections: hand position analysis, experiment questionnaire results, eye-tracker data analysis and driving performance analysis.

Chapter VI Conclusion – gives the conclusions that can be drawn from the results.

Chapter VII Future Work – gives a preview of what should be the objectives of future work in this field. It discusses improving experiment design, road types and analysis methods.

The List of References – presents the papers, reports and online resources that were used as the knowledge base in conducting this research and writing the paper. The references are given in the order in which citations appear in the text.

CHAPTER II

BACKGROUND

The background of this thesis focuses on glove based input solutions and in-car speech user interfaces.

Glove Based Input Devices

In this section, we will discuss the types of gloves that are either commercially available or are used in laboratory research. After that we will give a brief overview of glove-based research.

Commercial and Research Gloves

The glove solutions can be categorized into several groups: 1) joint angle, gesture gloves, 2) physiological measurement gloves, 3) consumer electronics solutions, 4) push-button, pinching and pressure sensitive gloves.

Joint angle, gesture gloves - **CyberGlove** [6] is a commercially available motion capture device by Immersion Inc., Figure 4. It is one of the most sophisticated glove solutions in the market today. It records 22 joint angles per hand. Resistive bending sensors are employed to translate hand and finger motion into joint rotation angles. The recording device is a separate system from the glove, mounted on the subject's forearm. As an option it can integrate additional technologies (InterSense, Polhemus, Ascension) for estimating the forearm's position and orientation in space. The glove can be applied wherever motion capturing is needed: prototype evaluation, virtual reality, biomechanics, animation, etc.

Figure 4 The CyberGlove by Immersion [6]

CyberGrasp [7] is a very interesting add-on to the CyberGlove, Figure 5. It is an exoskeletal force-feedback structure mounted on the back of the hand. It allows the users to "touch" computer generated virtual objects by exerting forces on the fingers. It is designed with telerobotics in mind. It was intended to allow the teleoperator not only to control an actuating system, but also to get feedback from it, i.e. to be able to "touch" the remote object.

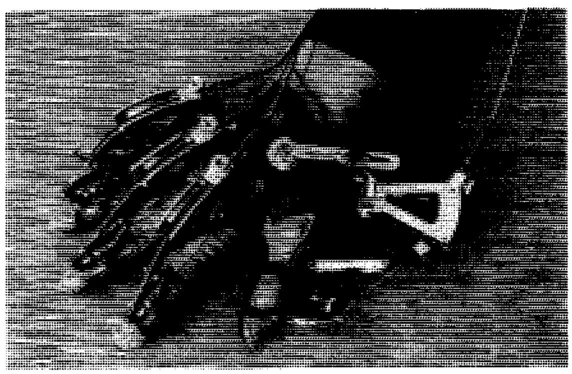

Figure 5 The CyberGrasp extension of CyberGlove [7]

The CyberGlove and its extensions have open fingertips, therefore there cannot be any sensing surface under the tips, as compared to our solution. The CyberGlove employs bending sensors which provide an analog signal, however this signal may be hard to use for triggering the PTT.

The **P5 glove** [8] is a virtual reality accessory by CyberWorld Inc, Figure 6. It is mostly used to control characters in games. The glove employs bending sensors to capture finger joint angles (flexion/extension) and an optical sensor to determine the glove's x, y, z position and orientation in space. The optical sensor interacts with a remote receptor device. The glove is wired and connects to a USB port. It has a distinctive plastic housing which rests on the back of the user's hand.

The P5's usage is also different from our solution's. Again, there are no buttons in it, only bending sensor, which produce analog signals. The plastic shell on the back of the hand could feel uncomfortable while driving. Also, because it is wired, it does not allow enough mobility to the driver.

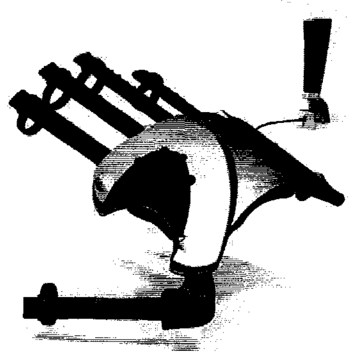

Figure 6 The P5 glove by CyberWorld [8]

The **5DT glove** [9] is produced by Fifth Dimension Technologies for motion capture and animation, Figure 7. It measures finger flexion using bending sensors. It connects to a computer either via USB or using Bluetooth wireless technology. The wireless connection has a range of up to 20 meters. The platform is open for further development, using the available SDK (software development kit). The 5DT also employs bending sensors and has open fingertips like the CyberGlove.

Figure 7 The 5DT glove by Fifth Dimension [9]

HandTalk [10] was developed at Carnegie Melon University. The glove is a part of a gesture-to-speech conversion system. It is developed to aid speech impaired persons. Finger angles are captured by bending sensors. Gestures are then matched with sign language words and transmitted wirelessly via Bluetooth to a cell phone which uses a text-to-speech application to output these words.

The **Gesture Jam Glove** [11] was developed at the University of Eindhoven. The glove reads gestures of the subjects and uses them to control computer application outputs, such as sound, video and images. It classifies gestures by emotional content, which can affect the computer output.

DataGlove [12] is a research/hobbyist glove, that measures the amount of bending of the fingers. It employs an interesting approach of measurement: it uses an infrared LED and sensor. If the finger is not bent, the sensor picks up the most light. If the joints move to a more closed fist position, the LED and sensor are not aligned anymore, so the amount of light is reduced. It can be used in virtual reality applications.

The **Gauntlet of Microcomputation** [13] is another glove-oriented research project. It uses bending sensors, so called piezo strips, which change their resistance when bent. It has a microprocessor board, which has to be attached to the forearm of the user. The project was aimed to create a high level user interface device for a computer system, based on finger movement recognition. To demonstrate its usage, a rock-scissors-stone game was implemented on the microprocessor.

Physiological Measurement Glove – The **Galvactivator** [14] was developed by MIT Media Lab. It is a fingerless glove, which is used to measure skin conductance. The measuring is done using two electrodes which lie on the palm. The electrodes capture change in the skin's conductance. This can be caused by an alteration of emotional state of the user, e.g. increased stress. Therefore, skin conductance can be used in estimating the subject's psychological and emotional state. The Galvactivator has a different use than our glove, but is mentioned here as a very interesting application of glove based sensors.

Consumer Electronics Solutions – There are also other, more task specific uses of gloves in information technology. For example, the **Swany G-Cell** [15] in Figure 8 acts as a Bluetooth hands-free set for a cell phone, but instead on the ear, it is worn on the hand. It has start-call, end-call buttons, a speaker, a microphone, vibration, etc. just like a hands-free set. The Swany G-Cell has its push-buttons on the back side of the hand, which is not suitable for our application while driving.

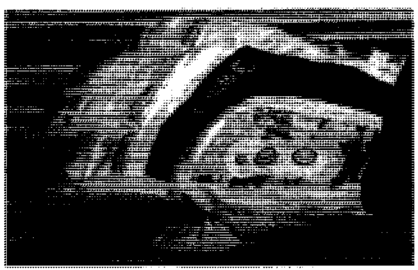

Figure 8 Swany G-Cell [15]

Sonic Control [16] was produced by the sports manufacturer, Reusch, Figure 9. It has the capability to act as a remote controller to personal entertainment devices, e.g. the iPod. The control buttons are located on the back of the glove and allow standard operations: play, stop, pause, skip, etc. It transmits these signals wirelessly to a remote operation enabled MP3 player. For PTT usage it is not appropriate, due to the position of the buttons.

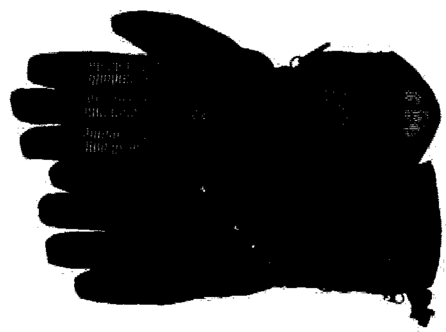

Figure 9 Sonic Control by Reusch [16]

Push-Button, Pinching Gloves – **Control Glove** [17] by Engineered Fibre Structures is a so called "pinch glove", shown in Figure 10. Pinch gloves get activated when two conducting glove surfaces are squeezed together, therefore closing an electrical circuit. These surfaces are usually located on the tips of the fingers. This glove can be used in patient rehabilitation, as a video game controller, as a computer interface, etc. The pinch information from the glove is transmitted wirelessly via Bluetooth.

Pinch gloves would be very interesting for PTT signal triggering. Since they have their active surface on the tips of the fingers, the PTT could be activated when to fingers are joined. Compared to our solution this one would lack a force and audio feedback, which are provided by the push-buttons in the fabric of our glove. However, pinching may be useful in avoiding accidental activations of the PTT function.

Figure 10 Control Glove by EFS [10]

A glove solution that is very relevant to our research is the **Handware Computer Input Device** (HCID) [18] developed by RallyPoint Inc. shown in Figure 11. It is designed to be used by solders in the field as an input device to the wearable computers or other equipment that they might use. A soldier's wearable computer typically consists of a head-mounted display and a processing unit worn around the waist. The HCID glove can be a natural method of input for such a system. The interface's advantage is that it can be operated even when the hands are busy with other devices, like holding a weapon or a steering wheel while driving. The glove has four push-buttons built into its fabric. The buttons at the tips of the middle and fourth finger activate radio communications. This is very similar to the function of push-buttons in our glove, which act as a push-to-talk activator of the speech recognizer system. Further, on the HCID, there is a sensor on the lower part of the index finger, which switches between map and mouse modes of operation. The last button on the pinky finger is used to either zoom in and out on a map or as a mouse click button. The middle finger of the glove also contains a force sensor strip that acts like a track pad. By pushing against a firm surface (wall, weapon, steering wheel) and rolling the finger on the sensor, the user can manipulate objects on the screen. Three accelerometers are built into the back of the glove to sense position and orientation of the hand. This way conventional hand-arm battlefield signals can be captured by the sensors and transmitted to other soldiers via textual commands to their heads-up screens. The glove's electronics is connected to the wearable computer via USB cable.

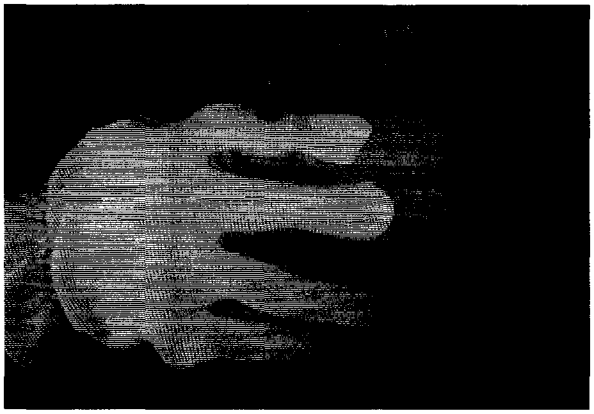

Figure 11 HCID by RallyPoint [18]

Some research laboratories and hobbyist have also developed some very interesting glove solutions, which might not be commercially available as the above mentioned ones.

Table 1 summarizes the above mentioned glove solutions and their key properties.

glove	type	measures	usage
CyberGlove	commercial	22 joint angles, forearm position & orientation	motion capture
P5	commercial	flexion/extension	virtual reality, gaming
5DT	commercial	flexion/extension	animation, motion capture
HandTalk	research	flexion/extension	gesture to speech
Gesture Jam Glove	research	flexion/extension	media control
DataGlove	hobbyist	joint angles	virtual reality
Gauntlet of Microcomp	hobbyist	flexion/extension	computer input
Galvactivator	research	skin conductance	emotion detection
Swany G-Cell	commercial	push-button action	cell phone control
Sonic Control	commercial	push-button action	MP3 player control
Control Glove	commercial	finger contact (pinching)	rehabilitation, gaming
Handware	commercial	push-button, acceleration,	military – input to

Computer Input Device		gripping force	wearable computer

Table 1 Glove product comparison

Glove Research Projects

A number of research projects has been conducted on sensored gloves. These glove solutions were constructed for various applications: *telerobotics*, *haptic input*, *rehabilitational medicine*, *virtual reality*, *entertainment, etc.* The author did not find any research done on gloves as a PTT solution or for in-car usage.

One of the fields of research where sensor gloves are often used is *telerobotics*. **Yun et al.** [19] discuss the use of a modified CyberGlove, as in Figure 4, in teaching a robotic system how to grasp objects at a remote location. The CyberGlove measures angles of the joints of the hand and in this case it is also equipped with force sensors at the tips of the fingers and near the joints. This way, the system records grasping patterns for different objects that will be used by the remote robot. The patterns include joint angular positions and force measurements, which are necessary in handling different objects properly (an egg should not be grasped by the robot with the same force as a brick). A similar system was developed by **Sato et al.** [20] shown in Figure 12. Again, the joint angles are provided by a CyberGlove. Its measuring capabilities are extended with pressure sensitive conductive rubber sensors at multiple points for measuring grip forces. A magnetic sensor gives information on wrist position and direction. The system was used to record and visualize gripping force data while the subject of the experiment was unscrewing a bottle cap. This was done to provide better understanding of gripping forces on various positions on the hand while performing simple everyday tasks. The grip force sensors could be used to trigger a PTT signal, if a digital comparator would be used, but does not seem to be a really good fit for our purposes.

Figure 12 Sato's SensorGlove [20]

In another telerobotics paper, **Mascaro and Asada** [21] present the use of a data glove to help coordinate human-robot collaboration using Petri nets. The glove records joint angles and grip forces on the human subject's hand. The gathered information (task knowledge) is shared with the robot co-worker to improve task state awareness.

Glove based input is also used in *medicinal rehabilitation* research. Rehabilitation is the process of recovery of neuro-musculo-skeletal abilities after injuries or illnesses of the human body. **Castro et al.** [22] present a glove solution for measuring grip forces which would be used in controlling neuromuscular electrical signals for restoring upper limb movements, Figure 13. A lycra commercial glove with force sensing resistors (FSR) is used to provide the feedback for the stimulation. The position of the elbow is recorded using an electrogoniometer. Experiments were conducted on 30 subjects grasping and lifting cylinders of 2,4,6,8 and 10N. The grasping forces were matched with the different cylinders (heavier objects require stronger grasp). ANOVA statistical significance was shown for this correspondence.

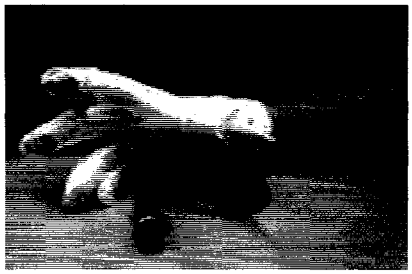

Figure 13 Castro's lycra FSR glove [22]

Gloves can also be used in evaluation of motor functions of patients using *virtual reality* (VR). **Koyanagi et al.** [23] designed a force feedback glove, shown in Figure 14, that can exert force on the subject's hands and that way represent the sensation of grasping objects in VR. The force feedback glove is loosely based on the CyberGrasp product. It is also able to measure joint positions, gripping forces and bending forces. Experiments were conducted on "touching" virtual reality spheres with different radii. The subjects were able to discriminate between small, medium and large spheres.

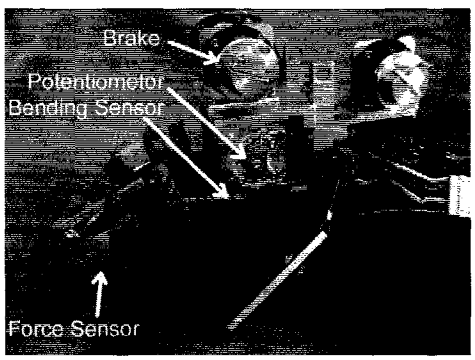

Figure 14 Koyanagi's force feedback glove [23]

Gloves are not only useful in rehabilitation, but they also might be used for *gesture/haptic input*, which could help disabled people. Gesture input refers to the technology that is able to convert gestures of people into coded computer messages. These devices could be used in pervasive computing as means of input for PDAs or wearable computers. One such system is presented by **Lee et al.** in [24]. They designed a glove which codes gestures into signs of the Korean alphabet, Figure 15. The system is considered to be a pinching glove, i.e. one that gets activated by pinching two or more fingers together. The activation is achieved by covering the tips of fingers and joints with a conductive silicon ink surface, which produces a short-circuit when the fingers are pinched.

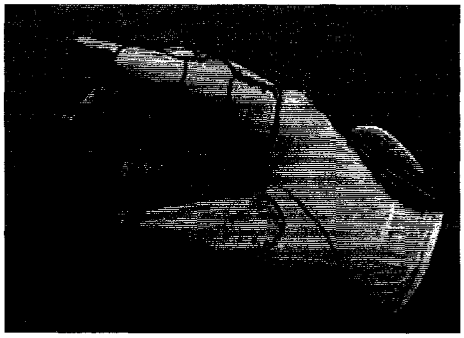

Figure 15 Lee's Pinching Glove [24]

Two experiments were conducted using this setup: Braille sign input and text input. Ten subjects participated in each. The users learned quickly how to generate Braille signs and Korean glyphs. They rated the glove as a more usable, more portable and more learnable solution compared to other standard types of Braille input, e.g. keyboard. This pinching glove solution is similar to our push-to-talk glove, in the sense that in both cases the sensitive surfaces are located on the tips of the finger. The main difference is that our system uses momentary push-buttons for activation, while the pincher uses conductive surfaces for shorting the appropriate circuits. These sensing surfaces could be used for triggering the push to talk signal but as the previous pinching solution, lack the force and audio feedback. Pinching might be a good solution outside the vehicle, but while driving the fingertips could be pinched naturally on the steering wheel, which could produce false activations.

Gestures could also be translated into speech instead of computer messages. Such a system was developed by **Fels and Hinton** [25]. The used CyberGlove gives joint angle position outputs. The system is capable to produce words and sentences by combining vowels and consonants using gestures. It can also modify the fundamental frequency and volume of speech. It could be used by speech impaired people as a means of spoken communication. The inputs are mapped to the output formant synthesizer using three RBF neural networks. One subject was trained 100 hours on the system, after which he was able to produce sentences intelligibly. The results are better than with conventional text-to-speech engines, thanks to the system's ability to control the fundamental frequency and volume of the speech more easily.

Connecting a gesture recognition glove to a personal computer using wires can cause usability problems. One of the solutions for this problem is to use wireless communication, as in our system. Another solution for the wire-problem is presented by **Park et al.** [26], who use an FPGA (field programmable gate array) to collect, process and display the gestures in an embedded environment on the arm of the subject. A 5DT data glove was used, which measures the flexion of the fingers using bending sensors. A total of 17 gestures were coded into the system for recognition. The accuracy of the system was around 94%.

