EVALUATION OF GESTURE-BASED CONTROLS FOR ROBOTIC SYSTEMS

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A THESIS

in

Computer and Information Science

Presented to the Faculties of the University of Pennsylvania in Partial

Fulfillment of the Requirements for the Degree of Master of Science in Engineering

2012

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Acknowledgements

I would like to thank Prof. Norm Badler for advising work on this thesis, as well as Prof. Kostas Daniilidis (CIS, University of Pennsylvania) and Prof. Steve Lane (CIS, University of Pennsylvania) for serving on the thesis committee. I would also like to thank Dr. Mubbasir Kapadia for providing help with the experiment design, Daniel Barber (Institute of Simulation and Training, University of Central Florida), for providing help with testing the gesture-based controls, and Robert Nesselrath (German Research Center for Artificial Intelligence) for providing the GestureTrainer code.

Abstract

Robotic control systems are becoming more common, especially in the military, and there is a growing need for better control interfaces. Arm and hand gestures are typical human forms of communication, so applying that to a robotic control system can yield a more intuitive system. With military applications, there are lives at stake, so having the most efficient, intuitive control system can make a large difference in the success of a mission and the safety of the soldiers involved. The work in [18] describes a gesture based control system that uses the Nintendo Wiimote to determine arm/hand gestures and control a robot. I propose to create a gesture based system using a smartphone and conduct an experiment similar to the work in [18], collecting survey data from the participants on the the effectiveness and ease of use of each system. This thesis aims to test the effectiveness/ease of use of smartphone gesture-based robotic control systems vs. traditional control systems.

Chapter 1

Introduction

The need for human-robot interfaces is increasing rapidly. The military has already begun using unmanned vehicles in several different arenas (air, ground, water). In order to develop the most efficient human-robot interface, we turned to a traditional form of human-human communication, arm and hand gestures. Arm and hand gestures are typical human forms of communication, so applying that to a robotic control system can yield a more intuitive system. With military applications, there are lives at stake, so having the most efficient, intuitive control system can make a large difference in critical moments and improve the safety of those involved. A more intuitive system will also reduce the training time and expenses for the operators of the vehicle.

The work in [18] describes a gesture based control system that uses the Nintendo Wiimote to determine arm/hand gestures and control a robot. They then conducted a study where subjects used Wiimote gesture system and a more standard system and filled out a survey to indicate how effective the Wiimote system was as compared to the standard control system for the robot.

I propose a gesture based system using a smartphone and conducted a human factors experiment similar to [18]. The system uses a Samsung Galaxy S II phone for the gesture-based input, a tilt-based controller, and a touch screen D-Pad controller, and a Microsoft XBOX 360 controller for the more traditional input. Subjects used each of the four controls in a random order to guide an iRobot Roomba vacuum cleaner through a short time trial course. The raw data (video and observations during the time trials) was analyzed with metrics like the time required to complete the course, number of times the subject went outside the course boundaries, number of times the subject acknowledged making a mistake, etc. After the experiment is complete, subjects also filled out a survey, and both sets of data were used to determine which control scheme is more effective and intuitive.

This thesis aims to test both the perceived and actual effectiveness and ease of use of smartphone gesture-based robotic control systems vs. traditional control systems.

This thesis introduces an inexpensive gesture based control system that uses commercial, off the shelf hardware (an Android smartphone and a Roomba vacuum cleaner). It also provides data showing both subjects' objective performance and their perceived experience with each controller.

The remainder of this thesis is organized as follows. In the next chapter, I present a taxonomy of related work. Chapter 3 provides implementation details for the different controls. Chapter 4 describes the design of the human factors experiment, including choice of hardware, track design, experimental procedure, and the questionnaire. In Chapter 5, I analyze and discuss the results of the experiment. Chapter 6 provides the conclusion and a brief summary.

Chapter 2

Related Work

There is a large body of work about robotic control systems that led up to this point. The work in [18] references three papers in human-robot interaction: [19], [16], and [5]. The work in [19] presents a computer vision based approach to human-robot communication where the computation is done onboard the robot. The work in [16] presents work on using both gestures and speech. The speech commands are used to augment and clarify the hand gesture commands. The work in [5] presents a system for using the Wiimote to control a robotic dog, even showing that the Wiimote outperformed the standard computer keyboard.

The work in [19] takes a computer vision based approach to gesture recognition. It explores several methods like template-based matching and neural networks. It is derived from several other vision-based works, like [11], which used optical flow to recognize up to 6 gestures, and [9], which recognizes pointing gestures using feature maps and the color of the user's clothing.

The work presented in [16] integrates speech recognition into the system, but it also uses a computer vision based gesture recognizer. It draws from [10], which recognizes static hand gestures from still photos, and CORA, a robotic assistant that uses speech and deictic gestures to execute commands (ex. "Turn and face me").

The work in [5] uses a Wiimote to control a Sony AIBO robotic dog. It describes a guide to designing effective human-robot interface [4]. It also describes [21], which classifies and details robotic control schemes and defines terminology related to HRI. The work in [21] defines the autonomy level of a robot as the percentage of the time that the robot carries out a task on its own (as opposed to intervention from the operator). Like [5], this paper deals with a robot with a low autonomy level.

Comparison to Prior Work

While this paper has most of its origin in [18], there are a few differences. The work in [18] uses a Nintendo Wiimote to control the actions of the robot, rather than a smartphone or XBOX controller. In the case of the smartphone, computation of gestures is performed on the phone, rather than on an intermediate computer. Like the work presented in [18], this system uses the movement of the controller, rather than a computer vision system to observe the user. This gives the added benefit that the user can move while controlling the robot without getting out of range of a camera. The work in [18] uses an algorithm based on the 2D gesture recognition presented in [17], while the gesture recognition system presented in this thesis is based on [13] and uses Dynamic Time Warping to classify gestures.

Chapter 3

Implementation of Control Systems

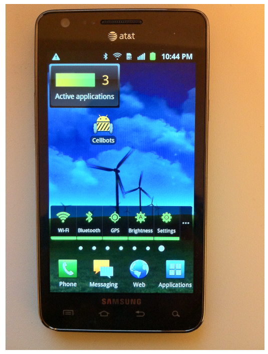
In this chapter I will describe the implementation of the four control systems used in the experiment. First, I describe the "standard" XBOX 360 controller setup, then the application used for the D-Pad and tilt controllers, and finally the gesture-based control application.

The robot in question is an iRobot Roomba 560 vacuum cleaner. None of the four control schemes require making modifications to the Roomba, and the vacuum/brushes are turned off during the experiment. It is controlled from a standard wireless Microsoft XBOX 360 controller and a Samsung Galaxy S II Android phone.

3.1 XBOX 360 Controller

The XBOX 360 controls for the Roomba are written in Python. The program uses a library called RoombaSCI to communicate with the Roomba via Bluetooth. RoombaSCI is a Python wrapper for iRobot's Serial Command Interface Specification, which allows commands to be sent to the Roomba through its serial port. Room-

(a) A Roomba 560



(b) A Samsung Galaxy S II

(c) An XBOX 360 controller

Figure 3.1: The hardware used in the study, a Roomba vacuum cleaner, a Samsung Galaxy S II, and an XBOX 360 controller.

baSCI abstracts tasks like setting up the connection and sending bytes to specific motors into commands like `FORWARD`, `STOP`, and `SPIN LEFT` [8]. It also allows the programmer to set the speed of the Roomba within the range allowed by the hardware (-500 - 500 mm/s)[7].

A RooTooth bluetooth-serial adapter was used to communicate with the computer wirelessly. The Pygame library is also used to properly capture the input from the controller.

The end result is a controller that can be used to move forward/backward and rotate to the left or right in place. The right trigger sends the `FORWARD` command, the left trigger sends `BACKWARD`, and the left analog stick pressed to the left or right sends a `LEFT` or `RIGHT` command (see Figure 3.2). The robot continues moving forward/backward/left/right as long as the trigger or analog stick is held, and will stop when it is released, or another button is pressed. When using the XBOX 360 controller, the robot can only move at the maximum speed, and it can only perform one of forward/backward or rotation at any given time (forward motion must stop in order to turn). The left and right controls are not gradual, meaning that leaning the analog stick partially to the side does nothing. In order to turn left/right, the analog stick must be pushed completely to one side or the other.

Figure 3.2: The XBOX 360 control scheme. The left analog stick controls left and right turns, while the triggers control forward and backward movement. Courtesy of http://game-machines.com[6].

3.2 Cellbots Application

The D-Pad and the tilt controls were downloaded to the phone as part of a single app called Cellbots. Cellbots is an open source Android application, available for free online or in the Android Market. The app comes with four control schemes, including the D-Pad controls and the tilt controls (Figure 3.3). It also included voice controls and an on-screen Atari-style joystick which were not used in the experiments but could be utilized in future research[2].