Glove related research has also been conducted for use in *3D user interfaces*, *virtual reality* and *entertainment*. **Molina et al.** [27] explore the usability of three different glove solutions for 3D user interfaces. In the first, a P5 data glove was used to control a 3D Tetris-like game on a plasma TV. Subjects found the glove to be a very appealing user interface, but they did experience fatigue in their shoulders after extensive play. The second solution also included a block-based game, but this time VR goggles were used together with a Kaiser pinch glove. The third solution represented a "Minority Report"-like interface where a CyberGlove was used to perform gestures like: fast forward, backward, point and select, pause, etc. The users liked the gesture based controls better than a possible button-based interface to a recording/playing device, i.e. a remote controller.

Data gloves can also be used in 3D CAD/CAM applications. **Ma et al.** [28] propose a glove-based method for introducing deformations in a 3D model of an object. As the users flex or extend their fingers, the shape of the virtual object changes. This paper concentrates on discussing the mathematical background of such a user interface, instead of the implementation of an actual glove.

A very interesting idea is presented by **Lam et al.** [29] in for usage of gloves in animating virtual 3D characters. As the input, a P5 glove was used. The P5 provides data on finger flexion/extension and wrist position and orientation. This information is used to map the movement of the fingers to 3D animation character models, as show in Figure 16. Successful experiments were conducted on altering a recorded gait into hopping or running using this method.

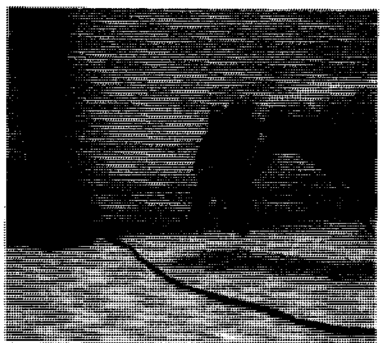

Figure 16 P5 glove used to edit 3D model gait [29]

Rodriguez et al. [30] used a glove as a control device to an interface capable of creating sonorous and visual compositions in real time. The glove contains pressure sensors on the fingertips. In this way it is somewhat similar to our design which uses push-buttons on the tips of the fingers.

Figure 17 Rodriguez's entertainment glove [30]

Table 2 contains the summary of the cited glove-based research papers and their main properties.

first author	field	glove & sensors used	measures
Yun	telerobotics	CyberGlove + force sensor	joint angles, grip forces
Sato	telerobotics	CyberGlove + force sensor + magnetic sensor	joint angles, grip forces, wrist position, direction
Mascaro	telerobotics, human-robot interaction	bending sensor + force sensor	joint angles, grip forces
Castro	rehabilitation	own glove, force sensor + electrogoniometer	grip force, elbow position
Koyanagi	rehabilitation, evaluation, VR	potentiometer + force sensor + bending sensor + force feedback	joint angles, grip forces, bend forces
Lee	gesture input	own pinching glove	detects finger pinches
Fels	gesture input	CyberGlove	joint angles
Park	gesture input	5DT, bending sensor	flexion
Molina	3D user interfaces, VR	P5, Kaiser, CyberGlove	flexion, joint angles
Ma	3D user interfaces	theoretical	flexion
Lam	animation, VR	P5	flexion, wrist

			position
Rodriguez	entertainment	own glove ,force sensors	touch force

Table 2 Glove research paper comparison

In addition to the systems and papers described, other authors have also compiled their surveys on glove based input devices, including a very good one by **Sturman and Zeltzer** [31]. It was published in 1994 and describes the state-of-the-art until then. For glove solutions prior to that date, please refer to this excellent summary.

In-car Speech User Interfaces

In this chapter, the literature on in-car speech user interfaces (SUI) will be reviewed. This is an important topic for this thesis, since we used the speech input of Project54 as the main device of operation in our experiment. Therefore it is important to review research on the characteristics of SUIs to be able to build on prior knowledge.

Speech user interfaces are starting to get commonly used in in-car devices. They have already been implemented in navigation systems, entertainment systems, cell phones [1] and also into integrated police cruiser environments [32]. Some car manufacturers have had speech recognizer technology factory-installed in their high-end vehicles for a longer time [33], in which they use voice to operate the cell phone, entertainment systems, air conditioning, etc. In recent times, Microsoft's Sync technology appeared as part of the standard equipment in Ford vehicles [34]. The Sync speech recognition engine can be used to control cell phones and entertainment systems in cars.

The most important concern about in-car devices is clearly safety. A thorough review of the research literature on safety and usability of speech-enabled in-car systems can be found in [1]. Any in-car device, whether with a speech interface or without, may introduce distraction to the driver. Researching driver distractions is important, because it is shown that they can cause traffic accidents. Distractions can be either physical or cognitive [35]. Physical distraction comes from device operation, which usually includes manual interaction and gaze diverting from the road. Cognitive distraction is caused by dividing the driver's attention between the driving task and a secondary task connected to the in-car device (mobile phone, navigation system, etc.). Speech interaction with devices reduces or eliminates the need for manual operation. This allows the drivers to keep their hands on the wheel and eyes on the road, thus reducing physical and visual distraction. This way, the driver could be able to operate the vehicle more safely [36]. Neale et al. [37] have found that distraction caused by wireless device usage (mostly cell phones) was the leading secondary task during crashes, near crashes and incidents.

In their thorough review of in-car speech user interfaces, **Baron and Green** [1] have come to a number of findings:

1) subjects performed either better or at least as well in driving (less lane position variation, less steering variation, steadier speed) while using a speech user interface compared to a manual interface,

2) examinees, in subjective workload measures, found speech interfaces to be less demanding than manual ones

3) task performance was usually better for the speech user interface

4) concurrent tasks interfere with driving

5) elderly drivers have difficulties coping in complex driving situations.

The review defines driving performance as the measures of how well the vehicle was driven along its intended path. The following measures of driving performance are reported: acceleration, velocity, steering (variance, standard deviation, steering reversal), lane position and keeping, following distance and response time. The time spent looking at the road is also connected with driving performance, since when drivers are not looking at the road they may miss important events, which in turn can lead to accidents.

Most of the literature reviewed in this report had a secondary, concurrent task for the drivers. The measures of task performance were: completion time and quality. The publication found that it is fairly hard to compare published papers on this topic, because of the lack of a common definitions, measures, testing methods, etc.

Medenica and Kun [36] researched two methods of interacting with the police radio: a manual interface vs. a speech interface. Subjects in the experiment were given the task to find a certain channel using the buttons on the faceplate of the radio and using the speech user interface which browses to the desired channel. Driving performance was measured by the variance of lane position, velocity and steering wheel angle. The results showed that driving performance degraded in all measures when the subjects were using the manual interface compared to the speech user interface. Also, NASA-TLX ratings show a higher workload for the haptic input.

Dragutinovic and Twisk [35] have compiled a thorough literature review on using mobile phones while driving. Among many other things, they have also looked at safety issues comparing conventional phone user interface (hand-held) versus using speech UI to place and receive calls (hands-free). They conclude, that hands-free kits allow the drivers to keep both hands on the wheel and solve the manual problems associated with dialing, holding, reaching for and dropping the phone. On the other hand they do not solve a major issue, which is the impact of the conversation itself on the cognitive workload of the driver.

Rosenfeld et al. [2] in one of their papers explore the future of speech user interfaces. They found that SUI has at least three major advantages that would allow its expansion in the future. First, speech is an ambient medium which does not require focused attention as compared to graphical/visual interfaces. This allows more freedom to the user to perform other tasks in the same time. Second, speech in their view is descriptive rather than referential (visual UIs). Therefore SUI and GUI can be complementary. Third, speech does not require a lot of real-estate, which is very advantageous in in-car environments, where space to put in a new UI is scarce. It can be said that speech can be scaled down to a smaller form-factor than GUIs and manual user interfaces.

From the above mentioned references it can be noticed that in most cases a secondary task with an in-vehicle device leads to decrease of driving performance. According to this pattern, one could propose that a mathematical model of the driver could be able to predict driving performance based on a secondary task. This interesting idea was pursued in the work of **Saviucci** [38]. He had explored several different types of mobile phone interfaces, some of them SUI based, and some with keypads. The driver model was implemented using the ACT-R cognitive architecture. This architecture models several properties of the driver: lower level vehicular control and higher level situation awareness and decision making. This idea was empirically tested on a population of 11 subjects. Their driving performance was compared to the predicted output of the model. The system was proved to produce good results in predicting the dialing time profiles of the subjects. The study also showed that the hands-free interface produced significantly less swerving in the lane compared to the keypad.

Besides the usage of speech user interfaces to control consumer in-car devices, as the mobile phone, navigation unit or entertainment system, speech can be used to automate and integrate specific devices in first responders vehicles, primary in police cruisers [32]. Project54 was developed with this intention in mind. It allows police officers to access a multitude of services, the lights, siren, radar, radio, license plate checks, etc. by a push of a button on a touch screen display or using the integrated speech user interface. This system, by its construction is a great research tool, that allows its developers to investigate differences in the effects of visual/manual and speech interfaces on driving. In the background of Project54, as the basis of the speech recognition, Microsoft SAPI was used. The performance of the system is increased by using a PTT button, which allows the system to listen for commands only when this button (located both on the touch screen and on the steering wheel) is activated, i.e. depressed.

Figure 18 A police officer is interacting with Project54

Recognition accuracy is further improved by using appropriate grammar and phrases. The grammar should be as small as possible. This is achieved by the system's treelike menu structure. Each time only one leaf is loaded as the grammar. Also, the phrases in each grammar should be as distinct as possible and relatively long. This paper not only describes the SUI but also other elements of the P54 system from an overview perspective.

It is important to know how the accuracy of the speech recognizer affects driving. Baron and Green [1] cite a work by Gellaty and Dingus [39] as the only paper found in their source pool which deals with accuracy. This work finds that poor recognition leads to longer task completion time and decrease in driving performance (affected measures: peak lateral acceleration and peak longitudinal acceleration).

In order to gain an even better understanding of the effect of SUI accuracy on driving performance **Kun et al.** [3] performed a study using the Project54 system. Their research also provided a deeper understanding of a number of other SUI characteristics. Several factor's were investigated that influence driving performance: recognition accuracy (high and low level), repair method (unrecognized and misrecognition) and push-to-talk modality (with PTT and without). The recognition rate of the system was manipulated in a Wizard-of-Oz type of scenario. The lower rate was at 44%, while the higher at 89%. The researchers were interested to see, if the lower recognition would distract or even frustrate the drivers, thus producing worse driving performance. To initiate the SUI's listening phase, most of today's in-car speech recognizers use a PTT button. In this experiment, two levels were investigated: 1) no PTT button, i.e. ambient recognition that listens to commands all the time and 2) PTT button located beside the drivers on their right side, near the emergency brake in most cars. The study was performed on 20 subjects, who drove in a curvy, rural highway scenario, following a leading vehicle. The driving performance was measured by the variance of the steering wheel angle, lane position and velocity. Results showed a statistically significant main effect of speech recognizer accuracy: participants tended to have worse performance (higher variance) while the recognition was at 44% compared to 89%. Looking at the PTT levels, the statistical analysis showed that when the recognition was low, the PTT method significantly affected driving performance. Namely, the usage of the ambient system (no PTT), produced less lane position variance while reaching for the remote PTT button on by the side of the driver caused swerving in the lane. This work is intended to follow up on these results and further explore the influence of different kinds of PTT activation methods on driving performance.

CHAPTER III

HARDWARE IMPLEMENTATION

This chapter gives an overview of the newly implemented wireless PTT glove. First the conventional, fixed PTT button's main features will be explained. Then, the design of the new glove will be presented. Finally, the glove pilot study and its results will be shown.

Fixed Push-To-Talk Solution

The Project54 Speech User Interface (SUI) is actively recognizing speech only when the push-to-talk (PTT) signal is present in the P54 system. It is usually activated with a push-button. It can be either an AirClick remote controller or a built-in button. In both cases it is fixed on the crossbar of the steering wheel.

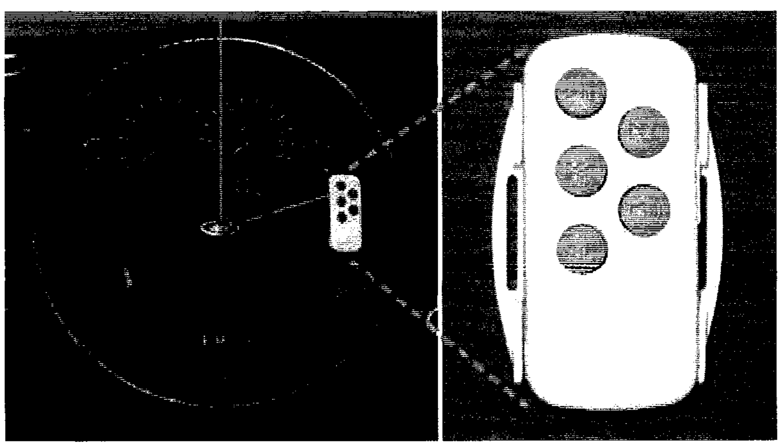

Figure 19 AirClick on the crossbar of the steering wheel

The fixed position can sometimes be inconvenient. The button can easily swerve out from the reach of the officer, when taking turns or while driving in curves. The position of the fixed button does not reflect the natural position of the hands of the wheel, which means that the driver usually has to perform an additional movement of the arm to reach the button.

Design of the Wireless PTT Glove

According to Step 1 in the Approach section of the Introduction chapter and in contrast to the existing fixed PTT solution, we proposed to mount the button onto the hand of the driver. A simple, momentary push-button was chosen for the task. Its favorable characteristics include auditory and tactile feedback when activated, i.e. a clicking sound and force feedback.

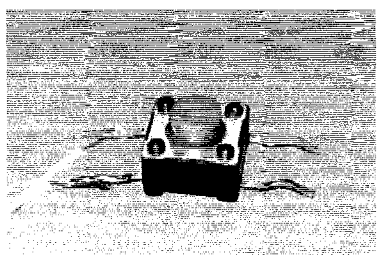

Figure 20 A momentary push-button

This button must be conveniently attached to the hand: it should be easy to put it on and take it off. Therefore we decided to install buttons into a general purpose glove. We chose to put them into the fabric of the glove at the tip of the index finger and the thumb. This way, the drivers had the buttons literally under the "tips of their fingers".

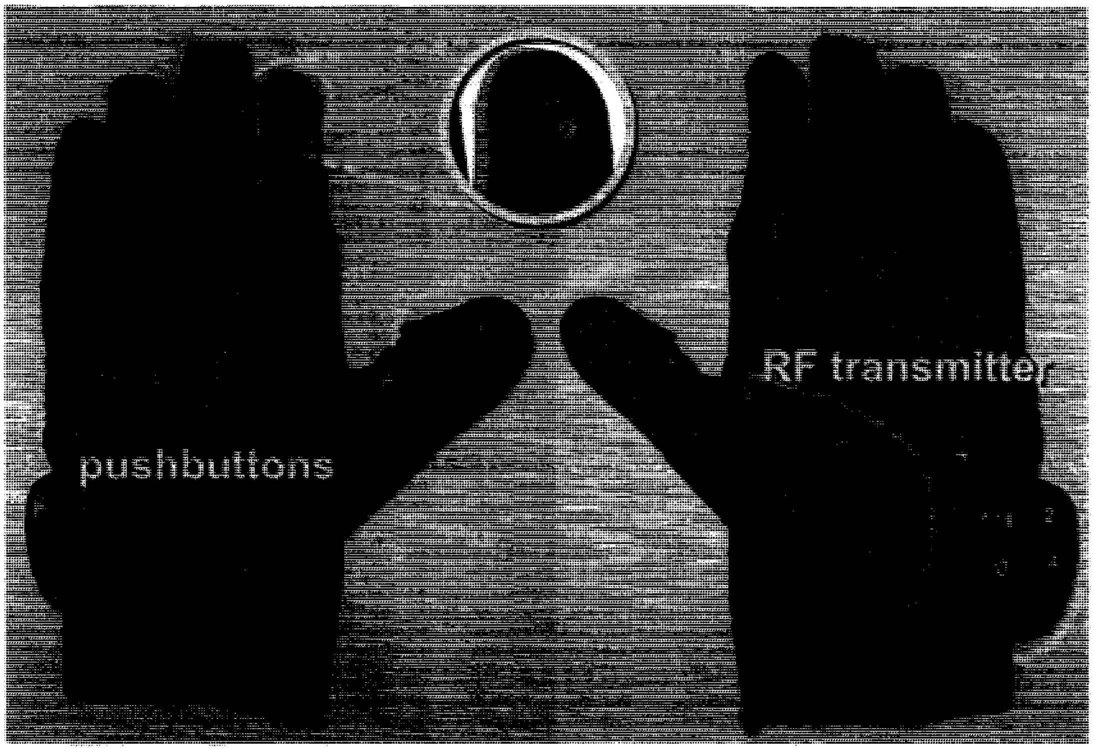

Figure 21 The wireless PTT glove

Figure 21 shows both the front and the back-face of the glove. Since the buttons are built into the fabric, they are not readily visible on the final product. Nevertheless, in the above figure, a blown-up circle is shown, where one of the two buttons is revealed, for better understanding. The active surface of the push-button can be seen as a brown circle, while the other parts of the button and the wires are covered with shrink-wrap isolation. The buttons are wired to the RF transmitter. The wires go through the fabric, i.e. they are not exposed and do not interfere with putting on and taking off the glove. The RF device transmits the PTT activation signal over wireless connection to the computer running Project54.

With this solution, the spatial constrain problem of the fixed PTT was solved, i.e. with the glove the drivers could press the button anywhere on the surface of the steering wheel and beyond. The police officers could use this glove in the future even outside of their vehicles in conjunction with the handheld P54 [40].

Pilot study

After the final hardware design and according to Step 2 of the Approach section of the Introduction chapter, the system had to be validated. We ran a pilot study with the glove on co-worker student subjects using our high fidelity simulator. The results of this pilot are summarized in [41].

Simulation Scenario. A new scenario was developed for this purpose, shown in Figure 22. The drivers were driving in a city environment. It consisted of straight sections, intersections and curvy parts. These three elements were combined with the following ideas in mind: 1) the straight sections should exert no steering wheel actions, therefore the PTT actions should not show significant difference between the glove and the fixed button; 2) the curvy road asks for moderate steering, which might emphasize differences between PTT solutions; 3) taking turns demands fast, high amplitude steering wheel action which should result in high discrimination between PTTs. This is expected, because the new glove solution allows more freedom to push-to-talk operation, while when the steering wheel is turned, the fixed button is hardly reachable. It is proposed that this inability to reach the button would result in either the degradation of driving performance for the conventional PTT solution, or longer reaction times compared to when using the glove. Reaction times are expected to be longer, because the drivers would wait until after the turn, when the button would rotate back into a position where it is easily operated. No such effects are expected for the glove since it should be always accessible and easy to use.