The D-Pad controls require the user to press one of four on-screen buttons, arranged in a cross. Like the XBOX 360 controller, the robot moves forward/backward and rotates in place when the appropriate button is held down, stopping when the

(a) The D-Pad controls. Each of the four directional buttons cause the robot to move.

(b) The tilt controls. Holding the center button and tilting the phone causes the robot to move.

Figure 3.3: Two of the screens from Cellbots, D-Pad and tilt.

button is released. Also like the XBOX 360 controller, the D-Pad only allows one speed and one type of movement at a time.

The tilt controls use the phone's accelerometers to control the robot. The user holds the phone horizontally (screen facing up) and holds down an on-screen button. While the button is held down, tilting the phone forward (rotation around its x-axis) causes the robot to begin to drive forward. The phone can be rolled right or left (rotating around its y-axis) to steer. Figure 3.4 shows the phone's axes.

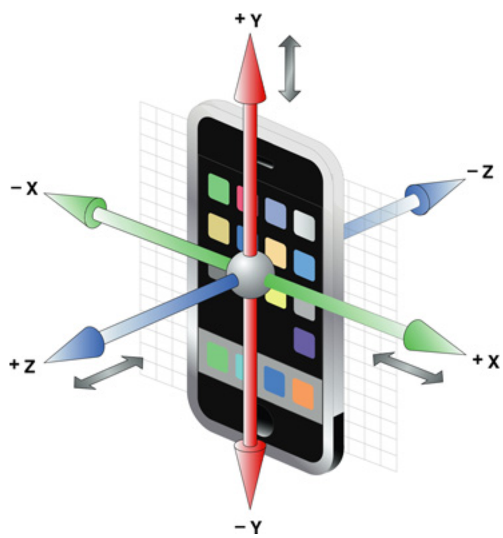


Figure 3.4: The smartphone's x, y, and z axes. Courtesy of Apple, Inc.[1]

The tilt controls differ from the other controls in two ways: first, the speed can vary. The more the phone is tilted forward, the faster the robot moves, up to the maximum speed of 500 mm/s. The second difference is that the tilt controls allow forward/backward motion and turning at the same time. For example, if the phone is tilted forward and rolled left, the robot will perform a left turn, rather than rotating in place.

3.3 Gesture-Based Control Application

The gesture-based controls are implemented on top of the existing Cellbots application. Cellbots is an open source application, so the gesture controls were added as a fifth control type.

To recognize the gestures using accelerometers only, I turned to another open source Android application called GestureTrainer. GestureTrainer is an implementation of the concepts outlined in [13] for gesture recognition using accelerometer data.

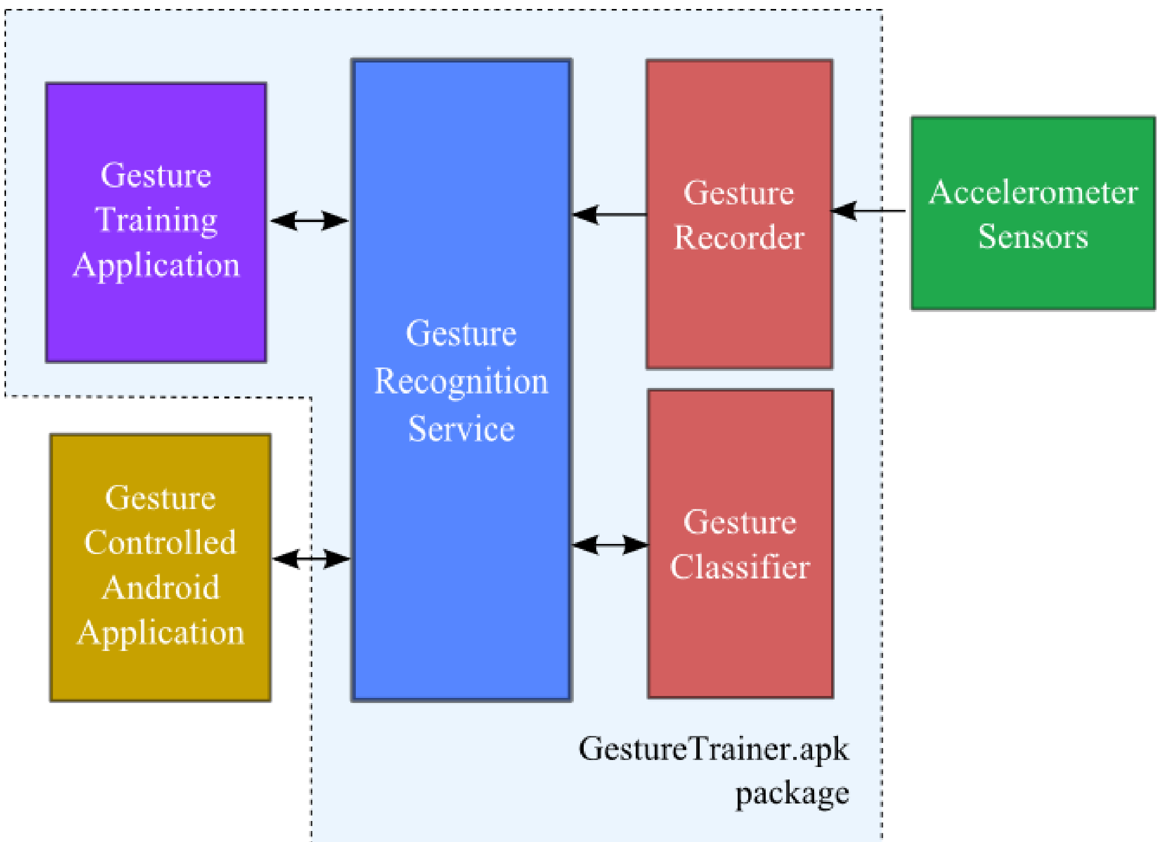


Figure 3.5: The GestureTrainer architecture. The Cellbots app was modified to include Gesture Recognition Service, Gesture Recorder, and Gesture Classifier, making it a Gesture Controlled Android Application. Courtesy of Robert Nesselrath[14].

Users can record and name their own gestures on the phone, and from then on when the gesture is performed and recognized, the name is sent to the Roomba. The phone recognizes gestures continuously, without the need to specify when the user is about to perform a gesture.

To record a gesture, the user presses a button to start “learning mode”. The phone receives a constant stream of events for every movement that the accelerometer picks up in the form of a vector of floats, $(\Delta x, \Delta y, \Delta z)$. If the norm of the vector is above a certain threshold, the movement is considered “significant” and the app begins recording the stream of vectors. When the phone receives 10 events in a row whose norms do not exceed the threshold, the gesture is determined to be complete. The list of xyz-vectors is stored as a Gesture object, and given the name specified by the user.

After exiting “learning mode”, the phone begins recognizing gestures immediately. When a gesture is detected, it is stored in a Gesture object, and sampled by one of several different feature extractors. The feature extractors serve to divide the gesture into a certain number of vectors, or normalize the values in the vectors. We then compute the distance between this sampled signal and each of the user's recorded gestures.

The distance calculation from Gesture a to Gesture b is done through the Dynamic Time Warping algorithm (see Appendix for source code). A $a.length \times b.length$ matrix of floats, $dist$, is constructed, where entry $dist(i, j)$ is the norm of the ith vector in a minus the jth vector in b. A second matrix of the same size, $cost$, is constructed so that the first column of $cost$ is the same as the first column of $dist$, and the rest of the entries are 0.

The $cost$ matrix is filled in dynamically from the top left ($cost(0,0)$) to the bottom right ($cost(a.length, b.length)$), iterating over rows first, then columns. To compute $cost(i,j)$, the current minimum cost is computed as

$$minCost = cost(i-1, j-1) + dist(i,j)$$

This is the value assigned to $cost(i,j)$. If $cost(i-1,j) + dist(i,j) < minCost$ or $cost(i,j-1) + dist(i,j) < minCost$, an additional offset penalty of 0.5 is added to $cost(i,j)$.

After the whole $cost$ matrix has been filled in, the entry $cost(a.length-1, b.length-1)$ (the bottom right corner), is the minimum cost between the two Gestures a and b. The stored Gesture with the smallest cost from the performed Gesture is the one that is selected to be sent to the Roomba. The last step is to check that cost against a threshold. If the cost is less than the threshold, then the command would be sent, otherwise no command is sent. This is to ensure that all commands sent were close matches, since every gesture will return a match with some stored gesture, even if there are no similar gestures. If the closest match has a high cost, it is not close enough to be executed as a command so it is ignored.

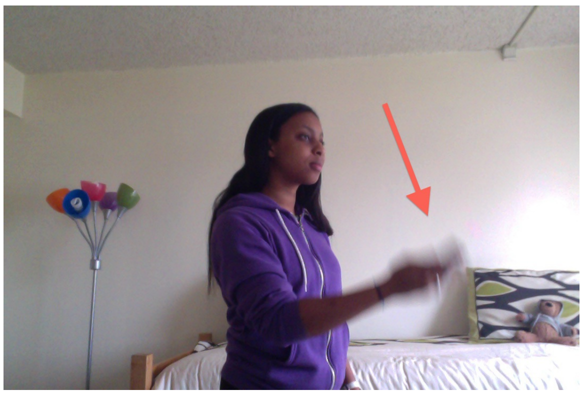
One of the major benefits of using this algorithm is that the gesture recognition is performed with only one sample. Other gesture recognition systems, like the one outlined in [17] require multiple samples to perform recognition reliably.

This code was integrated into Cellbots as another control view, to ensure that the same speeds/timing would be used for each control scheme on the phone (Figure 3.6).

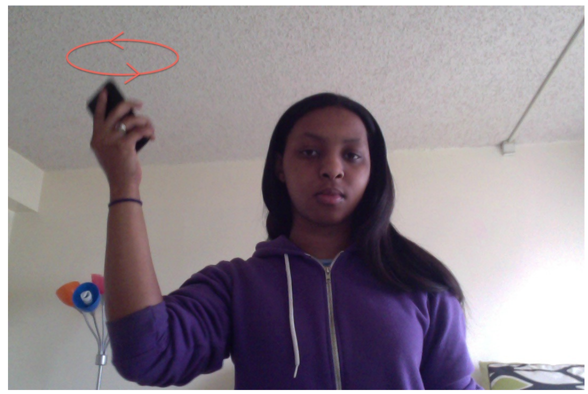
The gestures defined were `FORWARD`, `BACKWARD`, `LEFT`, and `RIGHT` (see Figure 3.7 for demonstrations of each gesture).

Figure 3.6: The gesture-based controller screen added to Cellbots. It uses the code and algorithms from GestureTrainer to perform gesture recognition, and also has a `STOP` button.

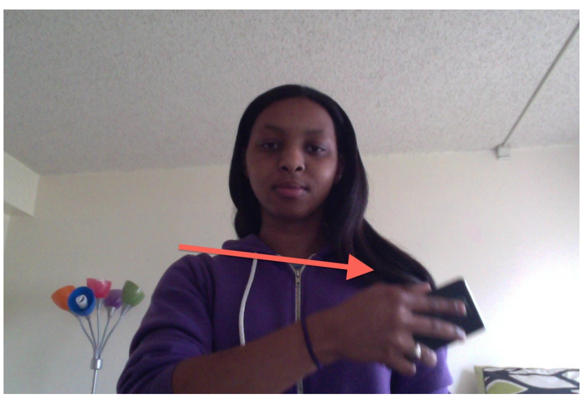
All the gestures are performed with the phone's screen facing the user. The `STOP` command was left as an on-screen button, rather than a gesture, to make it easier for the subject to maintain control (and for the sake of the hardware and testing environment).



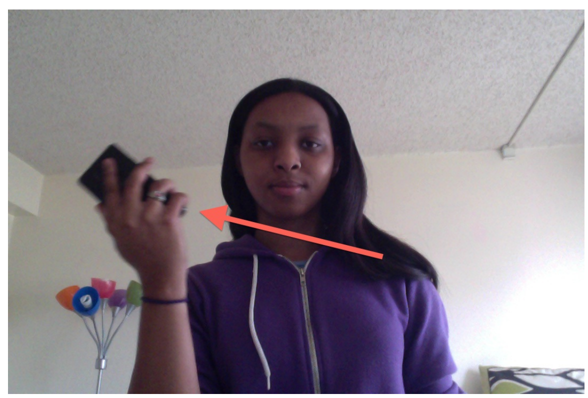
(a) `FORWARD` gesture (high to low).



(b) `BACKWARD` gesture (two counterclockwise circles).



(c) `LEFT` gesture (right to left).



(d) `RIGHT` gesture (left to right).

Figure 3.7: The four gestures defined in the gesture-based application.

Chapter 4

Human Factors Experiment Design

In this chapter I will describe the setup of the human factors experiment, as well as the design choices. The human factors experiment was conducted with 15 subjects to gauge the effectiveness of each controller. The experiment involved empirical metrics (such as time taken to complete course and number of times the robot crossed the boundaries), as well as qualitative data obtained through a questionnaire. The study was approved by the University of Pennsylvania Institutional Review Board and conducted accordingly (see Appendix for IRB documents).

4.1 Platform and Hardware

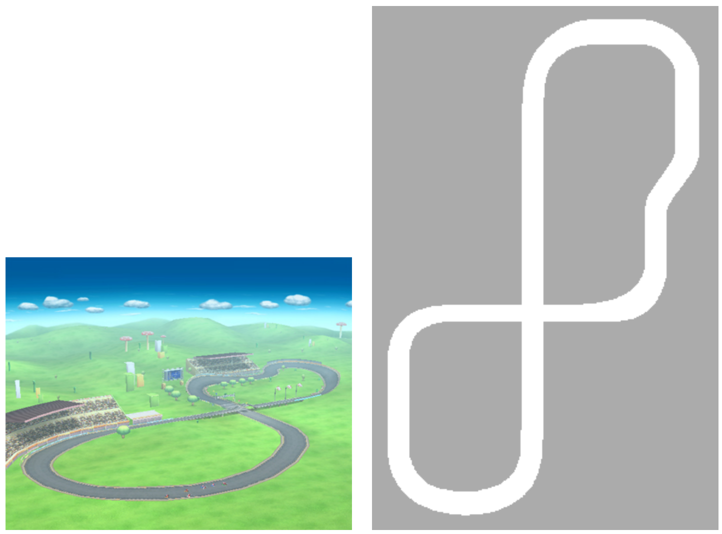
The Roomba was chosen because it is a commercial, off the shelf robot that is relatively easy to control via a store bought Bluetooth adapter. It has two motorized wheels in the center and a single caster in the front for smooth forward steering. The lack of a back caster meant that the Roomba's backwards movement could sometimes become slightly erratic at maximum speed, but for the most part, the movement was unaffected.

The Samsung Galaxy S II was chosen primarily for its gyroscopes. All Android phones come with accelerometers, but only some with gyroscopes, which help the phone to give more precise measurements. The Microsoft XBOX 360 controller was chosen because until recent games like “Mario Kart Wii”, most driving/navigating games are were made for the XBOX 360, making its controller a good “standard” controller.

4.2 Track Design

The track used in the experiments is based on a beginner’s time trial circuit from Nintendo’s “Mario Kart Wii” called Mario Circuit (sometimes Mario Raceway).

The course used in the study is a scaled down version of Mario Circuit, which is a slight variation on a traditional figure-eight course (see Figure 4.1). The course was chosen primarily because it involves two U-turns (one left, and one right), a left turn, a right turn, and two straightaways, allowing all the commands to be tested every lap. In the game, players race around the track for 3 laps, and the 3 lap requirement was kept for the experiment. Subjects completed 3 laps, then crossed the finish line a few yards away. A “Mario Kart Wii” course was also chosen because “Mario Kart Wii” is the best-selling racing game of all time, and Mario Circuit is an updated version of one of the classic courses, originally created by the game designers as the premier time trial course [12].



(a) Mario Circuit, as seen in the video game "Mario Kart Wii". Courtesy of http://smashbros.com[3].

(b) The original floor plan for the course used in the study. It was later scaled to be appropriate for the size of the Roomba and the lab space in which the experiment took place. Courtesy of Super Mario Wiki[20].

Figure 4.1: Comparison of the original Mario Circuit track with the course used in the experiments.

4.3 Questionnaire Design

The questionnaire opens with basic demographic questions (age, gender, field of study/profession, etc.), then asks about subjects' video game habits and computer experience. The questionnaire then asks the following specific questions about each of the four controllers (on a five-level Likert scale unless otherwise specified):

- How aware were you of the controls while you were using them?
- How awkward was holding the controller in your hand?
- Did you feel that you were fully in control of the robot at all times? (Yes/No)
- How difficult was it to maintain control while driving in a straight line?
- How difficult was it to maintain control while turning?
- How difficult was it to learn the controls?
- Did you perform as well as you wanted to in the obstacle course? (Yes/No)
- What was your favorite part about this control scheme? (Short Answer)
- What was your least favorite part about this control scheme? (Short Answer)

Finally, the questionnaire asks participants to rank controllers according to which they would use to accomplish a critical task, which they would use continuously for two hours, which was most intuitive, and which was most fun.

4.4 Experiment Procedure

When subjects arrived, they were first briefed on the purpose of the experiments. Every subject tried the controllers in a randomized order. A short period was allowed for the subject to get used to the controller before beginning the time trial course. The subject completed three timed laps around the course. Subjects were allowed to move between several locations outside the track during a run of the course, but were not allowed to touch the robot or follow it closely. The number of times the robot went outside the boundaries was recorded, along with the number of "mistake acknowledgements". I defined "mistake acknowledgements" as a physical or verbal cue that the subject performed a command they did not intend. Examples of mistake acknowledgements include stamping one's foot, shaking one's head, statements like "No" and "Oops", and swearing. After every run, the subject was informed of his/her time with that controller. Immediately after all four of the time trials were finished, the subject filled out the questionnaire.