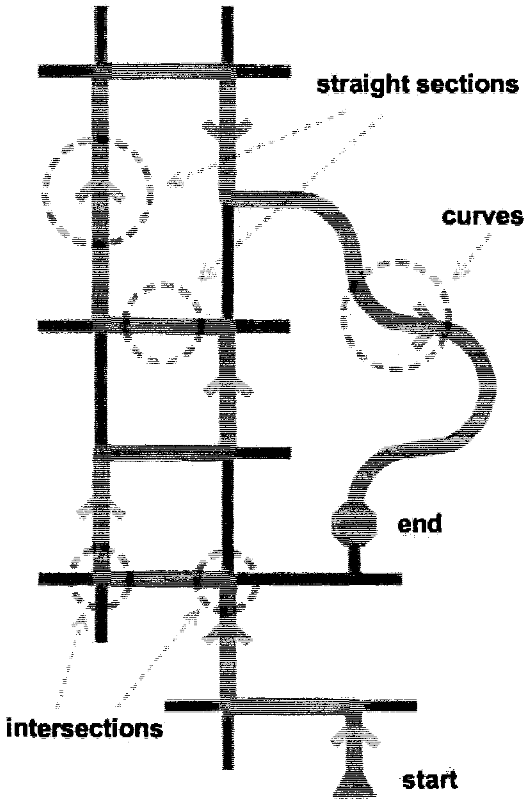

Figure 22 Map of the pilot study scenario

At intersections, the drivers always had only one correct way to turn. The limitation to only one correct solution was achieved by putting soft clues at intersections. The clues included: no left or right turn traffic signs, road work traffic signs, one way streets, traffic cones, etc. There was only one ambiguous intersection in the simulation. For this, the subjects were given the instruction before the start of the simulation, that they have to turn right onto Oak St. when they reach it. All these clues served the purpose of increasing the cognitive workload of the drivers. Under higher workload, the driving performance measures might get more emphasized.

Speech Task. The secondary task beside driving was to read and issue Project54 commands, which kept appearing in the simulation. The messages popped up either on the left or right part of the central screen for one second with 3 to 5 seconds interval between them. The high frequency of messages had the goal to put pressure on the drivers, i.e. to increase their workload. Some of the commands were: “main screen”, “patrol screen”, “emergency signals”, “records”, etc.

Independent and dependent variables. The type of the PTT, either glove or fixed, was a within-subjects (independent) variable of the study. This means that all of the drivers used both solutions consecutively and interchangedly. The data analyzed included (dependent variables): steering wheel, lane position and velocity variance, and also the reaction time to commands. The first three mentioned variables are direct indicators of driving performance [1], while reaction time tells us about the workload of the subject. If the reaction times to the speech task are longer, then most likely there is a high workload situation going on, e.g. taking turns at intersections.

We recorded the experiment with a video camera. From the footage , we hand-coded the position of the glove on the steering wheel when it was operated. Because of the limited precision of the video recording, we determined 15 degree bins and put the coded values in those.

Subjects. The participants of this pilot study were four male college students, recruited from our laboratory. Their age span was between 22 and 27. They all had valid driver licenses for a longer time. They also had prior experience with operating our driving simulator. Based on only four subjects, no statistically significant results can be claimed, but this pilot study’s scope was only to validate the usability of the PTT glove.

Experiment timeline. First, the subjects put on the glove to get familiar with it and get used to it. They found the positions of the buttons and operated them. They spent a few minutes, exploring how much force is needed to activate the momentary push-buttons. This was an important process for them, to be able to avoid false activations. After this, they were given to drive the actual simulation scenario while using the fixed button and the glove to perform the secondary task. During this testing phase of about 10 minutes, the subjects figured out which roads should be taken at certain intersections, based on the clues described above. After this process, they learned the simulation route, so that they did not take any wrong turns during the experiment itself. Also, the familiarization with the glove eliminated virtually all false activations.

After the training period, the drivers were given to drive the experiment which lasted also around 10 minutes. The order of using the glove or the fixed PTT was interchanged with every new subject.

Results. From hand-coding the video material, the position of the glove on the steering wheel was found. Using the recorded simulator data, the position of the hand on the wheel was also retrieved when the fixed PTT button was used. These two measures are compared in Figure 23.

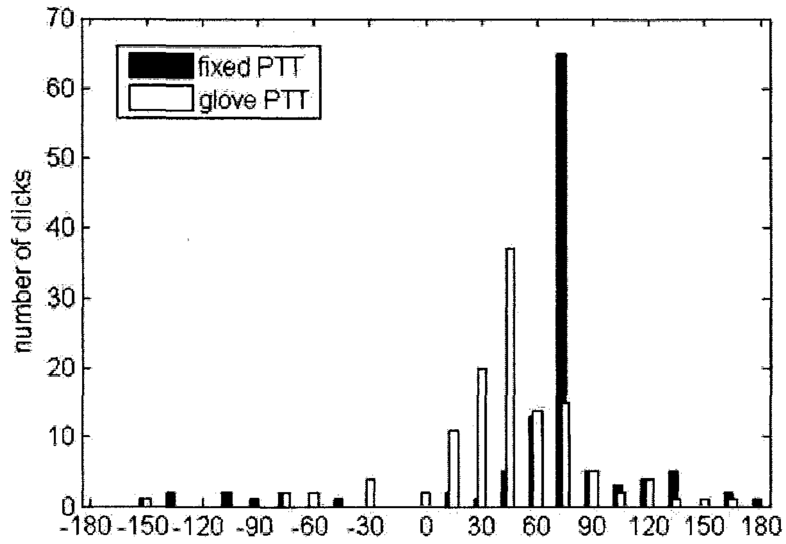

Figure 23 Angular position of the hand on the steering wheel [degrees]

In the above figure, 0 degrees is at the top of the steering wheel, while 90 degrees is the right-most point of it. In Figure 19 the vertical line represents 0°. There, it also can be seen that the position of the fixed PTT button is at 80°.

Figure 23 clearly shows, that the operation of the fixed PTT was highly concentrated around the 80 degree value, which is the position of the hand when driving straight. On the other hand the glove positions are much more dispersed with a mean value around 45°. Based on this data, it can be said, that the drivers tended to use the fixed solution mostly when they got to a straight portion of the road. The dispersion of the glove usage tells us, that with this solution, the drivers felt more freedom to operate it wherever they pleased to. The difference in means can indicate that the 45 degree hand position might be a more natural position for the drivers compared to the 80 degree location of the fixed PTT.

In accordance with the above results, it was also found, that reaction times to the appearing P54 commands while taking turns were generally longer for the fixed PTT button compared to the glove. This is shown in Figure 24. This can be explained by the fact, that when taking turns, the fixed button rotates away from the grasp of the drivers. This forces them to wait to get to a straight section, in order to operate it again. This does not happen for the glove, since the push-to-talk buttons are in this case always under the fingertips of the subjects. They can operate this solution at any steering wheel position, in any turn. The results of Figure 24 are averaged over all subjects, but because of the small number of participants, no statistical significance can be claimed.

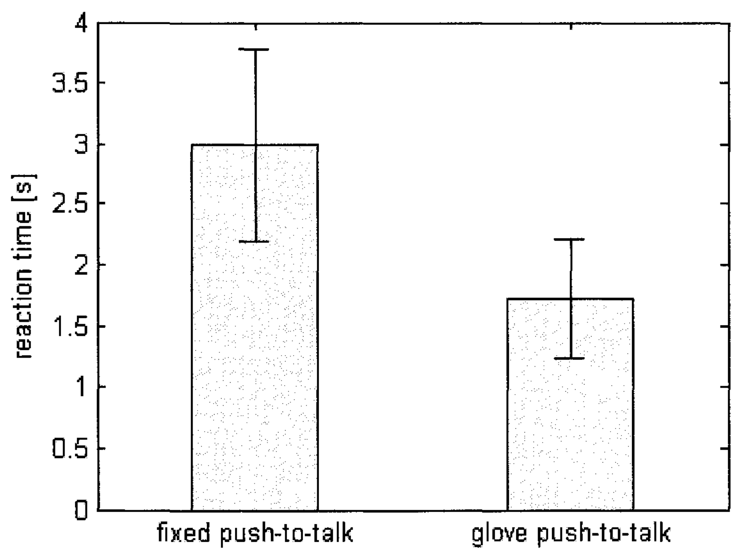

Figure 24 Reaction times while taking turns

Comparing driving performance measures (steering wheel and lane position variance) showed no difference between using the glove and the fixed PTT. Based on this it can be said, that in the worst case, using the glove does not degrade driving performance.

CHAPTER IV

EXPERIMENT DESIGN

Hardware implementation and testing done, according to Step 3 of the Approach section of the Introduction chapter, we decided to proceed with a full experiment in order to test the statistical significance of the difference between the fixed PTT and the wireless PTT glove.

Equipment Used

Two important research devices were used for this experiment: the driving simulator and the eye-tracker. In the following section, these devices are described in order to explain the variables they measured and the manner of their operation.

The Driving Simulator

All driving simulations were performed in our high fidelity DriveSafety DS-600c simulator.

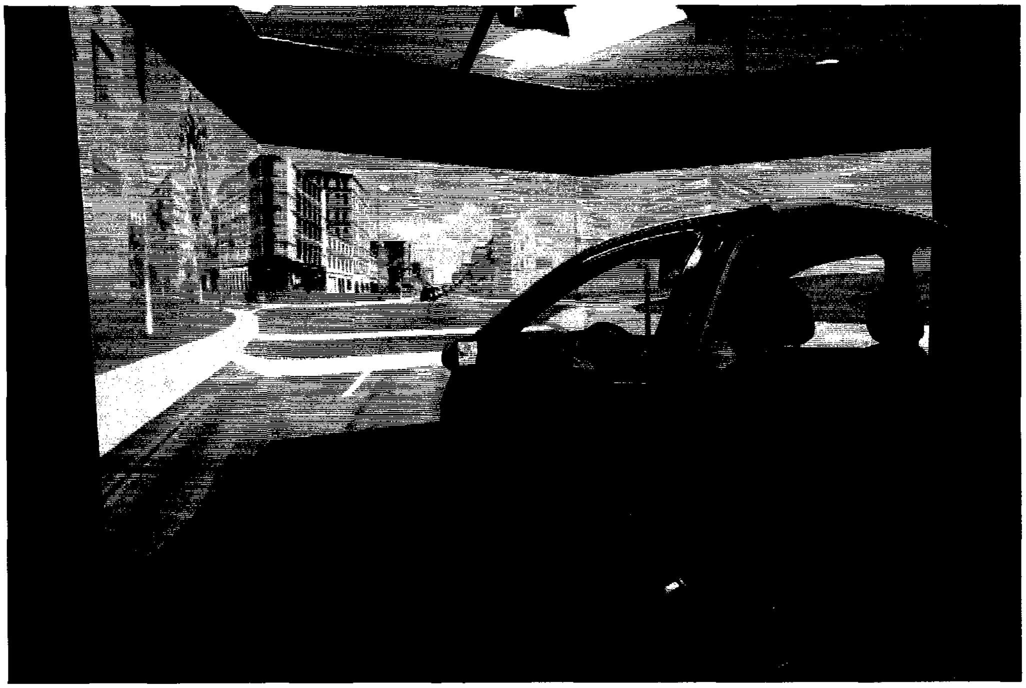

Figure 25 The DS-600c driving simulator

The simulator has a number of key features which include:

1) 180° field of view
2) Ford Focus cab
3) Motion platform
4) Realistic sound and vibration
5) Vection real-time simulation host computer
6) 5 visual channel computers
7) HyperDrive scenario authoring suite

The **field of view** of the simulator covers 180°. The simulation is projected by three aspheric mirror projectors onto three screens mounted on an encompassing steel frame structure as shown in Figure 25. These mirror projectors have the ability to cast a non-distorted image from close distance from a large elevation angle.

The subjects drive in a real Ford Focus **cab**. It has most of the interior features as the real car: fully functional seat, dashboard instruments, safety belt, steering wheel, pedals, windshield, blinkers, lights, automatic gear shift, etc. The dashboard is well simulated. The tachometer and speedometer are dynamically changing according to the flow of the simulation. The gas and break pedals have realistic feedback. The blinkers produce the expected clicking sound. The lights affect the simulation. The steering wheel is the same as in the real car, but to some of the subjects, it did not feel exactly realistic. It provides force feedback using an electric motor, but it seems that it cannot fully recreate the feedback of a hydraulic servo system found in most cars.

The simulator features a **motion platform** which simulates pitching movement of the car in the situations when it accelerates and decelerates. When accelerating, a car with front wheel drive will raise its front end. When braking, the front is lowered. This effect is very well simulated by the platform. Beside a ±2.5° pitching movement, it also provides 12.7 cm longitudinal motion.

The system provides **realistic sounds and vibrations**. The car engine and environment sound comes from 4 speakers located in the front part of the cab. The vibrations are provided by 2 transducers: one under the driver's seat and another in the steering column. Their main task is to simulate the vibrations caused by the engine.

The **Vection real-time software engine** provides the basis of the simulator 3D environment. It is run on real-time Linux operating systems. One of the 6 simulator computers (host) is dedicated for running this engine.

The 180° simulator setup requires **5 visual channels** which run on separate computers: front, left, right, central rear view and one for both left and right side view mirrors. All of the 6 computers (host + channels) are on the same LAN. The channels run on a real-time Linux operating system as the host. This OS allows deterministic frequency of frames (60Hz). A non real-time operating system (like Windows or other Linuxes) would not be able to provide such an environment.

The **HyperDrive Authoring Suite** allows developers to create imaginative driving scenarios. Roads are divided into tiles which can be interconnected. Many types of tiles can be found in the HyperDrive library (rural, city, highway, intersections, straight parts, curves, interchanges, etc.) There is even a possibility to create new tiles. Besides the tiles, entities can be placed to make the simulation lively (pedestrians, vehicles, road markers, plants, etc.) The created vehicles can be part of ambient traffic or those with programmed behavior. The ambient vehicles are automatically generated. They follow all traffic rules. The programmed vehicles can be made to traverse a set path.

A number of functionalities of the simulations can be programmed in the provided Tcl/Tk programming environment. It is possible to create location, time and virtual triggers that allow developers to create very life-like scenarios.

The Eye-Tracker

The Project54 lab has recently acquired a SeeingMachines faceLAB 4.0 eye-tracker system. It represents the state-of-the-art of the commercially available eye-tracking systems.

The tracker consists of a pair of stereoscopic cameras, 3 infra-red pods, additional lenses, mounting solutions and a laptop computer with pre-installed SeeingMachines software.

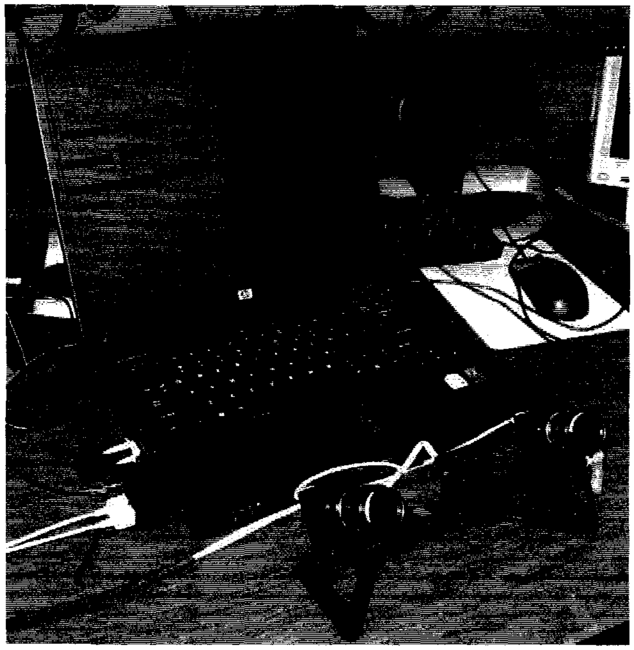

Figure 26 The eye-tracker system with desktop setup

The eye-tracker was set up in the simulator on top of the dashboard as it is shown in the following figure.

Figure 27 Camera position on the dashboard

This position was chosen for the cameras in order not to block too much of the road for the subject (cameras are low on the dash) and not to be blocked by the rotation of the hand on the steering wheel (cameras further apart).

The software of the system is capable of recording a vast number of variables with a 60Hz frequency: head position and orientation, eye rotation, gaze intersection with objects, saccade onset, blink time and duration, PERCLOS (measure of fatigue), etc. The eye-tracker is very sophisticated and works with a precision of under 1° if well calibrated.

The software package also provides a virtual world representation, in which real objects can be modeled with simple geometric shapes like rectangles and spheres. This very useful feature allows to easily figure out when the driver's gaze was directed towards a particular object.

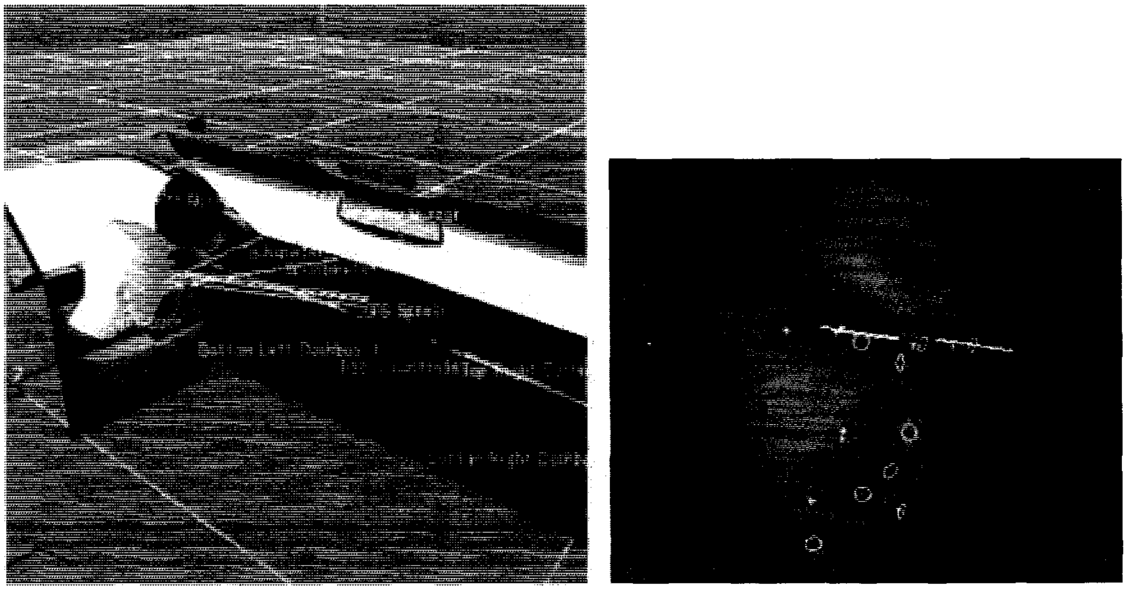

Figure 28 a) World Model and b) subject gazing at GPS screen

Figure 28 a) above, shows a virtual world that represents the interior setup of a passenger car. There are spheres in it which represent different objects of interest to the driver: GPS screen, speedometer, tachometer, left side view mirror, etc. In this world, a subject (b) is gazing towards the GPS screen, which is shown by the yellow gaze lines in both a) and b) image.

In the case of the experiment at hand, it would be important information to know when the subjects were looking down to find the position of each of the PTT solutions.

Dependent and Independent Variables

In every scientific experiment there are independent and dependent variables. The independent ones are hopefully controlled by the experimenter, while the dependent ones are changing automatically as a reaction to the change in the independent variables.

The independent variables (factors) of this experiment were: **PTT Method**, **Recognition Accuracy, PTT Type** and **PTT Order**. The first two were within-subjects while the second two were between-subjects factor.

PTT Method has three levels: fixed, glove and ambient. This variable is of the main interest for our experiment. By comparing its three levels we expect to find out more about the possible advantages of a PTT glove over the standard way of PTT activation. Ambient recognition means that there would not be any push-to-talk signals. In this case the system would listen to the driver all the time. This kind of a system is not feasible in reality in in-car environments, since the speech recognizer would have a very hard task of trying to interpret any speech signal picked up by the microphones. The signal could even be a conversation between the driver and the passengers or a voice on the car radio. Because of these reasons, an ambient recognizer would significantly degrade the precision of the speech user interface. In spite of this, it was still possible to use ambient recognition in our experiment, because the nature of Wizard-of-Oz designs. It means that it was not really the system performing the recognition, but the experimenter was producing the reactions instead. Ambient recognition was added to the list of levels because it provides a baseline for the other PTT Types.

The second factor (variable) of the experiment was **Recognition Accuracy**. It was manipulated again in a Wizard-of-Oz manner: the responses of the system were provided to the driver by the experimenter, instead of the real recognizer. This way, two accuracy levels were produced, high (89%) and low (44%). The order of the two was counterbalanced to suppress ordering effects.

The third factor to be examined was **PTT Type**, which had three levels: push-hold-release (PHR), push-release (PR) and no push (NP). The currently deployed Project54 system works according to the PHR sequence: PTT button push, hold, command utterance, release of PTT. The other proposed sequence would mark only the starting point of the command: PTT button push, release, command utterance. In this case the system would automatically have to detect the end-point of the speech command. This would be a relatively easy task for speech processing algorithms, if there was no noise. It is expected that the PR sequence should produce better driving performance results compared to push-hold-release, because the first button press lasts for a moment, and then allows free movement of the activating hand, while the other sequence requires the hand at the position of the PTT button during the whole time of the utterance. This could be hard to perform using the fixed PTT and taking a turn while trying to issue a command. The third level (NP) is introduced to accommodate the situation when the ambient recognizer is used, since it does not fall in any of the above levels.

The fourth factor, **PTT Order**, represents the sequence in which the subjects used the different PTT solutions. It was introduced during the execution of the experiment and it will be explained in detail in the next Chapter in the Driving Performance Data Section.

Table 3 below gives an overview of the layout of the experiment design considering the first three independent variables and their levels.

	Push-hold-release			Push-release			No push		
	Ambient	Fixed	Glove	Ambient	Fixed	Glove	Ambient	Fixed	Glove
High									
Low									

Table 3 Experiment Design

In the table, gray areas denote fields for which no data is available. This is due to the specific unbalanced design that was used. This arose, because the Ambient level of the **PTT Method** variable does not have Push-hold-release or Push-release level, unlike the Fixed and Glove, which do have PHR and PR levels. That is why it was necessary to denote the Ambient as a different level for the PTT Type: No push.

The dependent variables were: steering wheel variance, lane position variance, velocity variance, hand position on the wheel, fixation frequency on the PTT button, fixation duration and subjective satisfaction with particular PTT solutions (questionnaire feedback).

The first three of these are considered to be direct measures of driving performance, as explained in [1]. The hand position on the steering wheel for the fixed PTT button is calculated simply by adding 80° to the value of the steering wheel angle when the PTT action happens. This is done because the fixed solution is positioned on the crossbar of the steering wheel, which is displaced by eighty degrees compared to the top of the wheel (which is considered to be 0°). The hand position of the glove at the time of push-to-talk action is harder to figure out, since the glove is not constrained on the surface of the wheel. To get this value, the video footage of the experiments has to be transcribed by hand. At each PTT button action the position of the glove on the wheel needs to be extracted for each subject. A Sony HDV 1080i Handycam was used for this purpose, Figure 29. The precision of the recording is limited by the distance of the camera from the steering wheel and the darkness during the experiment. To account for imprecision, the angular values will be classified into 15° bins.

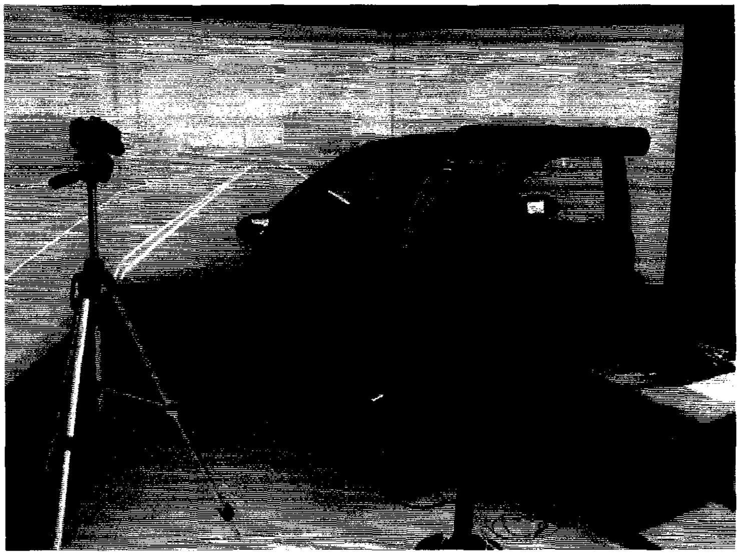

Figure 29 Position of the camera relative to the simulator

By collecting hand position data, it is expected to find out if there are any differences between glove and fixed button usage. Based on the pilot study we hypothesized that the histograms would be quite distinctive (see Figure 23).

The subjective opinion of the drivers should be gathered using a post-experiment questionnaire. It should use a Likert-scale, which expresses the level of agreement or disagreement with each of the questions. The most important questions considered comparison between the glove and fixed PTT button, asking if either of the two was easier to use and if either was more efficient.

Simulator Scenario

The scenario chosen for this experiment was very similar to the one used by Kun et al. [3]. This was done, because the curves in it proved to increase the driving task difficulty in order to have a challenging primary task (driving) for the subjects. On the other hand the road was not too complex so it would not cause simulator sickness problems [42] with many subjects.

The scenario consisted of straight sections and curvy parts. The curves took up 73% of the traveled road distance, while the rest was straight. All curves in the simulation were of the same kind, either left or right, with a radius of around 230 meters. The environment around the curves was changing from tile to tile, with additional buildings and trees.

The road represented a rural highway, with one lane in both directions, Figure 30. The separating road marker line between the lanes was full during all times, which prevented passing of vehicles. The lanes were of standard width of 3.6 meters according to AASHTO.

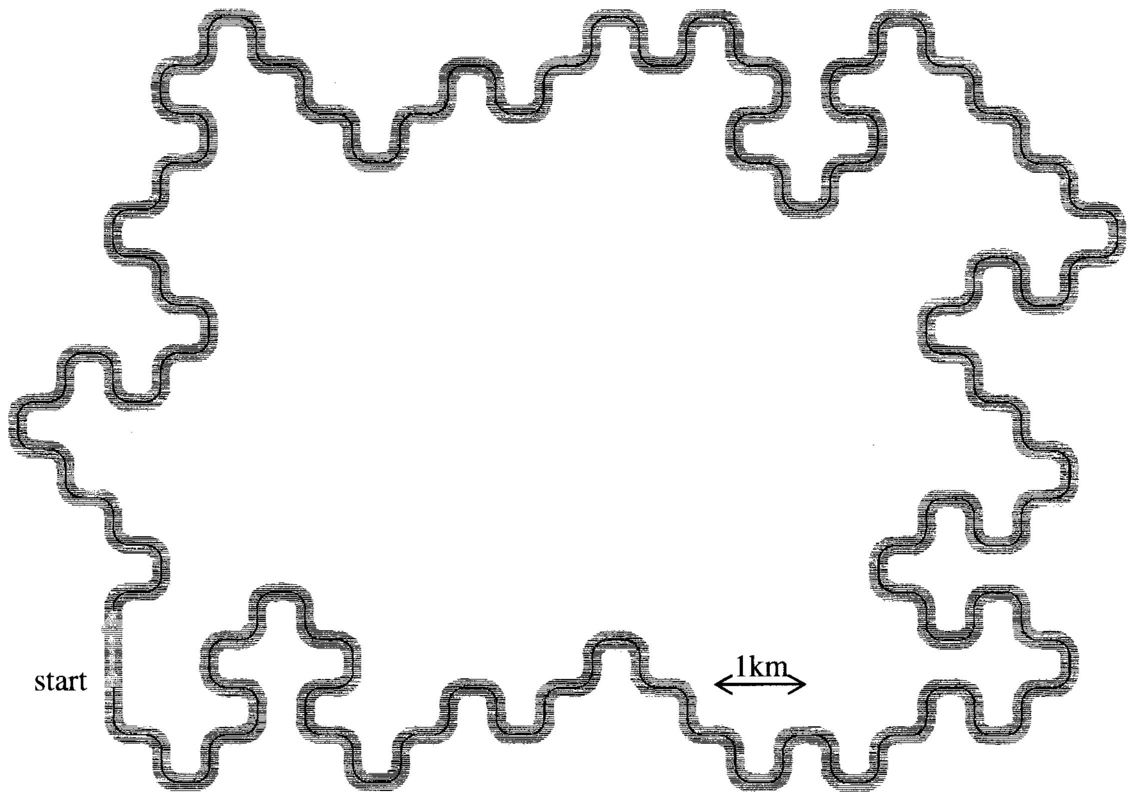

Figure 30 The experimental road

The primary driving task of the subjects was to follow a leading vehicle, which was created when the subject was ready to start driving. This vehicle was traveling with a constant speed of 60 mph, after the initial acceleration period. This velocity was chosen to be a high value, in order to have the driving workload of the subjects increased. On the other hand, it was not set too high, so the drivers would be able to operate their vehicle safely. The subjects were asked to follow the leading car at a distance that was convenient for them. They were asked to keep the distance as constant as possible, with emphasis on safe driving. The only strong rule communicated to them was that they should not allow the leading vehicle to escape out of their sight.

There was ambient traffic present during the experiment. The ambient vehicles were only present in the oncoming direction. In the direction of travel of the subject's vehicle, the ambient traffic was prohibited, since it would slow down the leading vehicle.

Secondary Task

The secondary task was a Wizard-of-Oz type of speech interaction with the Project54 system. The subjects were asked to retransmit messages via the radio system of P54. This task was the same as the one used in [3], with different channel names.

Each interaction would start by the system informing the subject of the received message, Then it would tell the driver where this message should be transmitted to. The transmission consists of choosing the appropriate zone, channel and issuing a retransmit command. Each time after this, the system informs the subjects, that the radio system should return to its original zone and channel (Zone Troop A Adam, Channel A Adam).

The names of zones and channels are used in the way as first responder services use it in New Hampshire. The zone names begin with the first letters of the alphabet, which are expanded by a word that begins with the same letter and serves as a method of error correction both for radio transmission and speech recognition. In this sense the zones are the following:

```
Zone Troop A Adam
Zone B Boston
Zone C Charlie
Zone D David
Zone E Edward
Zone F Frank
```

Listing 1 Zone names used in the experiment

The names of channels on the other hand, are names of geographic locations around the state.

An example of an interaction between the Project54 system and the subject can be seen in Listing 2.

System: "Message received from Troop A Adam. Retransmit message to channel L P South in zone C Charlie."
System: "Go to zone C Charlie."
Subject: "Zone C Charlie."
System: "Zone C Charlie."
System: "Go to channel L P South."
Subject: "Channel L P South."
System: "Channel Londonderry."
Subject: "Cancel."
System: "Cancel."
Subject: "Channel L P South."
System: "Channel L P South."
Subject: "Retransmit.
System: "Retransmit."
System: "Go to Zone Troop A Adam."
Subject: "Zone Troop A Adam."
System: "Zone Troop A Adam."
System: "Go to channel Troop A Adam."
Subject: "Channel Troop A Adam."
System: "Channel Troop A Adam. Listening."

Listing 2 A typical secondary task for high accuracy

It can be noticed, that every time the subject issues a command to the system it is repeated by Project54, as confirmation. The above listing contains one misrecognition. In this case, the system confirms a misrecognized channel. When the users notice this, they have to cancel this interaction, which is also confirmed. After the cancellation, the initial command has to be reissued. Interactions at the lower level of accuracy contain more misrecognitions as show in Listing 3.

System: "Message received from Troop A Adam. Retransmit message to channel Gilford in zone E Edward."
System: "Go to zone E Edward."
Subject: "Zone E Edward."
System: "Zone A Adam."
Subject: "Cancel."
System: "Cancel."
Subject: "Zone E Edward."
System: "Zone E Edward."
System: "Go to channel Gilford."
Subject: "Channel Gilford."
System: "Channel Lebanon."
Subject: "Cancel."
System: "Cancel."
Subject: "Channel Gilford."
System: "Channel Gilford."
Subject: "Retransmit."
System: "Retransmit."
System: "Go to Zone Troop A Adam."
Subject: "Zone Troop A Adam."
System: "Zone D David."
Subject: "Cancel."
System: "Cancel."
Subject: "Zone Troop A Adam."
System: "Zone B Boston."
Subject: "Cancel."
System: "Cancel."
Subject: "Zone Troop A Adam."
System: "Zone Troop A Adam."
System: "Go to channel Troop A Adam."
Subject: "Channel Troop A Adam."
System: "Channel Wolfboro."
Subject: "Cancel."
System: "Cancel."
Subject: "Channel Troop A Adam."

System: "Channel Troop A Adam. Listening."

Listing 3 A typical verbal task for low accuracy

It can be noticed, that in the case of low accuracy, the interaction is much longer than for high accuracy. In order to have the same number of user utterances, for each different level of PTT method the high accuracy interaction is repeated four times, while the low accuracy interaction is repeated two times. Of course, these repetitions are actually different interactions with the same number of recognitions/misrecognition.

All of the computer utterances in this experiment were generated by Microsoft SAPI5 using the voice of "Microsoft Mary".

In this experiment, all information exchange between the driver and the P54 system is designed to be done using voice, i.e. there is no information (input or output) concerning the secondary task that would be communicated to the driver in any modality other than speech. This is done in order to test a purely speech user interface as opposed to a multi-modal system.

Subjects

The recruitment and management of the subjects was an important task of this experiment. The subjects were paid to participate in order to motivate them to apply to our recruiting efforts and perform well during their stay in our lab. They were paid $15 in gift certificates for participating in the experiment that lasted around 1.5 hours. As additional motivation, they were also promised an additional $5 for successful completion and good performance. In the end, all subjects were rewarded with the full amount of $20. This way, their hourly rate amounted to about $13.5.

The recruiting was performed using flyers and promoting e-mails on university mailing lists. The fliers were either handed out in personal contact and posted on bulletin boards in Morse Hall and Kingsbury Hall at the Durham campus of the University of New Hampshire. The electronic version of the flyer was sent out to the student mailing list of the Electrical and Computer Engineering Department and to the Graduate School of UNH.

We had a satisfactory number of potential subjects replying to our ads. The subjects had to be scheduled for future time slots during 2.5 weeks. When deciding about the applicant, the only criteria were: possession of a valid driving license and no known history of motion sickness. The second criterion was established, because some of our subjects in this and prior experiments have had trouble with simulator sickness that the driving simulator may cause.

Motion sickness can be defined as a condition which arises when there is a disagreement between what a person perceives as a visual impression of movement and the body's sense of movement from the vestibular system. This system is located in the inner ear, which is responsible for the body's balance and sense of spatial orientation. Motion sickness can happen in ground vehicles, airplanes, spacecraft, water vessels and in simulators. In the simulator, this sickness can be even more emphasized, because the simulator cab cannot reproduce the horizontal acceleration and deceleration of a real vehicle. This is in contradiction with the visual input that the subject gets from the simulator screens.

In the case of our experiment, four subjects out of the total 28 participating could not finish the driving scenario, because of simulator sickness. Two female subjects got through most of the experiment, but they got gradually worse over time. One of them broke into sweat and stopped driving in a haste, while the other informed the experimenter that she felt dizzy before the appearance of visible physical symptoms. One of the male subjects could not cope with taking turns, and kept swerving out of them. This caused him to feel sick. The other male subject reported that the motion platform caused him to start feeling simulator sickness. He reported that the pitching movement felt very artificial to him. The other 24 subjects did not report any similar problems.

It could be concluded that once the dizziness and nausea sets in, the person cannot get better soon enough to be able to finish the experiment. Pauses of 5-10 minutes did not help them to get back to continue driving. Also, it seems that older persons are more prone to getting sick. Also, people who have had a history of feeling motion sick on roller coasters and similar rides seemed more likely to fail. Persons with longer driving experience and background in extreme sports seem to have less trouble in driving in the simulator. The above analysis should be considered to be only descriptive. No statistical significance of the effects was proven.

At the beginning of each experiment session, the drivers had to fill out a personal questionnaire. This data will be summarized here. According to the questionnaire, the average age of the drives was 26.04 years. Most of the subjects were graduate students (12), then undergraduate students (5). We also had some staff members of UNH, non-UNH employees and one high school student. There were 16 male participants and 8 female. This is due to the fact that much more males responded to our flyers. All of the participants where able to communicate well in English, 16 of them were native English speakers. Seventeen of the subjects came from the USA, 3 from China and one each from the following countries: Russia, South Korea, India and Germany. Twenty-two of them were right-handed, and two left. This number represent the ratio of these two groups in the general population well, since around 10% of all people are left-handed. On average, the subjects had 8 years driving experience. Two of the participants sat in a driving simulator before. Fifteen people were playing video/computer games at least once a month, while the other nine did not report playing before. Most of the participants had at least some experience with speech recognition systems (cell phones, laptops, desktops, customer service), while seven of them did not encounter any SUIs before.