Chapter 5

Results

In this chapter I will present the results of the experiments and questionnaire. First, a breakdown of the empirical data from the time trials is given, followed by the data from the questionnaire. Finally, I provide an analysis of both sets of data and present some hypotheses based on the combined data.

5.1 Time Trials

For the time trials, I recorded the time of each lap, the total time taken to complete the course, the number of "line faults" (robot crossing out of the boundaries), and "mistake acknowledgements" (defined in Section 4.4). The averages for each of these values are presented in Table 5.1. It should be noted that there were several subjects with times more than 2 standard deviations from the mean (3 in some cases). Because of the small sample size, their data was not excluded from the calculations. The full raw data can be found in the Appendix.

The XBOX 360 controller had the fastest average time, with 124.74s, while the

Controller	Avg. Time (sec)	Avg. Line Faults	Avg. Mistake Ack.
D-Pad	161.53	0.07	0.4
Tilt	164.58	2.13	2.6
Gesture	393.81	6.67	7.0
XBOX 360	124.74	0.93	0.5

Table 5.1: Average time taken to complete the course, average number of Line Faults, and average number of Mistake Acknowledgements for each of the four controller types.

D-Pad and Tilt controllers were both approximately equal (161.53s and 164.58s, respectively). The gesture-based controls performed the slowest, with an average time of 393.81s.

Though the XBOX 360 controller had the fastest average time, the fastest individual time belonged to the tilt controller: one subject completed the course in 83.3s, making the tilt controller the only controller with a total time under 100s.

The D-Pad averaged the fewest line faults by far, with 0.07 (there was a total of 1 line fault across all subjects), while the gesture-based controls again came in last with an average of 6.67 faults.

The D-Pad also averaged the fewest mistake acknowledgements, with 0.4 average mistake acknowledgements. The XBOX 360 controller was just behind the D-Pad with an average of 0.5 mistake acknowledgements. The gesture-based controls averaged 7.0 mistake acknowledgements, more than 17 times the average number of mistakes acknowledged with the D-Pad. The gesture-based system was also the only one where the minimum number of mistake acknowledgements was above 0; every single subject acknowledged at least one mistake.

5.2 Questionnaire

Presented here are answers to several relevant questions. More data can be found in the Appendix.

The D-Pad receieved mostly positive reviews, though 60% of respondents said that they were aware of the controls while using them. 80% said the controller was not awkward, and that they felt that they were fully in control of the robot at all times. 100% of respondents rated the controls as easy to learn. 80% said that they performed as well as they wanted to in the course. Many subjects enjoyed the “simplicity” and “familiarity” of the D-Pad, along with the fact that the directional arrows were visible. The most popular complaint about the D-Pad was that it could only handle one command at a time and could not turn and move simultaneously. It was also described as “mundane” and “less fun than [some other controls]”.

In a slight jump up from the D-Pad, 66% of subjects said they were aware of the tilt controls while using them. 53% rated the controls awkward, and only 60% said they felt in control of the robot at all times. 40% of respondents said they performed as well as they wanted to (a large deviation from the D-Pad). Subjects praised the tilt controls for being “intuitive”, “smooth”, and “fun”, while others criticized it for being “hard to control”.

The gesture-based controls did not fare as well. 80% of users said that they were aware of the controls while using them, and 66% described them as awkward. 86.7% of subjects said they did not feel in control of the robot at all times, and 86.6% said it was difficult to maintain control while turning (46% rated it hard to control while driving in a straight line). The majority of subjects rated the gestures somewhat easy to learn. Subjects enjoyed the “novelty” of the gesture-based controls, but ultimately decided it was “unresponsive”, “inaccurate”, and “frustrating” at times.

The XBOX 360 controller got slightly better ratings than the gesture-based controls. Most respondents said that they were somewhat aware of the controls, while 86.6% rated it not awkward. 86.7% said they felt that they were fully in control of the robot at all times, which is the most of all the controllers. 100% rated the XBOX 360 controller easy to learn. 86.7% performed as well as that wanted to in the course. Subjects praised it for being “familiar”, “easy to learn”, and for having a physicality that allowed them to keep their eyes on the robot at all times. There were, however, many complaints about not being able to turn while moving forward, like the tilt controls, and having no way to gradually increase the amount the robot was turning.

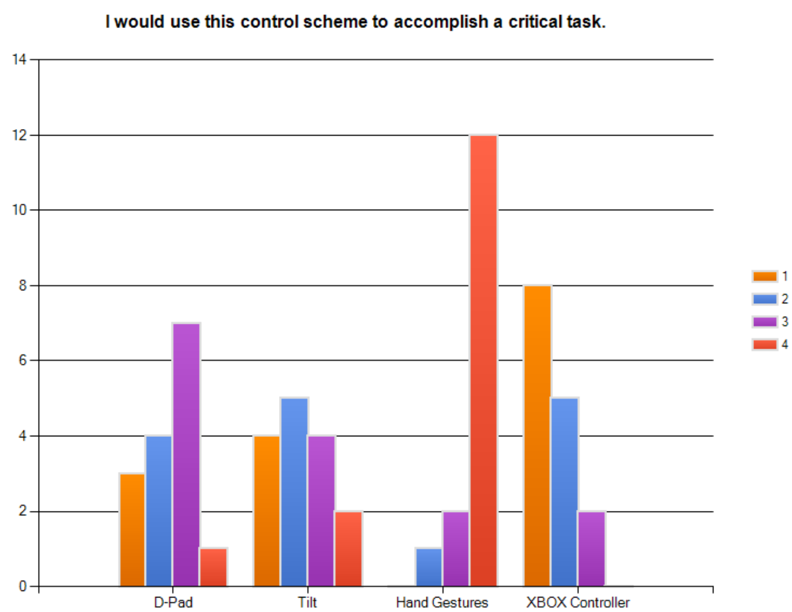


Figure 5.1: The numbers 1-4 indicate rank given to the controller for using it to accomplish a critical task. The XBOX 360 controller was the most popular for accomplishing a critical task; the gesture-based controls were the least popular.

The majority of subjects, 53.3% said that they would use the XBOX 360 controller as their first choice for accomplishing a critical task. 80% of subjects ranked the gesture-based controls last for accomplishing a critical task, with no users ranking it as their first choice (see Figure 5.1).

Similarly, 71% of subjects would use the XBOX 360 controller for two hours continuously, while 80% ranked the gesture-based controls in last place (see Figure 5.2).

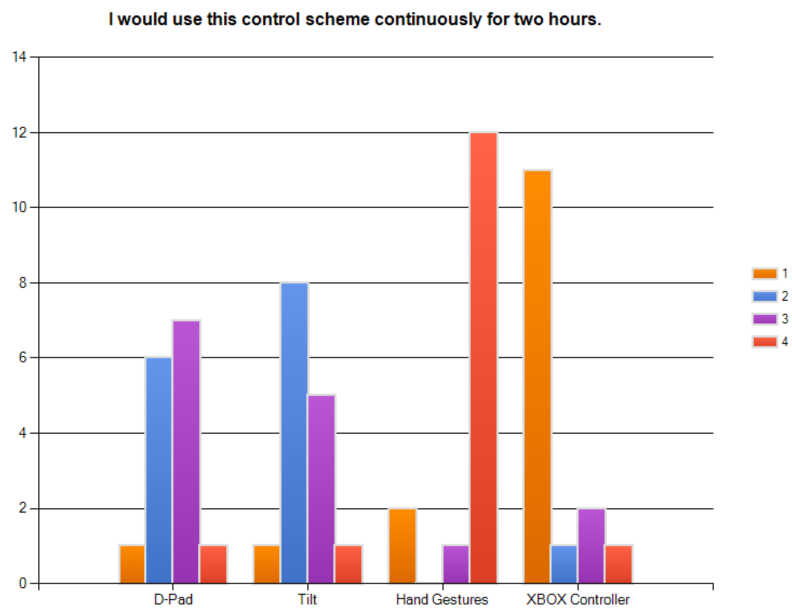


Figure 5.2: The numbers 1-4 indicate rank given to the controller for using it for two hours continuously. The XBOX 360 controller was the most popular for using continuously for two hours; the gesture-based controls were the least popular.

The tilt controller was ranked the most intuitive (40%), followed by the D-Pad, then the XBOX 360 controller. No subjects rated the gesture-based controls the most intuitive (see Figure 5.3).

The tilt controller was also ranked the most fun to use, followed by the XBOX 360 controller, with D-Pad and gesture-based tying for third (see Figure 5.4).