Experiment Timeline and Order

Experiment timing. This section gives a table of the timeline of an exemplar experiment with approximate time given in minutes. It also gives the list of actions that have to be taken prior to and after the subject has left the testing lab.

	Time (min)
Preparation before the subject arrives:	
1.Check simulator operation	
2.Start SymConnect, P54	
3.Test-run scenario, check if data is being recorded into appropriate files	
4.Check time synchronization of P54 and simulator host computer	
5.Test video camera operation	
Preparation for the experiment:	
Subject arrives to the lab	1
Short explanation - about what the subjects are going to be asked to do	2
Filling out the personal questionnaire – collecting data about the subject	3

Subject reads instruction sheet about the simulation and dialogue	3
Subject gets familiar with how to operate the simulator (no driving yet)	2
Sum:	11
Training:	
Subject in the simulator learns how to operate the AirClick and practices the verbal dialogue with the computer (no driving)	5
Subject drives the simulator for the first time, straight road, then curvy road	5
Subject practices the verbal task and PTT operation while driving	5
Glove introduction and operation – putting on the glove, driving with it, using the PTT buttons in the glove	5
Sum:	20
Experiment:	
Start video recording, erase old files in SymConnect, start simulation, load appropriate verbal task into SymConnect	1
Curve driving:	
Baseline driving – driving on a curvy road, following a lead car	2
PTT baseline driving – practicing the AirClick operation while driving, system says "Press the push-to-talk button"	2
PTT driving 90% , 40% - driving and performing the dialogue using the AirClick PTT	10
No PTT driving 90%, 40% - stopping, removing AirClick, driving and performing the dialogue without PTT	12
Glove 90 40 (with putting on, interchanged) – stopping, putting on the glove, driving and performing the dialogue with the glove	13
PTT baseline driving – simple AirClick operation while driving, like 4 steps before, for examining the learning effect (optional)	2
Baseline driving – also for examining the learning effect (optional)	2
Sum:	44
Ending experiment:	
Experimenter turns off video recording, backs up data files	1
Experimenter discusses impressions about the simulator, scenario and the experiment with the subject	2
Questionnaire – subject fills out the questionnaire about subjective experiences while driving – frustration, ease of use, efficiency, etc.	4
Sum:	7

Total time:	82min

Table 4 Experiment timing

Experiment order. To eliminate the order effects, a version of the Latin square approach was used when deciding about the sequence of experiments. Accordingly Table 5 shows how the experiment could be conducted. Rows show different subjects, while columns show in which order they would perform different parts of the experiment. The first word denotes the type of PTT used (ambient, fixed, glove), while the second word denotes the recognizer accuracy used (high and low).

1	amb. low	amb. high	fixed low	fixed high	glove low	glove high
2	glove high	glove low	amb. high	amb. low	fixed high	fixed low
3	fixed low	fixed high	glove low	glove high	amb. low	amb. high
4	amb. high	amb. low	fixed high	fixed low	glove high	glove low
5	glove low	glove high	amb. low	amb. high	fixed low	fixed high
6	fixed high	fixed low	glove high	glove low	amb. high	amb. low
7	amb. low	amb. high	fixed low	fixed high	glove low	glove high
8	glove high	glove low	amb. high	amb. low	fixed high	fixed low
9	fixed low	fixed high	glove low	glove high	amb. low	amb. high
10	amb. high	amb. low	fixed high	fixed low	glove high	glove low
11	glove low	glove high	amb. low	amb. high	fixed low	fixed high
12	fixed high	fixed low	glove high	glove low	amb. high	amb. low

Table 5 Latin square order of experiments

It can be seen in this table that the order of input hardware always changes, but the two values of accuracy within one input type always stay in sequence (e.g. "glove low" then "glove high"). This is done to eliminate the need to switch input modes too many times which can add up to a lengthy experiment (take off gloves, strap on AirClick, etc).

The table shows 12 repetitions for 12 subjects who belong to the same group (they all perform for example push-hold-release). The other group of subjects (e.g. push-release) can perform the same order of experiments as the previous group.

CHAPTER V

RESULTS AND DISCUSSION

After the experiment has been conducted on all subjects, the collected data had to be analyzed, as mentioned in Step 4 of the Approach section of the Introduction chapter. There were a number of sources of results in this experiment. First, from the video recordings and simulator output, the positions of the hands on the wheel could be coded for instances of PTT activation. The simulator output also provided steering wheel angles when a PTT button was activated. Next, we had the experiment questionnaire administered to the drivers after they completed driving, which provided us with their subjective opinion on the simulator and PTT solution. Then, we had the output of the eye-tracker, which gave us valuable data about the visual attention of the subjects. Finally, there were the measurements of driving performance coming from the simulator.

Hand Position on Steering Wheel while Operating the Fixed and the Glove PTT Buttons

The angular position of the hand on the steering wheel was hand-coded by one coder (a high school summer intern) using the video recording that was shot of the experiment using a digital camera. Because of the limited precision of the recording, the angular positions were classified into 15° bins. The encoding bins were selected as follows: all values from -7.5° to 7.5° were classified into the 0° bin, 7.5° to 22.5° to the 15° bin, and so on. The bins are shown in Figure 31.

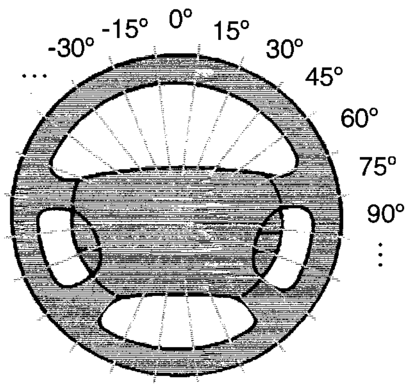

Figure 31 Steering wheel bins

Figure 32 shows a still frame from the video recording, with the overlaid cabin coordinate system for determining angular position of the hand. The cabin coordinate system is fixed with respect to the cabin even as the steering wheel rotates.

Figure 32 Overlay of the cabin coordinate system on the steering wheel

This video overlaying technique is used only for encoding the position of the appropriate PTT finger while using the glove. The coding procedure was not applied for the fixed PTT, because in that case, the activating finger is always located at an 80 degree angle in the coordinate system of the steering wheel (relative coordinate system), because of the fixed nature of this PTT solution. For the sake of clarity, Figure 19 is reproduced here to explain the position of the fixed button. All five Airclick buttons act in the same way by activating the PTT signal.

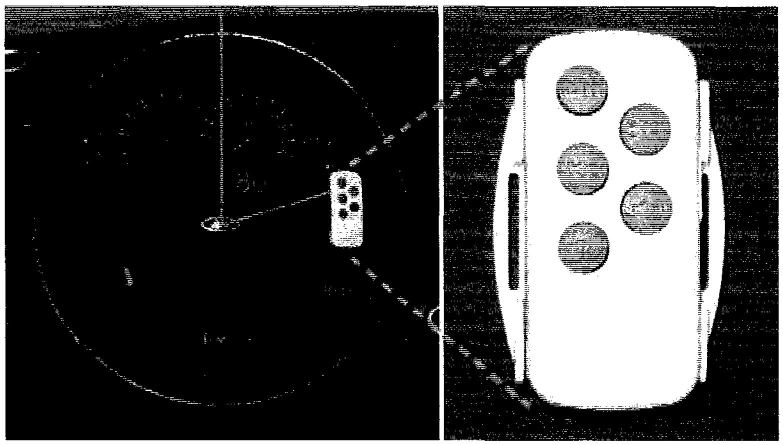

Figure 33 AirClick on the crossbar of the steering wheel and its position in the steering wheel coordinate system

In our data processing we also introduce a steering wheel coordinate system. The origin of the steering wheel coordinate system is fixed the top of the steering wheel. Thus, this coordinate system rotates with respect to the cabin coordinate system as the steering wheel rotates. The position of the AirClick in the steering wheel coordinate system is shown in Figure 33. Positive angles are counted in the clockwise direction. Figure 34 contrasts the two coordinate systems which are used to interpret data in the following section.

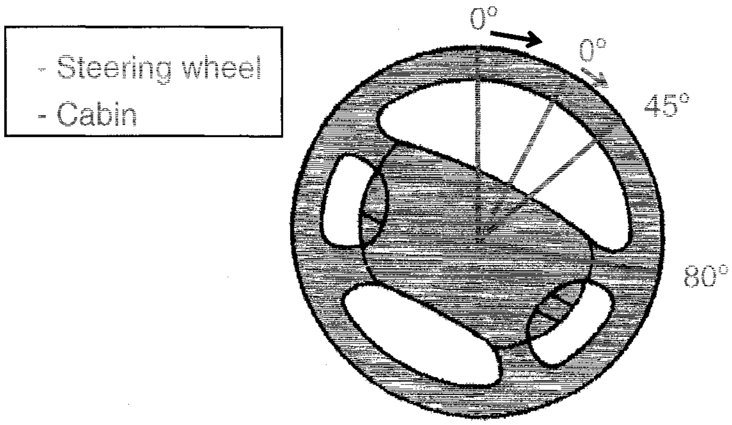

Figure 34 Cabin and steering wheel coordinate systems

During the experiments we noticed that the subjects often held their hands at a different position while using the glove as compared to using the fixed PTT. This phenomenon was further explored by compiling histograms of hand and wheel positions when either of the PTT solutions was activated. It delivered interesting results, shown in the figures below.

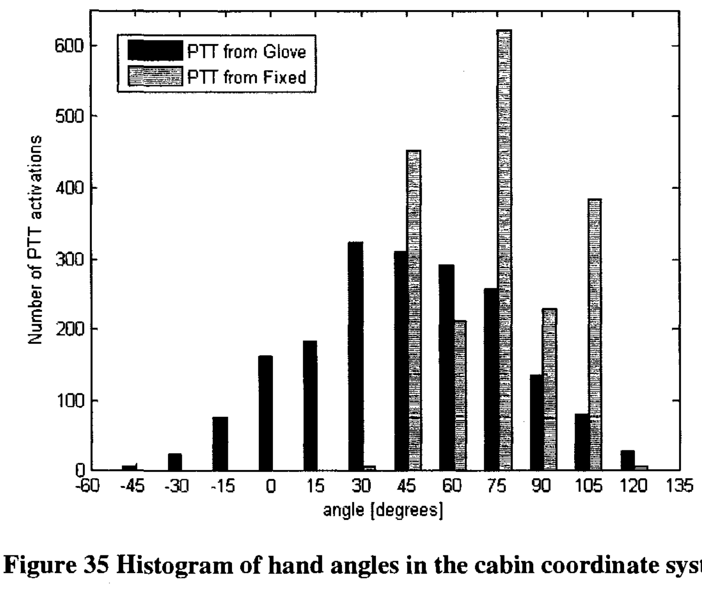

Figure 35 Histogram of hand angles in the cabin coordinate system

Figure 35 shows the angle positions in cabin coordinates for the drivers' hand while operating one or the other PTT solution. The blue bars represent glove positions hand-coded from the video footage. The orange bars were calculated by first adding 80° to the value of the steering wheel angle provided by the simulator, since this represents the position of the fixed PTT, and then assigning the result to one of the 15°-wide bins. It can be clearly noticed that there is a distinction between the values for the glove and the fixed solution. The blue glove bars are more spread out resembling a Poisson distribution with a mean around 45°, while the orange bars for the fixed button are more concentrated with a mean around 75°. This is due to the fact that the fixed button position is directly connected to the absolute steering wheel angle by adding 80 degrees. Clearly, when given a choice, drivers prefer to use, or are at least willing to experiment with using, a wider area of the steering wheel than afforded by the fixed PTT button. Also, they prefer to keep their hands and activate the PTT button around the "2 o'clock" position on the steering wheel (30-45 degrees), just as we were all taught in driver's education!

Figure 36 shows the position of the glove on the steering wheel in the steering wheel coordinate system. The fixed PTT button operations in this graph would all fall into the 75° bin, because in the relative coordinate system the push-button is at a fixed location. This graph can be interpreted similarly to the one in Figure 35. The peak in the 30 degree bin is prominent, again pointing to the fact that the "2 o'clock" position is popular.

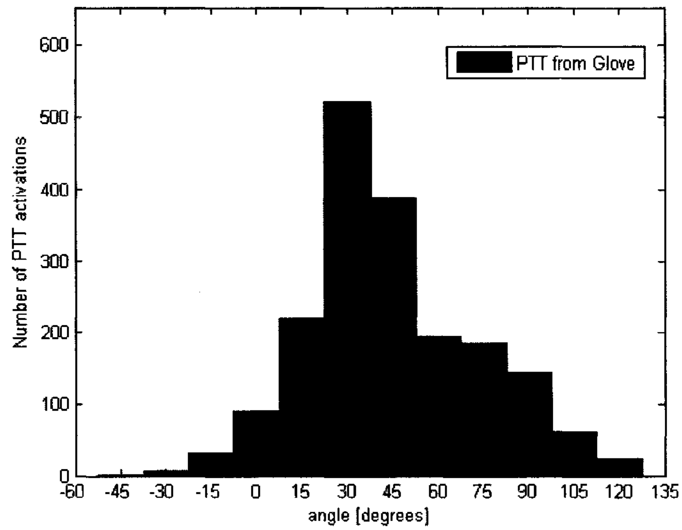

Figure 36 Histogram of hand angles while using the glove in the steering wheel coordinate system

Finally, the simulator provided steering wheel angles for time instances when a PTT button was pressed. Figure 37 shows the histogram of steering wheel angles for PTT button-presses, i.e. it shows the histogram of steering wheel positions when a PTT button was activated. These values are symmetrical around 0 degrees. They are distributed between driving straight and driving in left and right curves. Three distinctive spikes can be noticed in the histogram, for straight driving (0°), left (-30°) and right curves (30°). It can be seen that there is not much difference between the glove and the fixed PTT case. This means that the type of PTT solution used did not have effect on when the drivers decided to operate the system, i.e. the curves were slight, so they did not wait until they got to a straight part of the road to talk to the SUI. This was also confirmed by the questionnaire data described below.

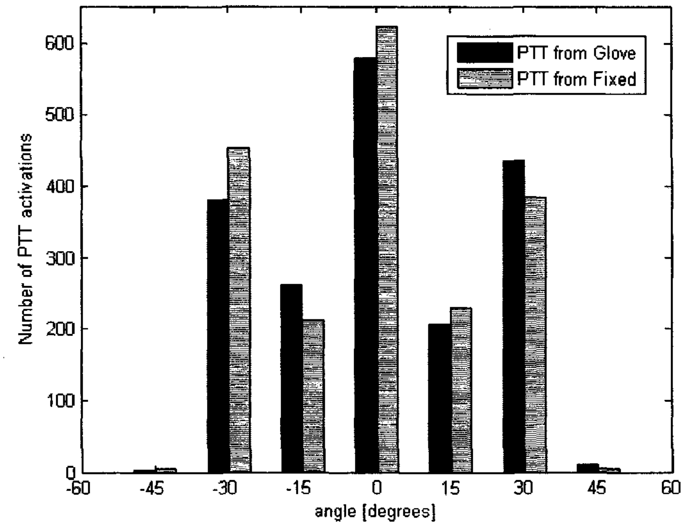

Figure 37 Histogram of steering wheel angles

Reviewing Figure 35 and Figure 37, we can see that while users operated the PTT buttons in almost identical steering wheel angles, they utilized the flexibility of the glove by placing their hands at angular positions that were presumably more comfortable than the 80 degrees required to operate the fixed PTT button.

Experiment Questionnaire Results

The experiment questionnaire questions were designed using the Likert-scale. The 5 possible answers were: yes, somewhat, neutral, not quite, not at all. The results of a Likert-scale questionnaire cannot be analyzed by the tools of quantitative statistics. Instead descriptive statistics has to be used [43]. This means that instead of the mean and standard deviation, medians, modes and interquartile ranges have to be used. Even if the levels of the Likert-scale are converted into numbers, e.g. ranging from 1 to 5 (one – yes; five – not at all), there is no sense calculating the mean, because it is usually a rational number between 1 and 5 (for example 4.34), which does not make any sense in terms of the level names. A value of 4.34 cannot be converted back to a named level (somewhat mostly disagree?). Even the median must not be an integer value (readily convertible back to a named level) in the case when the number of elements in the observed vector is even. Similar is the case with the interquartile range too. The median and mode are measures of a similar nature as the mean, while the interquartile range is similar to standard deviation, in that it describes the variability of the process.

The median is defined as the 50^{th} percentile of a sample. It can be explained as the number which separates the higher half of a given sample from the lower half. The mode is the number occurring most frequently in the population. The interquartile range is the spread of the sample between the lower and higher quartile (25^{th} percentile and 75^{th} percentile).

Another method of visualizing Likert-scale results is to plot a histogram of the data. This is done for example in Figure 38.

The responses to some of the statements in the questionnaire will be analyzed in detail in the following sections, while others will just be overviewed after that.

Statement (S): Using the PTT button while driving interfered with driving.

Response (R): Mode – Somewhat

Median – Neutral

Interquartile range – 2 units

Discussion: Drivers found mostly that the usage of the PTT button somewhat interfered with their driving performance. This is visualized in Figure 38 below. It can be noticed that the Mode and Median give different results. This is due to the asymmetric nature of the distribution. The Interquartile range is relatively high, spanning 2 answer levels. In effect ten of the 24 subjects thought that the fixed PTT button interfered with driving, which is a relatively high number.

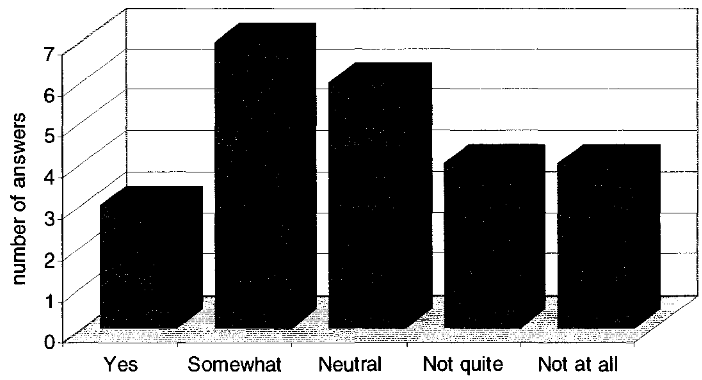

Figure 38 Answer histogram for "Using the PTT button while driving interfered with driving."