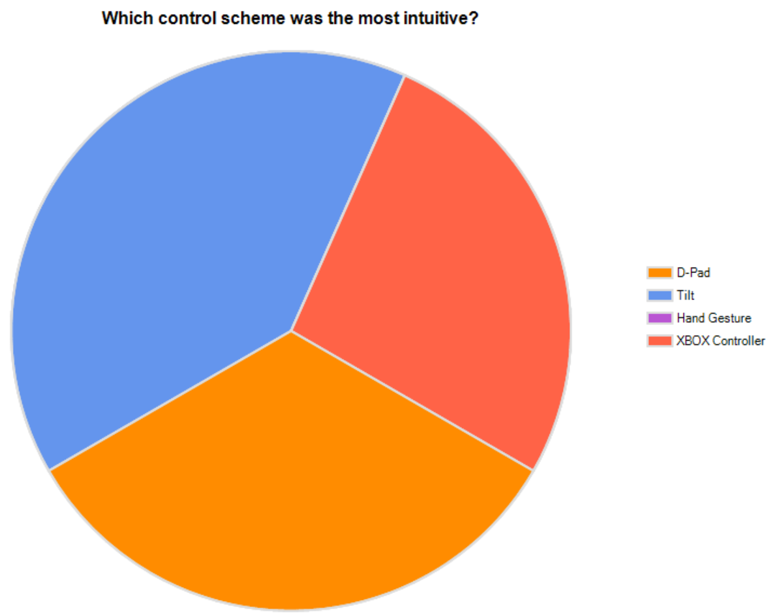


Figure 5.3: The tilt controller was ranked the most intuitive, while the gesture-based controller was ranked the least intuitive.

5.3 Analysis and Hypotheses

Empirical data shows that the XBOX 360 controller was the fastest, and the second most “error free”, meaning a low number of line faults and mistake acknowledgement. The gesture-based controls performed poorly, with an average time, average number of faults, and average mistake acknowledgement more than twice that of all the others controllers. The qualitative data also showed that the gesture-based controls were not well suited to the task.

Based on these two sets of data, I believe that the gesture-based controller is not a good system for direct control of a vehicle.

One major problem with the gesture-based controls is the timing. In order to recognize a gesture, the gesture must be fully completed. This means that when a

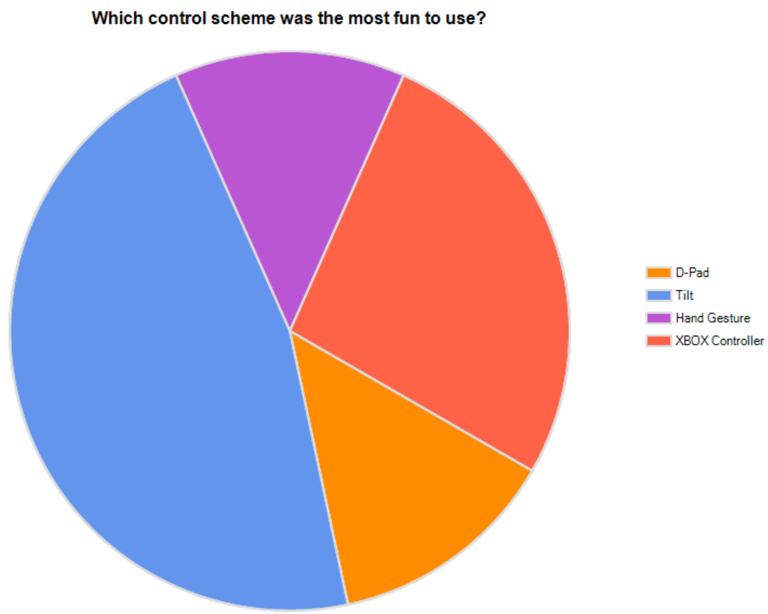


Figure 5.4: The tilt controller was ranked the most fun to use, while the D-Pad and gesture-based controls tied for 3rd place.

subject wants to issue a command, he/she must complete the entire movement before the phone can classify the gesture and send it to the robot. Compare this to pressing a button, which is almost instant. There is no recognition process with a button press, so as soon as the button is fully pressed, the command can be sent to the robot. Many subjects felt frustrated waiting for the entire gesture to finish and be classified before the command was sent. Often, subjects tried to make up for the lost time by gesturing faster/more firmly, but this would often cause unwanted accelerometer data which led to incorrect classifications.

This could be remedied in part by using a system more like the one usually used with the Microsoft Kinect. Rather than gestures, most of the commands are given through positioning of the hands/body. Using the position of the hand, a system could be constructed that allows for faster recognition, along with gradual turning and speed changes, rather than sending a string of commands.

The other major problem with the gesture-based controls was accuracy. Gestures can be recognized incorrectly, whereas buttons cannot provide incorrect information (a user could accidentally press the wrong button, but a properly working set of buttons will always send the right information). The fact that gestures do not have 100% accuracy adds a layer of computer error on top of the possible human error, which can be very dangerous.

The emotions of the user also come into play with gesture-based controls in a way that they do not with buttons or tilt based controls. A calm user will gesture a certain way, while an agitated user will usually gesture more wildly. A wild gesture's accelerometer data is much more likely to appear different from the original gesture's data, making it more likely to be classified incorrectly. This is amplified into a negative feedback cycle when a user makes a mistake, because often the user will gesture more vehemently to correct the mistake, leading to more mistakes. Buttons and tilt-based controllers are not affected by how frantic or agitated the user is.

This is not to say that gesture-based controls have no place in robotics, but that they would most likely be better suited for a higher-level set of commands. Gesture-based controls were originally explored because gestures are a natural human form of communication, but when humans gesture, it is very rarely to communicate low level directions like "go forward", "stop, and "rotate left". More often the commands assume a certain level of autonomy on the part of the receiver. For example, telling another person "join me" through a hand gesture assumes that the person will figure out how to navigate the room on his own. Many subjects said that they felt that the gesture-based controls were "unintuitive" (no subject ranked it as the most intuitive) "frustrating", and "tiring". I believe it is because the commands being sent were too low-level for the gesture-based controls used in the study to be effective.

Gestures used between humans also rely on the fact that the receiver can see/-calculate where the other person is indicating. Many human gestures for navigation correspond to phrases with an explicit point of reference (ex. "follow me", "go over there"). The Army Field Manual details many such gestures [15]. Using gestures to control the robot's direct movement was therefore somewhat unintuitive to subjects who were not used to applying a high-level form of communication to a low-level command. 53.3% of the subjects improved over the three laps, which indicates that the gesture-based controls used in the study may require more training time, not less as was originally thought.

Chapter 6

Conclusion

In this thesis, I presented a suite of robotic control systems: an XBOX 360 controller, a touchscreen D-Pad, a tilt controller, and a hand gesture controller. All systems were composed of commercial, off the shelf hardware. A study with empirical and qualitative data was conducted to determine the most effective of the controllers. The empirical data showed the XBOX 360 controller to be the most effective (fastest), and the D-Pad to be the least error prone. By contrast, the gesture-based controls were shown to be both the slowest and the most error prone. The qualitative data showed that the gesture controls were thought to be the least intuitive and one of the least enjoyable controllers to use, while the tilt controller was ranked the most intuitive and the most enjoyable. The fact that the controller that was ranked the most intuitive and fun was not the most effective controller brings up several more questions on the importance of intuitive systems vs. effective systems.

The tilt controller allowed the robot to move and turn at the same time, which would appear to be an advantage, yet it performed slower than the XBOX and D-Pad controllers. One reason for this could have been that recovering from errors was more difficult. The tilt controller had more errors than the XBOX and D-Pad controllers, and a lot of time was lost in attempting to reverse or maneuver out of a tight spot. An interesting metric to record in the future would be the average distance traveled between mistakes. This could indicate that if a system performs poorly, it just needs a better way to recover, rather than being labeled as “ineffective” across the board.

Based on the data and analysis, gesture-based controls should continue to be explored, but the focus should shift to the context of more autonomous robots who can safely navigate their own environment. It appears that most of the problems that subjects had with the gesture-based controls could be alleviated by implementing a different set/style of commands. Results for gesture-based controllers could perhaps be improved by allowing the subject to define his/her own gestures, or implementing more tilt style controls using accelerometer data combined with computer vision or voice data.

There is also room to experiment in the future with hybrid control schemes. For example, consider a system where close quarters movement or direct manipulation (e.g. driving) is controlled by a tilt, dpad, or xbox-like controller, and high level commands (e.g. “go home”) can be given in the form of gestures. A control system like this might be the best fit for some tasks. The context in which the human and the robot interact can drastically change the effectiveness of the controls, and being able to switch contexts while using the same controls could have a huge impact.

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Appendix

Gesture Recognition Code

This is the portion of the GestureTrainer/Cellbots code that calculates the distance between two Gestures, a and b. The Gesture class is essentially an object wrapper for `String label`,which represents the Gesture's name, and `List<float[]> values`, which represents the stream of (x, y, z) values recorded.

```
/*
 * DTWAlgorithm.java
 *
 * Created: 18.08.2011
 *
 * Copyright (C) 2011 Robert Nesselrath
 *
 * This program is free software; you can redistribute it and/or
 * modify it under the terms of the GNU General Public License
 * as published by the Free Software Foundation; either version 2
 * of the License, or (at your option) any later version.
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place - Suite 330, Boston, MA
   02111-1307, USA.
 */
```

```java
package de.dfki.ccaal.gestures.classifier;

import java.util.ArrayList;

import de.dfki.ccaal.gestures.Gesture;

public class DTWAlgorithm {

  static float OFFSET_PENALTY = .5f;

  static private float pnorm(ArrayList<Double> vector, int p) {
    float result = 0, sum;
    for (double b : vector) {
      sum = 1;
      for (int i = 0; i < p; ++i) {
        sum *= b;
      }
      result += sum;
    }
    return (float) Math.pow(result, 1.0 / p);
  }

  static public float calcDistance(Gesture a, Gesture b) {
    int signalDimensions = a.getValues().get(0).length;
    int signal1Length = a.length();
    int signal2Length = b.length();

    // initialize matrices
    float distMatrix[][];
    float costMatrix[][];

    distMatrix = new float[signal1Length][];
    costMatrix = new float[signal1Length][];

    for (int i = 0; i < signal1Length; ++i) {
      distMatrix[i] = new float[signal2Length];
      costMatrix[i] = new float[signal2Length];
    }

    ArrayList<Double> vec;

    // calculate distances
    for (int i = 0; i < signal1Length; ++i) {
      for (int j = 0; j < signal2Length; ++j) {
        vec = new ArrayList<Double>();
        for (int k = 0; k < signalDimensions; ++k) {
          vec.add((double) (a.getValue(i, k) - b.getValue(j, k)));
        }
```

```
        distMatrix[i][j] = pnorm(vec, 2);
      }
    }

    // genetischer Algorithmus um den gÃ¼nstigsten Pfad zu finden
    for (int i = 0; i < signal1Length; ++i) {
      costMatrix[i][0] = distMatrix[i][0];
    }

    for (int j = 1; j < signal2Length; ++j) {
      for (int i = 0; i < signal1Length; ++i) {
        if (i == 0) {
          costMatrix[i][j] = costMatrix[i][j - 1] + distMatrix[i][j];
        } else {
          float minCost, cost;
          // i-1, j-1
          minCost = costMatrix[i - 1][j - 1] + distMatrix[i][j];
          // i-1, j
          if ((cost = costMatrix[i - 1][j] + distMatrix[i][j]) < minCost
              ) {
            minCost = cost + OFFSET_PENALTY;
          }
          // i, j-1
          if ((cost = costMatrix[i][j - 1] + distMatrix[i][j]) < minCost
              ) {
            minCost = cost + OFFSET_PENALTY;
          }
          costMatrix[i][j] = minCost;
        }
      }
    }
    return costMatrix[signal1Length - 1][signal2Length - 1];
  }

}
```

Time Trials Raw Data

Below is the raw data from the time trials. Every subject tried the course with every controller, though there was a malfunction that prevented several people from completing three laps. The standard deviations for time, line faults, and mistake acknowledgements are provided for reference.

		XBOX						
Subject		**Lap 1**	**Lap 2**	**Lap 3**	**Total**	**Line Faults**	**Mistake Ack**	**Order**
12		61.3	53.6	38.4	153.3	1	1	4
26		41.7	33.8	35.3	110.8	2	0	4
46		58.1	45.6	44.8	148.5	1	0	3
85		44.1	45.7	54.5	144.3	2	1	1
37		58.1	53.4	46.6	158.1	0	0	4
17		39.6	34.0	30.0	103.6	1	0	1
45		42.0	33.4	34.2	109.6	0	1	1
18		37.2	35.3	30.2	102.7	3	3	3
54		50.3	47.3	50.1	147.7	0	0	2
24		40.0	34.6	34.9	109.5	0	0	4
55		54.1	-	-	-	0	1	1
81		48.8	49.9	-	-	1	1	3
23		34.8	35.9	32.0	102.7	1	0	2
95		39.6	-	-	-	1	0	2
83		35.3	35.2	35.6	106.1	1	0	4
	Average:	45.666666667	41.361538462	38.883333333	124.74166667	0.9333333333	0.5333333333	
	Min:	34.8	33.4	30	102.7	0	0	
	Max:	61.3	53.6	54.5	158.1	3	3	
				Standard dev.	23.010924612	0.8837151017	0.8338093878	

		D-PAD						
Subject		**Lap 1**	**Lap 2**	**Lap 3**	**Total**	**Line Faults**	**Mistake Ack**	**Order**
12		80.9	55.1	63.4	199.4	0	2	1
26		53.0	47.4	51.3	151.7	0	0	3
46		46.3	42.7	44.2	133.2	0	0	2
85		71.4	77.8	107.5	256.7	0	2	4
37		58.9	52.6	48.5	160	0	0	2
17		54.6	58.7	47.1	160.4	0	0	2
45		47.7	42.8	44.5	135	0	1	2
18		55.5	50.2	47.0	152.7	0	0	4
54		65.8	52.9	53.9	172.6	0	1	3
24		48.1	46.7	47.5	142.3	0	0	3
55		54.5	52.7	46.3	153.5	0	0	3
81		51.9	47.0	49.5	148.4	0	0	4
23		59.4	50.2	46.4	156	1	0	4
95		52.1	45.8	50.1	148	0	0	3
83		54.7	49.2	49.1	153	0	0	1
	Average:	56.986666667	51.453333333	53.086666667	161.52666667	0.0666666667	0.4	
	Min:	46.3	42.7	44.2	133.2	0	0	
	Max:	80.9	77.8	107.5	256.7	1	2	
				Standard dev.	30.69635778	0.2581988897	0.7367883976	

Subject		TILT Lap 1	Lap 2	Lap 3	Total	Line Faults	Mistake Ack	Order
12		79.2	180.5	97.8	357.5	9	10	2
26		43.5	81.4	57.9	182.8	4	5	1
46		32.1	31.9	30.3	94.3	0	0	4
85		46.9	73.2	94.0	214.1	6	3	3
37		171.8	252.6	68.8	493.2	0	7	1
17		32.3	24.4	26.6	83.3	0	0	4
45		31.6	29.0	27.4	88	0	0	3
18		33.8	28.9	30.2	92.9	1	1	2
54		54.9	50.2	64.5	169.6	3	3	4
24		32.9	29.4	33.8	96.1	0	0	2
55		47.5	29.6	34.6	111.7	1	3	2
81		37.7	47.3	64.9	149.9	1	3	2
23		34.8	32.9	34.8	102.5	1	0	1
95		39.8	27.9	27.7	95.4	0	0	1
83		38.4	30.6	68.4	137.4	6	4	2
	Average:	50.48	63.32	50.78	164.58	2.1333333333	2.6	
	Min:	31.6	24.4	26.6	83.3	0	0	
	Max:	171.8	252.6	97.8	493.2	9	10	
				Standard dev.	115.77278363	2.8502297318	2.9952343099	

Subject		WAVE Lap 1	Lap 2	Lap 3	Total	Line Faults	Mistake Ack	Order
12		319	325	314	958	39	45	3
26		122.8	131.9	156.6	411.3	12	10	2
46		84.0	70.1	66.7	220.8	2	1	1
85		101.9	146.7	98.5	347.1	2	12	2
37		201.5	173.0	85.9	460.4	4	3	3
17		280.7	135.9	97.3	513.9	9	4	3
45		112.0	113.2	83.4	308.6	7	4	4
18		143.5	145.6	89.2	378.3	12	5	1
54		160.4	93.8	146.7	400.9	2	3	1
24		89.0	168.6	95.2	352.8	3	2	1
55		166.5	104.6	113.0	384.1	2	5	4
81		97.1	83.1	96.9	277.1	0	3	1
23		83.6	74.7	72.0	230.3	2	1	3
95		97.7	77.2	80.6	255.5	0	1	4
83		175.7	105.2	127.2	408.1	4	6	3
	Average:	149.02666667	129.90666667	114.88	393.81333333	6.6666666667	7	
	Min:	83.6	70.1	66.7	220.8	0	1	
	Max:	319	325	314	958	39	45	
				Standard dev.	176.99972908	9.7590007295	10.973995235	

Questionnaire Data

What follows is the data from the SurveyMonkey questionnaire. The short answers provided by each subject are listed at the end.