S: Using the glove while driving interfered with driving.

R: Mode – Not quite

Median – Not quite

Interquartile range – 1.5 units

Discussion: The subjects found that using the glove did not quite interfere with driving, Figure 39. In this case, the Mode and Median are at the same level, while the Interquartile range shows less variance. More than half of the participants (15/24) thought the glove did not interfere with driving.

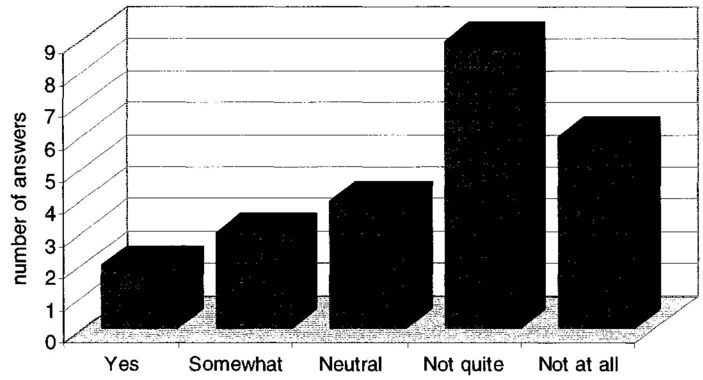

Figure 39 Answer histogram for "Using the glove while driving interfered with driving"

S: It was easier to use the glove compared to the PTT button.

R: Mode – Yes

Median – Yes

Interquartile range – 2.5 units

Discussion: In this comparison question, users found the PTT glove to be easier to use compared to the fixed PTT solution, shown in Figure 40. The Mode and Median agree in this opinion, while the IQR is high. Clearly, most subjects preferred the glove over the fixed PTT button.

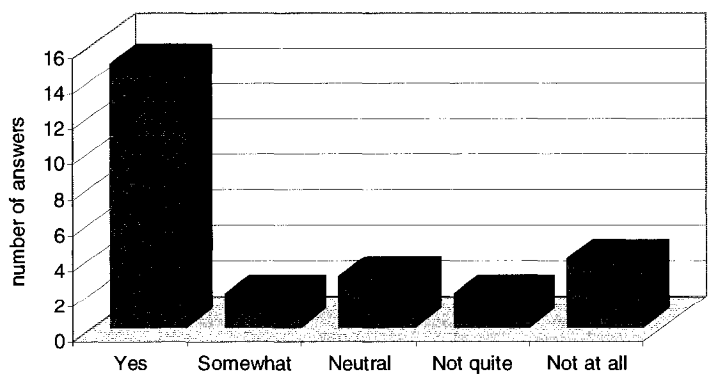

Figure 40 Answer histogram for "It was easier to use the glove compared to the PTT button"

S: It was more frustrating to use the glove compared to the PTT button.

R: Mode – Not at all

Median – Not at all

Interquartile range – 2 units

Discussion: To counter-balance the previous question, it was asked if the glove frustrated the subjects comparing to the fixed PTT button, which they rejected with high Mode and Median values. Figure 41 shows the histogram of the answers.

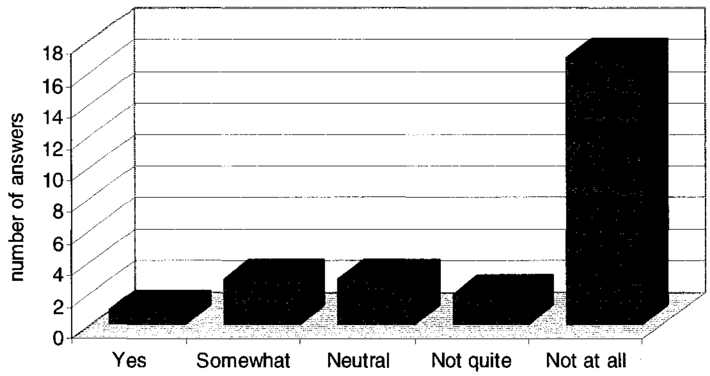

Figure 41 Answer histogram for "It was more frustrating to use the glove compared to the PTT button"

Looking at the responses to other statements, which are not covered in detail, a few more things can be noticed. The subjects felt very comfortable driving the simulator (the ones who did not have to leave due to simulator sickness – responses from those subjects are not included in the results). Most of them did not find the driving task to be difficult. They did not have problems understanding what their task was. They did not wait to get to an easier part of the road to operate the PTT. They all noticed that speech recognizer A performed better than speech recognizer B (A – high accuracy; B – low accuracy). They were not at all frustrated by recognizer A, and somewhat frustrated by B. They found that using the ambient recognizer (no PTT) did not interfere with driving. They found that it was fairly easy to use all three methods we examined (fixed PTT, glove, ambient). The median classified the fixed PTT button to be "somewhat" easy to use, the glove to be exactly between "somewhat" and "fully" easy, while ambient recognition was deemed to be "fully" easy to use. The Mode classified all of them to be "fully easy". The users mostly did not find any of the solutions to be frustrating, except for the Median of the fixed PTT, which was declared "not quite" frustrating, as opposed to "not at all" frustrating. Ten subjects out of the 24 reported explicitly looking down during the experiment to find the location of the fixed PTT button. A few subjects (3) have expressed their opinion about the possible effect of the usability of the glove on driver convenience during the summer period.

Visual Attention Data

Our eye-tracker system, described in Chapter IV, proved to be a great asset in information gathering. It provided us with a large number of additional information which we did not have in earlier experiments. Gaze tracking measures were found to be most useful of all the eye-tracking data gathered.

Using the virtual world capability of faceLAB 4.0, several virtual objects were created. The most important objects for the study were the steering wheel and speedometer. The faceLAB software logs the information of gaze intersection with these objects. This is done very precisely, as it was discovered by comparing the eye-tracker output with the video footage. During the experiment, it was noticed by the experimenter that some of the subjects have glanced down to find the position of the fixed PTT glove, right before operating it. This motivated the further investigation of the eye-tracker data for clues of this. It was noticed that there were many visual fixations at the steering wheel object. These fixations have been found to coincide with the reported effort of some of the drivers to find the fixed PTT button on the crossbar of the wheel. By looking at the video, it was also noticed that these fixations down were highly correlated with the operation of the PTT button, which followed right after the fixation. The delay between looking down and pushing the button was in most cases less than 2 seconds. There was no other reason except the PTT button to look down onto the steering wheel. Because of these reasons, all fixations down at the wheel at most 2 seconds before the PTT action were classified as fixations at the PTT button. This was verified by the experimenter for four randomly selected subjects by looking into the video footage.

Any time spent not looking at the road ahead could potentially cause a safety threat, since an unexpected event can occur anytime. A delay in reaction to such an event can cause hazardous driving situations. It has been noticed in this experiment, by applying the above described measures, that while using the fixed PTT solution, drivers have spent much more time looking down, away from the screen, compared to the situation when the glove was used. It was noticed that they spent time looking for the fixed PTT button, while in the case of the glove, they do not have to look down to find it, since the PTT switch is always located under their fingertips.

There were two objects created in the eye-tracker's virtual world to collect eye fixations: speedometer (encompassing all the instruments around it like the tachometer, fuel gauge, engine temperature gauge, etc.) and the lower part of the steering wheel, which is not overlapping with the speedometer object. For counting the fixations for the glove PTT solution, all the events recorded on both the speedometer and steering wheel object were taken into account. This was done, because the drivers usually held their hands at a higher position on the steering wheel, which could be registered by the eye-tracker as an intersection either with the speedometer or steering wheel object. For the fixed PTT solution, the counting depended on the angle of the steering wheel. When the steering wheel was held straight or turned in a right curve, only the fixations on the steering wheel object were recorded, because for these cases the fixed PTT button on the crossbar was always within the area of this virtual object. On the other hand, when the subjects were taking left turns, the fixations on the speedometer were also counted in addition to fixations on the steering wheel, because in this case, the PTT button was located at a position which would be covered by the speedometer object.

Figure 42 below shows the number of fixations at the PTT during interactions, averaged over all subjects. It can clearly be noticed that there were much more fixations at the fixed PTT button than on the glove PTT. The mean length of fixations down to the fixed PTT button was found to be 0.31 seconds. The mean length of fixations at the wheel when using the glove PTT button was 0.26 seconds.

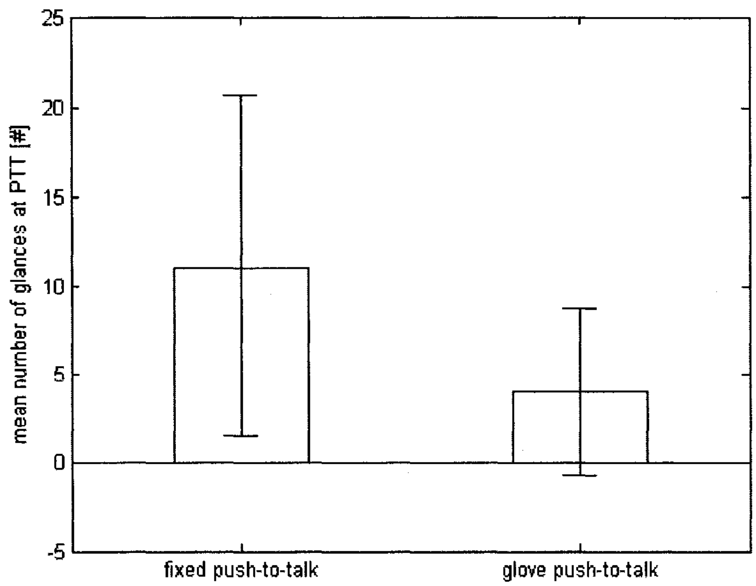

Figure 42 Number of fixations at the PTT during interactions

This data was analyzed using the one-way ANOVA (analysis of variance) statistical method. The F ratio of this analysis was found to be 10.3562. The probability that the difference between the means arose due to chance, i.e. the probability that the data from the two levels came from the same distribution is less than 0.0024 ($p<0.0024$).

	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
ANOVA	1	595.0208	595.021	10.3562	0.0024

Table 6 ANOVA results

The statistical measures of the two distributions are given in Table 7 below.

	fixed PTT	glove PTT
Samples	24	24
Mean [#]	11.0417	4
Standard deviation [#]	9.6165	4.7365
Median [#]	8.5	3
Interquartile range [#]	15	4.5

Table 7 Data measures

The above tables and figure show a clear statistically significant difference between the fixed PTT and the glove from the aspect of number of fixations away from the road to the PTT device. By diverting their gaze from the road while using any PTT solution, the subjects increased their risk of not being able to react to sudden events in due time. This negative effect, as we saw above, proved to be much more prominent for the fixed button.

Driving Performance Data

We performed a univariate ANOVA to determine the effect of four factors on driving performance. The four factors were (with levels in parentheses):

1. Recognition Accuracy (High or Low),
2. PTT Method (Fixed or Glove with Ambient Recognition data excluded),
3. PTT Type (PHR or PR) and
4. PTT Order (ambient-fixed-glove, fixed-glove-ambient or glove-ambient-fixed).

Note that we excluded the Ambient Recognition data from our ANOVA analysis. This was done since the PTT Type factor does not make sense for Ambient Recognition and thus the two cannot be considered together. The first two were within-subjects factors, while PTT Type and PTT Order were between-subjects factors.

While balancing the number of subjects for each level of the variables under 1,2 and 3 above, we unintentionally created a situation in which the presentation order of the fixed, glove and ambient levels was not counterbalanced. This means that there are cases of the order of these levels that are not present in the experiment. Also, the presentation orders present in the experiment do not appear in equal numbers within the PHR and PR

PTT Types. This is important when analyzing the effects of factors other than PTT Type, while keeping PTT Type constant (either PHR or PR). The order of presentation for each subject is shown below.

Subject	Order	PTT Type
user01	FGA	PHR
user04	FGA	PHR
user05	AFG	PHR
user06	GAF	PHR
user07	FGA	PHR
user09	AFG	PHR
user10	GAF	PHR
user12	GAF	PR
user13	AFG	PR
user14	FGA	PR
user15	AFG	PR
user16	GAF	PR
user17	FGA	PR
user18	AFG	PR
user19	GAF	PR
user20	FGA	PR
user21	AFG	PHR
user22	GAF	PR
user23	FGA	PHR
user24	AFG	PHR
user25	GAF	PR
user26	FGA	PHR
user27	AFG	PHR
user28	GAF	PR

Table 8 Ordering effect

In this table FGA stands for "fixed, glove, ambient" order, AFG for "ambient, fixed, glove" while GAF is the "glove, ambient, fixed" order. This ordering effect may have the negative consequence of affecting the results of comparing other driving performance variables. To handle this situation we have introduced a new independent between-subjects variable, PTT Order, which has the levels of the three orders present in the experiment: FGA, AFG and GAF. This way we were able to account for the influence of this ordering effect on the results and even come up with an interesting new result, which is presented in this section below.

We evaluated the following driving performance measures:

1. Variance of steering wheel angle (in degrees squared),
2. Variance of lane position (in meters squared),
3. Variance of velocity (in meters/second squared) and
4. Variance of distance to the leading vehicle (in meters squared).

In the analysis of data below, the values for "user10" have been omitted, since his data was deemed to be an outlier [44], i.e. the variance of his driving was largely different compared to the values of other subjects (more than 1.5 IQRs away from the 75th percentile).

We found that recognition accuracy affected steering wheel angle variance significantly ($p<0.013$). This result replicates the result of our previous study [3] which found a similar relationship between recognition accuracy and steering wheel angle variance. The means of the variances are shown in Figure 43. High Recognition Accuracy resulted in lower variance, which indicates better driving performance.

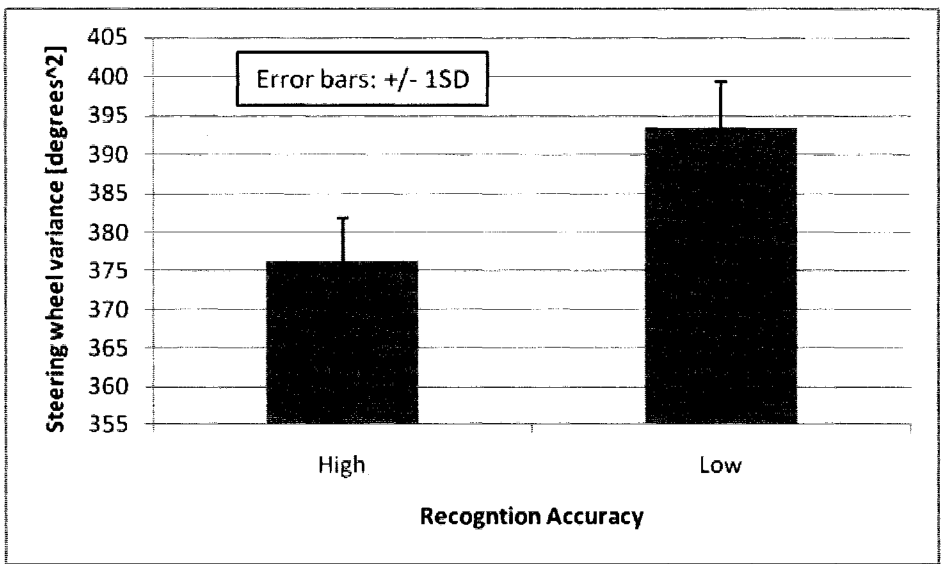

Figure 43 Steering wheel angle variance is affected by Recognition Accuracy

We also found that the interaction between Recognition Accuracy, PTT Type and PTT Order had a significant effect on steering wheel angle variance ($p<0.04$). The means of the variances are shown in Figure 44. Figure 44 shows visually that most of the variances associated with Low Accuracy are higher than those associated with High Accuracy. The lowest variance was recorded for High Accuracy, push-hold-release (PHR) PTT Type and the fixed-glove-ambient PTT Order. The fixed-glove-ambient order means that the data that produced this lowest variance came from users who used the fixed PTT first and then the glove PTT (ambient data is not used in this calculation). Note that for High Accuracy and the push-release (PR) PTT Type the FGA order again produced the lowest variance. One explanation for the low variance may be that these users appreciated the improvement in the PTT Type (they preferred the glove over the fixed PTT) and were not at all frustrated by the interaction and thus performed well on the driving task. On the other hand, users who experienced the AFG order have already experienced the ambient recognition and for them the transition from ambient recognition to the fixed PTT mode may have introduced a reason for frustration and thus worse performance. Presumably these users performed better with the glove PTT than with the fixed PTT, however, their fixed PTT performance may have been bad enough to make the overall variance high. Similarly the GAF order may have introduced frustration in the fixed PTT case, while performance during the starting glove PTT case may have been negatively influenced by the lack of experience with the simulator.

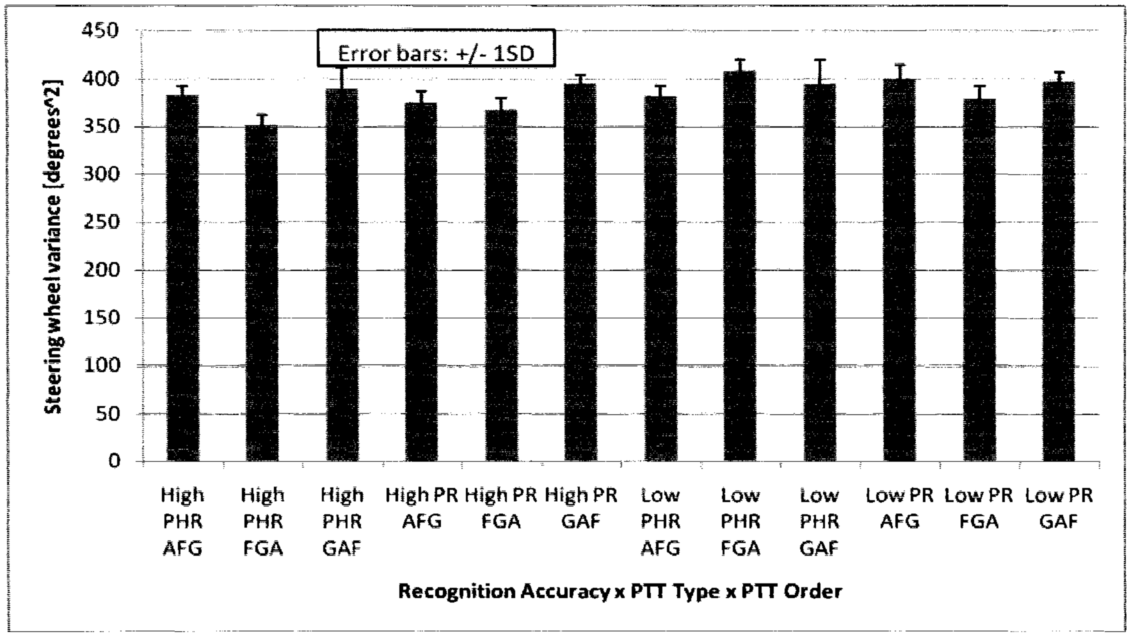

Figure 44 Steering wheel variance is affected by the interaction of Recognition Accuracy, PTT Type and PTT Order

We also used univariate ANOVAs to evaluate the performance of the fixed PTT versus ambient recognition and the performance of the glove PTT versus ambient recognition. Note that these comparisons can only be done by fixing the PTT Type and considering PTT Method as a within-subjects variable. Thus, we used only three of the factors listed above:

1. Recognition Accuracy (High or Low)
2. PTT Method (Fixed/Glove or Ambient Recognition)
3. PTT Order (ambient-fixed-glove, fixed-glove-ambient or glove-ambient-fixed).

We evaluated the same four driving performance measures as in the analysis above.

When the PTT Type was set to PHR (push-hold-release) none of the factors influenced driving performance significantly.

When PTT Type was set to PR (push-release) we found significant interaction effects. Let us first look at the comparison of driving performance when using the fixed PTT to driving performance when using ambient recognition. In this case we found that the interaction between PTT Method and PTT Order had a significant effect on lane position variance (p<0.03). The means of the variances are shown in Figure 45.

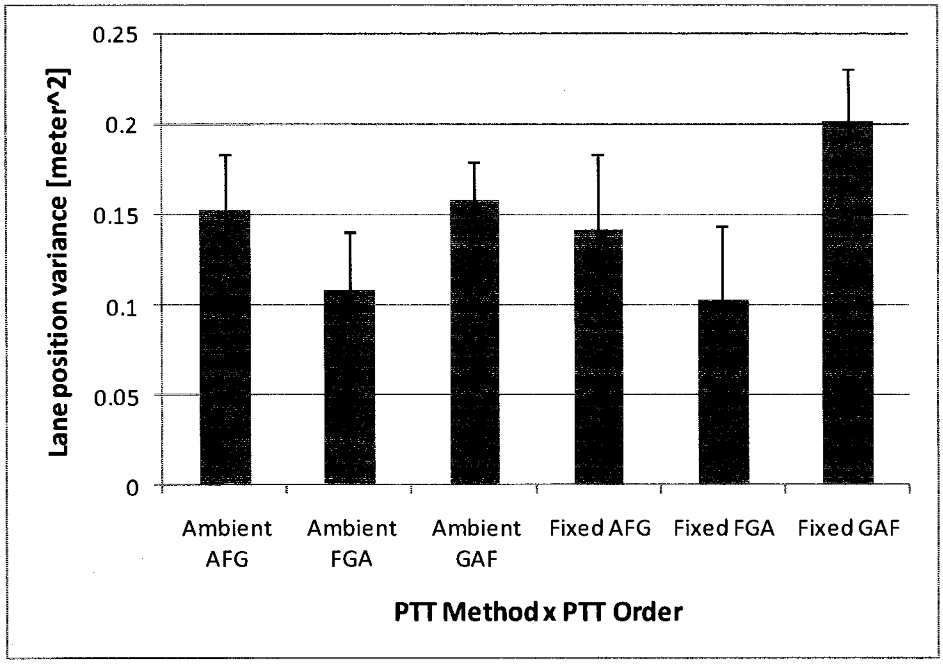

Figure 45 Lane position variance is affected by the interaction of PTT Method and PTT Order

Further analyzing the interaction between PTT Method and PTT Order for the PR sequence on lane position variance, we found that glove vs. ambient recognition does not yield a statistically significant result (ANOVA p<0.61), as opposed to the fixed vs. ambient case. The means for this comparison are show in Figure 46.

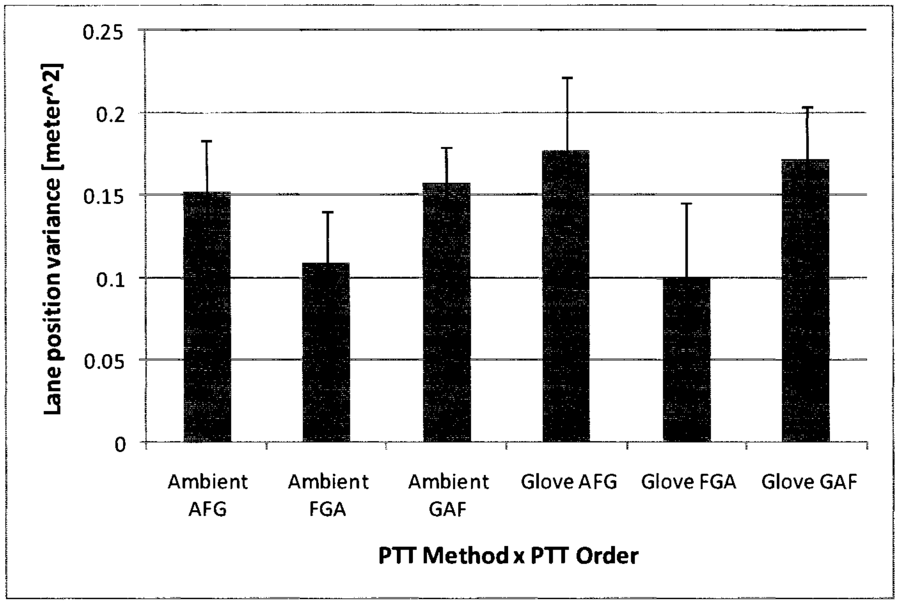

Figure 46 Lane position variance not affected by glove vs. ambient

A similar situation arises when analyzing the effect of fixed PTT compared to the glove on lane position variance. No significance is observed here either (ANOVA p<0.47) in contrast to the fixed vs. ambient case shown in Figure 45. The means for this analysis are shown in Figure 47.

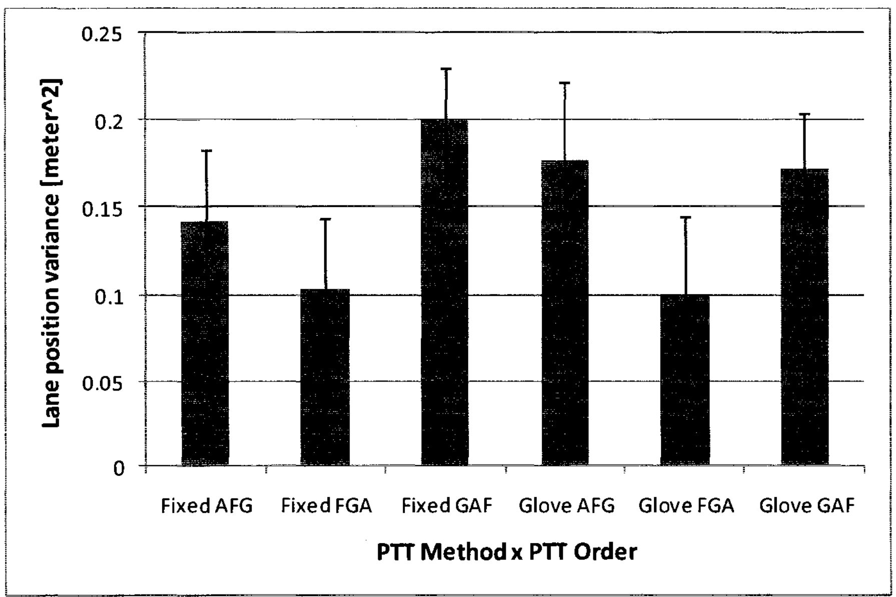

Figure 47 Lane position variance not affected by glove vs. fixed

In the above three cases the only statistically significant difference observed was the difference between lane position variance when using the fixed PTT button vs. lane position variance when using ambient recognition. These results support our hypothesis, shown in Figure 1, that it is the hardest to use the fixed PTT button, easier to use the glove and easiest to use the ambient recognizer. However, while we have found a difference between the proposed hardest (fixed) and easiest (ambient) methods, we have not found a difference between the method in the middle (glove) and the other two methods.

Getting back to the significant result, we propose that the data shown in Figure 45 can be best understood by recoding the PTT Order factor into a Previous Experience factor. Previous Experience indicates if the PTT interaction type that came before the current one was good or bad relative to the current one. Thus, if the current PTT Type is Glove and the previous one was Fixed PTT we can argue that the Previous Experience was relatively Bad. If the current PTT Type is Glove PTT and the previous one was Ambient Recognition then the argument is reversed and the Previous Experience is relatively Good. Our hypothesis is that Bad Previous Experiences will improve performance on the current PTT Type while Good Previous Experiences will decrease performance on the current PTT Type. After all, a Good Previous Experience indicates that the current PTT Type provides a worse user interaction experience which may result in frustration and thus worse driving performance. A Bad Previous Experience indicates that the current PTT Type provides an improved user interaction experience and hopefully no frustration and thus better performance.

We recoded the data according to Table 9.

Original factors (PTT Method x PTT Order)	Re-coded factors PTT Method x PTT Order – Previsou Experience	Explanation
Ambient AFG	Ambient AFG - Starting	Ambient recognition is the starting type of interaction.
Ambient FGA	Ambient FGA - Bad	Ambient recognition comes after a glove PTT experience, which is relatively bad in comparison.
Ambient GAF	Ambient GAF - Bad	Ambient recognition comes after a glove PTT experience, which is relatively bad in comparison.
Fixed AFG	Fixed AFG - Good	Fixed PTT comes after an ambient recognition experience, which is relatively good in comparison.
Fixed FGA	Fixed FGA - Starting	Fixed PTT is the starting type of interaction.
Fixed GAF	Fixed GAF - Good	Fixed PTT comes after an ambient recognition experience, which is relatively good in comparison.

Table 9 Re-coding the data

The variances labeled with the re-coded factors are shown in Figure 48, where we also rearranged the variances in increasing order from left to right. We find that the lowest variance occurs during a starting experience and during ambient recognition which follows a relatively Bad Previous Experience. The highest variance, indicating worst driving performance, comes during fixed PTT interaction that follows a relatively Good Previous Experience. This view of the data indicates that the order effect may in fact be related to the memory of the previous interaction type. If the previous interaction type (coded as the Previous Experience factor) was good the user is more likely to perform worse on the current interaction type and vice versa.

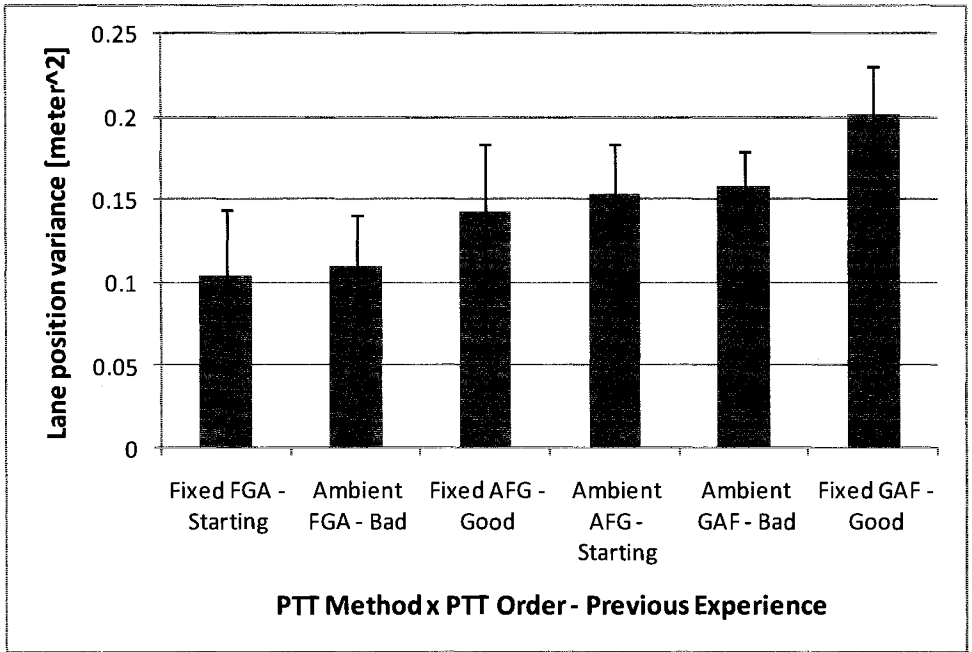

Figure 48 Re-coded factors

Let us now look at the comparison of driving performance when using the glove PTT to driving performance when using ambient recognition. We found that the interaction of Accuracy, PTT and PTT Type has a significant effect on the variance of steering wheel angle ($p<0.05$). The variances are shown in Figure 49.

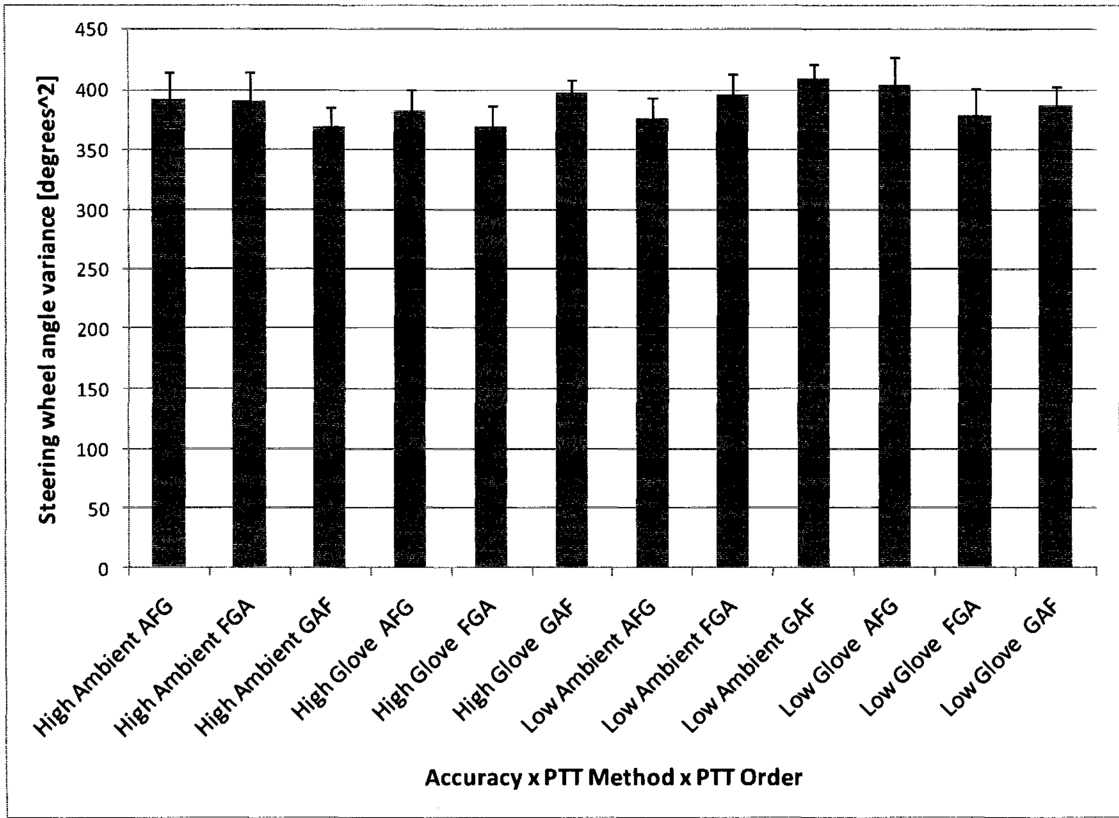

Figure 49 Steering wheel variance is affected by the interaction of Accuracy, PTT Method and PTT Order

Again, re-coding the factors in a fashion similar to the one proposed above we get Figure 50. In this graph we see that best performance is achieved when recognition accuracy is high and the previous experience was relatively bad, while the worst performance is achieved when recognition accuracy is low or when the recognition accuracy is high but the interaction under scrutiny is the first interaction of the experiment. Again, we hypothesize that bad the previous experience may in some cases induce positive feelings about the current, apparently improved, interaction type. We also hypothesize that participants did get better at operating the simulated vehicle as the experiment proceeded. If this hypothesis is correct we should allow for longer training at the beginning of experiments.

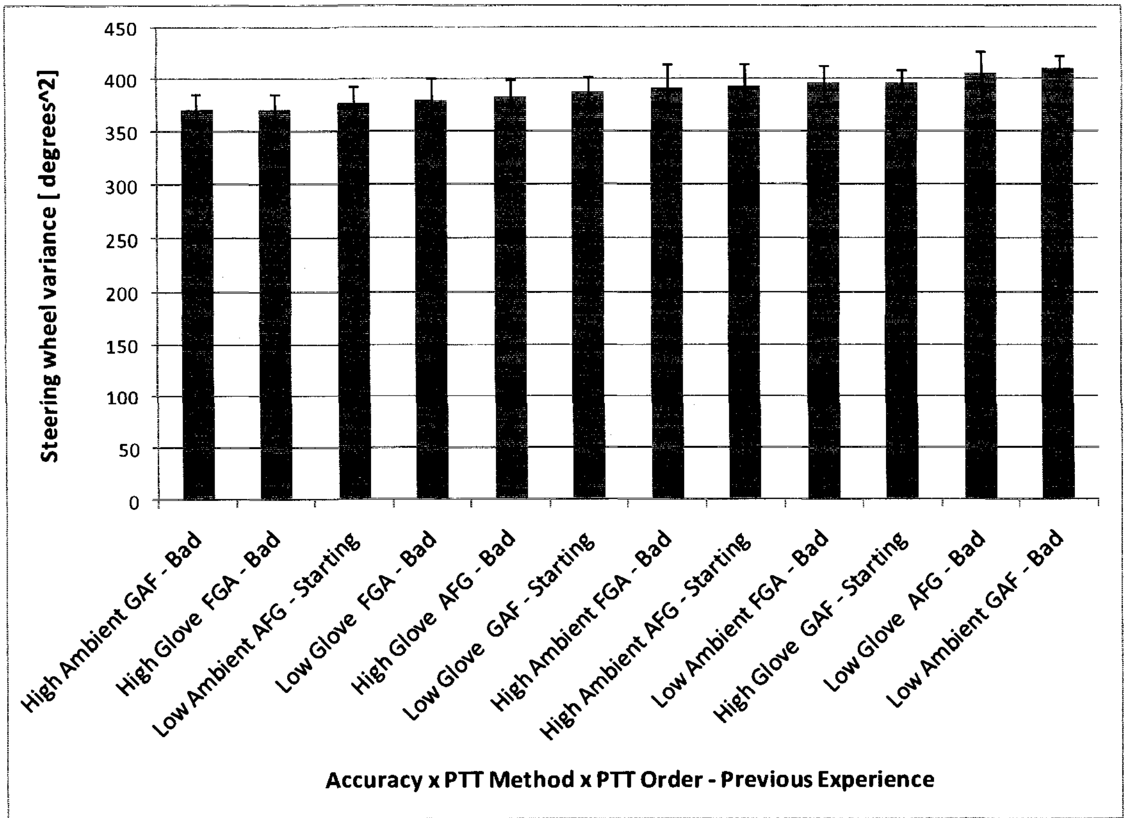

Figure 50 Steering wheel variance is affected by the interaction of Accuracy, PTT Method and PTT Order – Previous Experience

CHAPTER VI

CONCLUSION

The proposed steps of the research in Chapter I section Approach were listed as follows:

1. Design and implement a prototype wireless push-to-talk glove
2. Perform a pilot study to validate the usability of such a solution
3. If successful, perform a full experiment using the glove
4. Analyze the collected data
5. Compile future steps for possible follow-up experiments

Step 1 was successfully completed by designing and implementing the wireless PTT glove. A pilot study was conducted to validate the proposed design, according to Step 2. Since this study was deemed to be successful in showing differences between the PTT glove and fixed button solution, a full experiment was scheduled and performed.