Evaluation of Gesture-Based Robotic Control Systems

SurveyMonkey

1. What is your subject number?

	Response Average	Response Total	Response Count
Subject Number	**46.73**	**701**	15
		answered question	**15**
		skipped question	**0**

2. Are you male or female?

	Response Percent	Response Count
Male	**60.0%**	**9**
Female	40.0%	6
	answered question	**15**
	skipped question	**0**

3. Which category below includes your age?

	Response Percent	Response Count
17 or younger	0.0%	0
18-20	20.0%	3
21-29	**66.7%**	**10**
30-39	13.3%	2
40-49	0.0%	0
50-59	0.0%	0
60 or older	0.0%	0
	answered question	**15**
	skipped question	**0**

4. How would you rate your level of fluency in English?

	Response Percent	Response Count
Basic	0.0%	0
Proficient	0.0%	0
Fluent	**100.0%**	**15**
	answered question	**15**
	skipped question	**0**

5. What is your year in school? Please specify if you are an undergraduate or graduate student. If you are not a student, please write "N/A".

	Response Count
	15
answered question	**15**
skipped question	**0**

6. What is your main field of study? If you are not a student, please state your occupation.

	Response Count
	15
answered question	**15**
skipped question	**0**

7. In what order did you try the controllers?

	1st	2nd	3rd	4th	N/A	Rating Average	Response Count
D-Pad (Phone)	13.3% (2)	33.3% (5)	**40.0% (6)**	13.3% (2)	0.0% (0)	2.53	15
Tilt (Phone)	26.7% (4)	**40.0% (6)**	13.3% (2)	20.0% (3)	0.0% (0)	2.27	15
Hand Gestures (Phone)	**33.3% (5)**	20.0% (3)	**33.3% (5)**	13.3% (2)	0.0% (0)	2.27	15
XBOX Controller	26.7% (4)	6.7% (1)	13.3% (2)	**46.7% (7)**	6.7% (1)	2.86	15
						answered question	**15**
						skipped question	**0**

8. What is your level of computer literacy? (1 is novice, 7 is expert)

	1	2	3	4	5	6	7	Rating Average	Response Count
Novice -> Expert	6.7% (1)	0.0% (0)	6.7% (1)	20.0% (3)	13.3% (2)	13.3% (2)	**40.0% (6)**	5.33	15
								answered question	**15**
								skipped question	**0**

9. What is your level of experience with computer programming? (1 is novice, 7 is expert)

	1	2	3	4	5	6	7	Rating Average	Response Count
Novice -> Expert	**40.0% (6)**	6.7% (1)	0.0% (0)	20.0% (3)	13.3% (2)	0.0% (0)	20.0% (3)	3.40	15
								answered question	**15**
								skipped question	**0**

10. Have you ever used a robotic control system before (e.g., RC toys)?

	1	2	3	4	5	6	7	Rating Average	Response Count
No experience -> extensive experience	6.7% (1)	26.7% (4)	13.3% (2)	20.0% (3)	**33.3% (5)**	0.0% (0)	0.0% (0)	3.47	15
								answered question	**15**
								skipped question	**0**

11. How many hours per week do you spend playing console games (XBOX / XBOX 360, PlayStation/ PS2/ PS3, Wii, GameCube, Nintendo 64, Dreamcast, SNES, NES)?

	Response Percent	Response Count
0	33.3%	5
< 1	**40.0%**	**6**
1-3	20.0%	3
4-9	6.7%	1
10+	0.0%	0
	answered question	**15**
	skipped question	**0**

12. Which types of game controllers have you used (choose all that apply)?

	Response Percent	Response Count
Gamepad, D-Pad only (e.g. NES, Super Nintendo)	84.6%	11
Gamepad with analog sticks (e.g. XBOX 360, Playstation)	92.3%	12
Tilt or gesture based (e.g. Wii, Playstation Move)	76.9%	10
Touchscreen (e.g. iPhone, Android)	**100.0%**	**13**
Full Body (e.g. Kinect, DDR, Guitar Hero/Rock Band)	69.2%	9
	answered question	**13**
	skipped question	**2**

13. Do you feel that your level of video game experience helped or hindered your performance in the experiment?

	Response Percent	Response Count
Helped	**66.7%**	**10**
Neither	26.7%	4
Hindered	6.7%	1
answered question		**15**
skipped question		**0**

14. How aware were you of the controls while you were using them? (1 is Not aware, 5 is Very aware)

	1	2	3	4	5	Rating Average	Response Count
Not aware -> Very aware	0.0% (0)	13.3% (2)	26.7% (4)	**33.3% (5)**	26.7% (4)	3.73	15
answered question							**15**
skipped question							**0**

15. How awkward was holding the controller in your hand? (1 is Not at all awkward, 5 is Very awkward)

	1	2	3	4	5	Rating Average	Response Count
Not at all awkward -> Very Awkward	**40.0% (6)**	**40.0% (6)**	20.0% (3)	0.0% (0)	0.0% (0)	1.80	15
answered question							**15**
skipped question							**0**

16. Did you feel that you were fully in control of the robot at all times?

	Response Percent	Response Count
Yes	**80.0%**	**12**
No	20.0%	3
answered question		**15**
skipped question		**0**

17. How difficult was it to maintain control while driving in a straight line? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	**80.0% (12)**	13.3% (2)	6.7% (1)	0.0% (0)	0.0% (0)	1.27	15
answered question							**15**
skipped question							**0**

18. How difficult was it to maintain control while turning? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	26.7% (4)	**46.7% (7)**	20.0% (3)	6.7% (1)	0.0% (0)	2.07	15
answered question							**15**
skipped question							**0**

19. How difficult was it to learn the controls? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	**86.7% (13)**	13.3% (2)	0.0% (0)	0.0% (0)	0.0% (0)	1.13	15
						answered question	**15**
						skipped question	**0**

20. Did you perform as well as you wanted to in the obstacle course?

	Response Percent	Response Count
Yes	**80.0%**	**12**
No	20.0%	3
answered question		**15**
skipped question		**0**

21. What was your favorite part about this control scheme?

	Response Count
	15
answered question	**15**
skipped question	**0**

22. What was your least favorite part about this control scheme?

	Response Count
	15
answered question	15
skipped question	0

23. How aware were you of the controls while you were using them? (1 is Not aware, 5 is Very aware)

	1	2	3	4	5	Rating Average	Response Count
Not aware -> Very aware	6.7% (1)	20.0% (3)	6.7% (1)	**40.0% (6)**	26.7% (4)	3.60	15
						answered question	15
						skipped question	0

24. How awkward was holding the controller in your hand? (1 is Not at all awkward, 5 is Very awkward)

	1	2	3	4	5	Rating Average	Response Count
Not at all awkward -> Very Awkward	20.0% (3)	**33.3% (5)**	26.7% (4)	13.3% (2)	6.7% (1)	2.53	15
						answered question	15
						skipped question	0

25. Did you feel that you were fully in control of the robot at all times?

	Response Percent	Response Count
Yes	**60.0%**	**9**
No	40.0%	6
	answered question	**15**
	skipped question	**0**

26. How difficult was it to maintain control while driving in a straight line? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	**40.0% (6)**	20.0% (3)	13.3% (2)	26.7% (4)	0.0% (0)	2.27	15
						answered question	**15**
						skipped question	**0**

27. How difficult was it to maintain control while turning? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	**33.3% (5)**	13.3% (2)	13.3% (2)	26.7% (4)	13.3% (2)	2.73	15
						answered question	**15**
						skipped question	**0**

28. How difficult was it to learn the controls? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	40.0% (6)	**46.7% (7)**	13.3% (2)	0.0% (0)	0.0% (0)	1.73	15
						answered question	**15**
						skipped question	**0**

29. Did you perform as well as you wanted to in the obstacle course?

		Response Percent	Response Count
Yes		40.0%	6
No		**60.0%**	**9**
		answered question	**15**
		skipped question	**0**

30. What was your favorite part about this control scheme?

	Response Count
	15
answered question	**15**
skipped question	**0**

31. What was your least favorite part about this control scheme?

	Response Count
	15
answered question	15
skipped question	0

32. How aware were you of the controls while you were using them? (1 is Not aware, 5 is Very aware)

	1	2	3	4	5	Rating Average	Response Count
Not aware -> Very aware	6.7% (1)	0.0% (0)	13.3% (2)	13.3% (2)	**66.7% (10)**	4.33	15
						answered question	15
						skipped question	0

33. How awkward was holding the controller in your hand? (1 is Not at all awkward, 5 is Very awkward)

	1	2	3	4	5	Rating Average	Response Count
Not at all awkward -> Very Awkward	6.7% (1)	6.7% (1)	20.0% (3)	20.0% (3)	**46.7% (7)**	3.93	15
						answered question	15
						skipped question	0

34. Did you feel that you were fully in control of the robot at all times?

	Response Percent	Response Count
Yes	13.3%	2
No	**86.7%**	**13**
	answered question	**15**
	skipped question	**0**

35. How difficult was it to maintain control while driving in a straight line? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	13.3% (2)	26.7% (4)	13.3% (2)	**33.3% (5)**	13.3% (2)	3.07	15
						answered question	**15**
						skipped question	**0**

36. How difficult was it to maintain control while turning? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	0.0% (0)	13.3% (2)	0.0% (0)	**53.3% (8)**	33.3% (5)	4.07	15
						answered question	**15**
						skipped question	**0**