During the experiment data was collected from the simulator, eye-tracker, video camera and using questionnaires. The subsequent analysis of this corpus gave a number of interesting findings. First, the video footage showed that drivers, while using the glove, tended to hold their hands at a natural (2 o'clock) position on the steering wheel while operating the PTT button. Also, they used it in a broader operation range as compared to the fixed PTT button, which is confined to a fixed location on the steering wheel. Second, the post-experiment questionnaire data showed that subjects considered the new PTT solution to be easier to use and not to be frustrating compared to the fixed button. Third, the eye-tracker data on fixations to the PTT button indicate that the fixed solution draws much more attention away from looking at the road ahead compared to the glove. Finally, the driving performance data shows that recognition accuracy of the speech user interface significantly affects driving performance. Lower accuracy led to worse driving performance and vice versa. Also the analysis suggests that the prior experience with a PTT Type (glove or fixed) can affect drivers' performance. If the experience was moving from Bad to Good, the drivers tended to have better performance in certain situations.

Based on the lessons learned during the implementation, pilot study and experiment, future work steps are proposed for a possible follow-up experiment, which could help broaden our understanding of the characteristics of in-car speech user interfaces.

We had two major hypotheses in our work. The first proposed that a wireless PTT glove could be used to indicate to the recognizer the beginning and end of user utterances, both from inside and from outside the vehicle. In this thesis we examined the in-vehicle operation of such a PTT solution. We have found that this is a viable solution for activating the SUI. Subjective opinion of the drivers also approves this, since they mostly found the glove to be an easy, non-frustrating, natural and non-interfering solution. Some of the drivers have noticed possible flaws of the system that could be addressed in the future: it might be inconvenient to wear a full glove during the summer period.

The other major hypothesis proposed that driving performance will be affected by multiple factors related to the characteristics of the speech user interface, the type of road traveled and the psychological state of the driver. These questions were addressed in detail.

We hypothesized that driving performance will be better when using the ambient recognizer compared to the use of the glove PTT button. On the other hand it was expected that the glove PTT button will perform better than the fixed. We did not find direct evidence for this proposed step in the driving performance data. No direct statistical significance was found between these levels. An explanation for this might be that the road that the subjects used was not hard enough to drive on to be able to discriminate between these levels. Indirect data, as discussed in the section above, shows us that there might be a qualitative difference between using the glove and fixed button. If the Previous Experience was Bad and the drivers moved to a better, easier solution (e.g. first using fixed, then glove), then the subjects tended to have better driving performance as compared to a situation when the Previous Experience was better than the current one. In other words the driver's performance increased when switching to a better interface system (fixed to glove, glove to ambient).

We also hypothesized that driving performance for the push-release PTT operation will influence driving performance less than the push-hold-release sequence. We did not find statistical significance for this hypothesis. Based on the data analysis done, it can be concluded, that none of the solutions was better or worse in our experiments.

The third hypothesis was the following interactions between PTT glove usage, PTT interaction type, speech recognizer accuracy, different road types and various other factors, affect driving performance in different ways. It was shown in the sections above, that there are a number of factors that can additionally affect driving performance. As we have seen before, this study confirmed, that recognition accuracy does affect driving performance. Also it was found that PTT Order (and possibly the related Previous Experience factor) can be significant in certain situations. Also, PTT solution types can affect other measures of driver performance, like the time spent looking away from the road, overall driver satisfaction with the interface method and hand position on the steering wheel. It is also proposed that simulation roads which are of a higher complexity (e.g. city driving) compared to the road type used in this research (rural curvy highway) could affect driving performance. We hypothesize that the complexity of the road used in this experiment was not high enough to possibly reveal direct differences between different PTT solutions, which suggests that a higher complexity road might show differences.

The first and main goal of our research was to create a prototype PTT solution that would contribute to providing a seamless experience for users in interacting with a speech user interface both inside and outside a vehicle. This goal was partially achieved by designing and implementing our new wireless PTT glove. We have showed its merit in an in-car environment, which was the focus of this thesis. In order to fully achieve this goal the glove PTT could be interfaced to a handheld computer operating outside the vehicle.

The second goal was to evaluate the impact of using the new PTT solution on driving performance. The constraints on this goal were that the evaluation be done only on a two-lane, curvy, rural road with limited traffic, traversed in daytime, and only using one speech interaction task. This goal was accomplished. Many positive effects of using the glove have been found comparing the glove to the fixed PTT: more natural hand position during driving, less impact on visual attention and better subjective opinion. Driving performance was found to be on the same level for both solutions.

CHAPTER VII

FUTURE WORK

According to Step 5 of the Approach section of the Introduction chapter, future directions of the current research will be discussed in this chapter. The research on new PTT solutions like the glove could be continued in several directions. First, the current experiment did not provide discrimination for strict driving performance measures (lane position, steering angle, etc.) between the fixed and the floating PTT solution. Second, the glove could be tested with police officers as subjects. Next, besides inside a vehicle, the glove could be used also outside it, providing a continuous UI experience for the subject. Finally, the glove itself could be improved to be less intrusive while providing more sensing capabilities [18]. These possible directions will be examined in short in the following section.

New Driving Scenario

The research of any kind of in-car device, usually involves the introduction of a secondary task next to driving. This task has the function to divert the attention of the operator from driving to the new device, thus affecting driving performance measures. The amount of this change of performance can characterize the proposed new in-car instrument or novel interaction method. The amplitude of this change can also depend on the complexity of the primary task. A complex driving task would compete for more attention of the driver compared to a simple task. This situation of overloading the attention of the driver creates a good starting point for performance differences. In the case of the current experiment, the driving task could be made more complex in order to have more pronounced performance differences. The so far used scenario with only gentle curves, proves to be a simple one. A more challenging scenario could involve city driving with intersections, straight parts and sharper curves. Intersections are especially good, because they exert a lot of visual and cognitive load. It is supposed that in these cases, the distinction between the fixed and the floating PTT solutions could be more pronounced. These situations could also affect the drivers in waiting to operate the PTT after they reached an easier part of the road. As it was seen in the results of the experiment questionnaire this was not the case for the current experiment, but was seen as an effect tool in the pilot study.

Police Officers as Subjects

Since the deployed Project54 system is mostly used by police officers, it would make sense to test the glove with officers as subjects. Police officers are trained professionals. It is a part of their job to learn to use all the equipment in their vehicles. They also have much more driving experience than most of the subjects that were performing our experiments. These reasons make them members of a special group of professionals compared to the general population. Because of these differences the experiments may produce different results with officers as subjects compared to using the subject pool of students and staff at UNH.

Out-of-Vehicle Usage

Project54 already has its handheld version, which is intended for out-of-vehicle usage [40]. This version runs on a PDA device and connects to the in-car system for control and data retrieval. For example, the PDA can contact the central vehicle computer with a driver's license query, which would be forwarded to headquarters using digital radio. The results would then be sent back to the cruiser and from there to the handheld device in a matter of seconds.

In this environment the glove could also be potentially used. The PTT glove could facilitate the operation of the system. Here it would also act as a PTT trigger, but in this case in conjunction with the PDA version of the P54 software.

A Future Ubiquitous Glove

A more complex system, compared to the PTT glove, could provide additional functionality. A similar idea was proposed by RallyPoint, where it is suggested, that soldiers could use intelligent gloves in communication with each other [18]. In our case, beside the push-buttons, the glove could contain other sensor devices too, e.g. gyroscopes, accelerometers, pressure sensing strips, etc. Gyros could provide orientation, accelerometers give information on movement, while pressure sensors quantify grip forces inside the glove. A glove equipped with all these devices could render a 3D interface environment similar to the one presented in the motion picture "Minority Report" [45]. It could be used for controlling some of the devices in the P54 system using hand gestures.

In the above sense there are lots of possibilities to further develop the glove system into a possible semi-intelligent, context-aware, ubiquitous, pervasive, wearable user interface.

LIST OF REFERENCES

[1] Adriana Barón, Paul Green, "**Safety and Usability of Speech Interfaces for In-Vehicle Tasks while Driving: A Brief Literature Review**," University of Michigan Transportation Research Institute, Technical Report 2006-5, 2006.

[2] Ronald Rosenfeld, Dan Olsen, Alex Rudicky, "**Universal speech interfaces**," *Interactions*, vol. 8, no. 6, 2001.

[3] Andrew Kun, Tim Paek, and Zeljko Medenica, "**The Effect of Speech Interface Accuracy on Driving Performance** ," *Interspeech,* Antwerpen, 2007.

[4] Lisbeth Harms, "**Variation in Drivers' Cognitive Load. Effects of Driving Though Village Areas and Rural Junctions**," *Ergonomics*, vol. 34, no. 2, pp. 151-160, 1991.

[5] Omer Tsimhoni, Paul Green, "**Visual Demand of Driving and the Execution of Display-Intensive In-Vehicle Tasks**," Human Factors and Ergonomics Society, 2001.

[6] Immersion Inc., **"Wireless Data Glove: The CyberGlove® II System"** *http://www.immersion.com/3d/products/cyber_glove.php* , last visited July 28, 2008.

[7] Immersion Inc., **"CyberGrasp™ Exoskeleton"** *http://www.immersion.com/3d/products/cyber_grasp.php* , last visited July 28, 2008.

[8] Virtual Realities Inc., **"P5 Glove"** *http://www.vrealities.com/P5.html*, last visited July 28, 2008.

[9] Fifth Dimension Technologies Inc., **"5DT Data Glove 5 Ultra"** *http://www.5dt.com/products/pdataglove5u.html*, last visited July 28, 2008.

[10] Bhargav Bhat, Hemant Sikaria, Jorge L. Meza, Wesley Jin, **"HandTalk "**

http://www.ece.cmu.edu/~ece549/spring08/team12/index.html , Carnegie Mellon University, last visited July 28, 2008.

[11] University of Technology Eindhoven, **"Gesture Jam"** *https://w3.id.tue.nl/nl/education/domain_play/showcase/gesture_jam/* , last visited July 28, 2008.

[12] Kevin Mellott, **"The DataGlove Project"** *http://www.geocities.com/mellott124/DataGlove.htm* , last visited July 28, 2008.

[13] Gary Hsu, Jonathan Chan, **"Gauntlet of uComputation"** *http://instruct1.cit.cornell.edu/courses/ee476/FinalProjects/s2005/gch22jdc48/web/index.html* , Cornell University, last visited July 28, 2008.

[14] Jocelyn Scheirer, Rosalind Picard, **"Galvactivator"** *http://www.media.mit.edu/galvactivator/* , Massachusetts Institute of Technology, Media Lab, last visited July 28, 2008.

[15] Swany and Texsys GmbH, **"Swany G-Cell"** *http://www.texsys.de/products/gcell.html* , last visited July 28, 2008.

[16] Reusch GmbH, **"Sonic Control"** *http://www.reuschusa.com/prod.php?p=CON2690140* , last visited July 28, 2008.

[17] Engineered Fibre Structures Ltd., **"Control Glove"** *http://www.fibrestructures.com/innovations.html* , last visited July 28, 2008.

[18] RallyPoint Inc., **"Handwear Computer Input Device"** *http://www.rallypoint.info/docs/hcid.pdf* , last visited July 28, 2008.

[19] Myung Hwan Yun, David Cannon, Andris Freivalds, Geb Thomas, "**An Instrumented Glove for Grasp Specification in Virtual-Reality-Based Point-and-Direct Telerobotics**" *IEEE Trans. on Systems, Man and Cybernetics, Vol. 27, No. 5,* 1997.

[20] Sigeru Sato, Makoto Shimoyo, Yoshikazu Seki, Akihiko Takahashi, Shunji Shimizu,

"**Measuring System for grasping**", *IEEE Workshop on Robot and Human Communication*, 1996.

[21] Stephen Mascaro, Harry Asada, "**Hand-in-Glove Human-Machine Interface and Interactive Control: Task Process Modeling Using Dual Petri Nets**", *Proc. IEEE International Conference on Robotics and Automation*, 1998.

[22] Maria Claudia Castro, Alberto Cliquet Jr., "**A Low-Cost Instrumented Glove for Monitoring Forces During Object Manipulation**," *IEEE Transactions on Rehabilitation Engineering* 1997.

[23] Kenichi Koyanagi, Yuki Fujii, Junji Fushuro, "**Development of VR-STEF System with Force Display Glove System**," *ICAT*, 2005.

[24] Seongil Lee, Sang Hyuk Hong, Jae Wook Jeon, "**Designing a Universal Keyboard Using Chording Glove**," *CUU*, 2003.

[25] Sidney Fels, Geoffrey Hinton, "**Glove-TalkII: An Adaptive Gesture-to-Formant Interface**," *Conference on Human Factors in Computing Systems*, 1995.

[26] In-Kwon Park, Jung-Hyun Kim, Kwang-Seok Hong, "**An Implementation of an FPGA-Based Embedded Gesture Recognizer Using a Data Glove**," *ICUIMC*, 2008.

[27] Jose Molina, Arturo Garcia, Diego Martinez, Francisco Manjavacas, Victor Blasco, Victor Lopez, Pascual Gonzalez, "**An Implementation of an FPGA-Based Embedded Gesture Recognizer Using a Data Glove**," *VRST*, 2006.

[28] Lizhuang Ma, Rynson W. H. Lau, Jieqing Feng, Qunsheng Peng, Janis Wong, "**Surface Deformation Usign the Sensor Glove**", *ACM VRST97*, 1997.

[29] Wai-Chun Lam, Feng Zou, Taku Komura, "**Motion Editing with Data Glove**," *ACE04*, 2004.

[30] David Rodriguez, Ivan Rodriguez, "**VIFE_alpha v.01 Real-time Visual Sound Installation Performed by Glove-Gesture**," *NIME05*, 2005.

[31] David Sturman, David Zeltzer, "**A Survey of Glove-based Input**," *IEEE Computer Graphics and Applications*, 1994.

[32] Andrew L. Kun, W. Thomas Miller, William H. Lenhart, "**Computers in Police Cruisers**," *IEEE Pervasive Computing*, vol. 3, no. 4, 2004.

[33] Paul Heisterkamp, "**Linguatronic product-level speech system for Mercedes-Benz cars**," San Diego, Association for Computational Linguistics, 2001.

[34] Microsoft, Ford, **"Sync Technology"** *http://www.syncmyride.com/*, last visited July 28, 2008.

[35] Nina Dragutinovic, Divera Twisk, "**Use of mobile phones while driving - effects on road safety** ," SWOV Institute for Road Safety Research, Leidschendam, The Netherlands, Report 2005-12, 2005.

[36] Zeljko Medenica, Andrew Kun, "**Comparing the Influence of Two User Interfaces for Mobile Radios on Driving Performance**," *Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design* 2007.

[37] Vicki L. Neale, Thomas A. Dingus, Sheila G. Klauer, Jeremy Sudweeks, Michael Goodman, "**An Overview of the 100-Car Naturalistic Study and Findings**", National Highway Safety Administration, 2005.

[38] Dario D. Salvucci, "**Predicting the effects of in-car interfaces on driver behavior using a cognitive architecture**", Proceedings of the Conference on Human Factors in Computing Systems, 2001.

[39] Andrew W. Gellatly, Thomas A. Dingus, **"Speech Recognition and Automotive Applications: Using Speech to Perform In-Vehicle Tasks"**, *Proceedings of the Human Factors 32nd Annual Meeting,* Human Factors and Ergonomics Society, 1998.

[40] Andras K. Fekete, Andrew L. Kun, **"Handheld Computing in Law Enforcement: A Pilot Study"**, *IE08*, 2008.

[41] Oskar Palinko, Andrew L. Kun, **"Prototype Wireless PTT Glove"**, *IE08*, 2008.

[42] Mark S Sanders, Ernest J McCormick, **"Human Factors in Engineering and Design"**, Seventh Edition, McGraw-Hill, 1993.

[43] Nora Mogey, Learning Technology Dissemination Initiative, **"So You Want to Use a Likert Scale"**, *http://www.icbl.hw.ac.uk/ltdi/cookbook/info_likert_scale/*, last visited July 28, 2008.

[44] Marcello Pagano, Kimberlee Gauvreau, **"Principles of Biostatistics"**, Duxbury Press, 2000.

[45] Steven Spielberg, **"Minority Report"**, 20th Century Fox and Dreamworks Pictures, 2002.

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

University *of* New Hampshire

Research Conduct and Compliance Services, Office of Sponsored Research
Service Building, 51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

01-Nov-2007

Kun, Andrew
Electrical & Computer Eng Dept
Kingsbury Hall
Durham, NH 03824

IRB #: 2980
Study: Speech Sample Collection for Speech Recognition Engine Comparison and Development
Approval Expiration Date: 24-Jun-2008
Modification Approval Date: 31-Oct-2007
Modification: Collection of additional data (e.g. physiological measures) per 10/22/2007 email

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved your modification to this study, as indicated above. Further changes in your study must be submitted to the IRB for review and approval prior to implementation.

Approval for this protocol expires on the date indicated above. At the end of the approval period you will be asked to submit a report with regard to the involvement of human subjects in this study. If your study is still active, you may request an extension of IRB approval.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* This document is available at http://www.unh.edu/osr/compliance/irb.html or from me.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie F. Simpson
Manager

cc: File