37. How difficult was it to learn the controls? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	20.0% (3)	6.7% (1)	**46.7% (7)**	6.7% (1)	20.0% (3)	3.00	15
						answered question	**15**
						skipped question	**0**

38. Did you perform as well as you wanted to in the obstacle course?

	Response Percent	Response Count
Yes	20.0%	3
No	**80.0%**	**12**
	answered question	**15**
	skipped question	**0**

39. What was your favorite part about this control scheme?

	Response Count
	15
answered question	**15**
skipped question	**0**

40. What was your least favorite part about this control scheme?

	Response Count
	15
answered question	15
skipped question	0

41. How aware were you of the controls while you were using them? (1 is Not aware, 5 is Very aware)

	1	2	3	4	5	Rating Average	Response Count
Not aware -> Very aware	13.3% (2)	20.0% (3)	20.0% (3)	13.3% (2)	**33.3% (5)**	3.33	15
						answered question	15
						skipped question	0

42. How awkward was holding the controller in your hand? (1 is Not at all awkward, 5 is Very awkward)

	1	2	3	4	5	Rating Average	Response Count
Not at all awkward -> Very Awkward	**73.3% (11)**	13.3% (2)	6.7% (1)	6.7% (1)	0.0% (0)	1.47	15
						answered question	15
						skipped question	0

43. Did you feel that you were fully in control of the robot at all times?

	Response Percent	Response Count
Yes	**86.7%**	**13**
No	13.3%	2
	answered question	**15**
	skipped question	**0**

44. How difficult was it to maintain control while driving in a straight line? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	**93.3% (14)**	6.7% (1)	0.0% (0)	0.0% (0)	0.0% (0)	1.07	15
						answered question	**15**
						skipped question	**0**

45. How difficult was it to maintain control while turning? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	40.0% (6)	**53.3% (8)**	0.0% (0)	6.7% (1)	0.0% (0)	1.73	15
						answered question	**15**
						skipped question	**0**

46. How difficult was it to learn the controls? (1 is Easy, 5 is Difficult)

	1	2	3	4	5	Rating Average	Response Count
Easy -> Difficult	**73.3% (11)**	26.7% (4)	0.0% (0)	0.0% (0)	0.0% (0)	1.27	15
						answered question	**15**
						skipped question	**0**

47. Did you perform as well as you wanted to in the obstacle course?

	Response Percent	Response Count
Yes	**86.7%**	**13**
No	13.3%	2
	answered question	**15**
	skipped question	**0**

48. What was your favorite part about this control scheme?

	Response Count
	15
answered question	**15**
skipped question	**0**

49. What was your least favorite part about this control scheme?

	Response Count
	15
answered question	**15**
skipped question	**0**

50. I would use this control scheme to accomplish a critical task.

	1	2	3	4	Response Count
D-Pad	20.0% (3)	26.7% (4)	**46.7% (7)**	6.7% (1)	15
Tilt	26.7% (4)	**33.3% (5)**	26.7% (4)	13.3% (2)	15
Hand Gestures	0.0% (0)	6.7% (1)	13.3% (2)	**80.0% (12)**	15
XBOX Controller	**53.3% (8)**	33.3% (5)	13.3% (2)	0.0% (0)	15
				answered question	**15**
				skipped question	**0**

51. I would use this control scheme continuously for two hours.

	1	2	3	4	Response Count
D-Pad	6.7% (1)	40.0% (6)	**46.7% (7)**	6.7% (1)	15
Tilt	6.7% (1)	**53.3% (8)**	33.3% (5)	6.7% (1)	15
Hand Gestures	13.3% (2)	0.0% (0)	6.7% (1)	**80.0% (12)**	15
XBOX Controller	**73.3% (11)**	6.7% (1)	13.3% (2)	6.7% (1)	15
				answered question	**15**
				skipped question	**0**

52. Which control scheme was the most intuitive?

	Response Percent	Response Count
D-Pad	33.3%	5
Tilt	**40.0%**	**6**
Hand Gesture	0.0%	0
XBOX Controller	26.7%	4
	answered question	**15**
	skipped question	**0**

53. Which control scheme was the most fun to use?

	Response Percent	Response Count
D-Pad	13.3%	2
Tilt	**46.7%**	**7**
Hand Gesture	13.3%	2
XBOX Controller	26.7%	4
	answered question	**15**
	skipped question	**0**

Page 1, Q1. What is your subject number?		
1	83	Apr 30, 2012 2:02 PM
2	95	Apr 30, 2012 1:18 PM
3	23	Apr 30, 2012 12:19 PM
4	81	Apr 30, 2012 10:42 AM
5	55	Apr 30, 2012 9:54 AM
6	24	Apr 30, 2012 8:48 AM
7	54	Apr 29, 2012 1:56 PM
8	18	Apr 28, 2012 5:15 PM
9	45	Apr 28, 2012 11:50 AM
10	17	Apr 28, 2012 9:51 AM
11	37	Apr 27, 2012 8:27 PM
12	85	Apr 27, 2012 12:44 PM
13	46	Apr 27, 2012 11:45 AM
14	26	Apr 26, 2012 1:29 PM
15	12	Apr 25, 2012 10:02 PM

Page 1, Q5. What is your year in school? Please specify if you are an undergraduate or graduate student. If you are not a student, please write "N/A".		
1	Undergraduate (3rd Year - Junior)	Apr 30, 2012 2:02 PM
2	Graduate	Apr 30, 2012 1:18 PM
3	N/A	Apr 30, 2012 12:19 PM
4	NA	Apr 30, 2012 10:42 AM
5	Undergraduate (3rd Year - Junior)	Apr 30, 2012 9:54 AM
6	Undergraduate (submatric)	Apr 30, 2012 8:48 AM
7	n/a	Apr 29, 2012 1:56 PM
8	undergraduate	Apr 28, 2012 5:15 PM
9	Graduate	Apr 28, 2012 11:50 AM
10	Undergraduate (3rd Year - Junior)	Apr 28, 2012 9:51 AM
11	N/A	Apr 27, 2012 8:27 PM
12	Graduate	Apr 27, 2012 12:44 PM
13	Undergraduate (3rd Year - Junior)	Apr 27, 2012 11:45 AM
14	graduate	Apr 26, 2012 1:29 PM
15	Undergraduate (2nd year - sophomore)	Apr 25, 2012 10:02 PM

Page 1, Q6. What is your main field of study? If you are not a student, please state your occupation.		
1	Visual Studies	Apr 30, 2012 2:02 PM
2	Computer and Information Science	Apr 30, 2012 1:18 PM
3	Business	Apr 30, 2012 12:19 PM
4	Playwright	Apr 30, 2012 10:42 AM
5	Theatre	Apr 30, 2012 9:54 AM
6	Math	Apr 30, 2012 8:48 AM
7	artist/musician	Apr 29, 2012 1:56 PM
8	Theater	Apr 28, 2012 5:15 PM
9	Computer Science	Apr 28, 2012 11:50 AM
10	Digital Media Design	Apr 28, 2012 9:51 AM
11	Administrative Assistant	Apr 27, 2012 8:27 PM
12	Robotics	Apr 27, 2012 12:44 PM
13	Business	Apr 27, 2012 11:45 AM
14	Computer Graphics and Game Technology	Apr 26, 2012 1:29 PM
15	English Literature/Cinema Studies	Apr 25, 2012 10:02 PM

Page 2, Q21. What was your favorite part about this control scheme?		
1	Never got unexpected results	Apr 30, 2012 2:04 PM
2	Simplicity	Apr 30, 2012 1:20 PM
3	It was one that I was very familiar with.	Apr 30, 2012 12:22 PM
4	Simplicity, familiar control scheme	Apr 30, 2012 10:43 AM
5	simple to use	Apr 30, 2012 9:55 AM
6	Familiarity with controls from video game experiences (mostly GameBoy)	Apr 30, 2012 8:50 AM
7	easier than gesture	Apr 29, 2012 2:00 PM
8	simple, but not ambiguous	Apr 28, 2012 5:17 PM
9	Granular turning	Apr 28, 2012 11:51 AM
10	simple interface	Apr 28, 2012 9:53 AM
11	Since you simply had to stop holding the directorial arrow to stop, I found it easier to control it. I also liked how easy it was to make the robot turn.	Apr 27, 2012 8:29 PM
12	Seeing the directional arrows made it easy to use the controller	Apr 27, 2012 12:50 PM
13	I didn't need to be careful of my hand position the way I did for the tilt.	Apr 27, 2012 11:47 AM
14	how easy it was to control degree of turn	Apr 26, 2012 1:30 PM
15	The clean-cut, easy nature of the controls made driving the robot very a secure, steady experience.	Apr 25, 2012 10:10 PM

Page 2, Q22. What was your least favorite part about this control scheme?		
1	turning and moving not well integrated	Apr 30, 2012 2:04 PM
2	The need to stop touching the screen entirely to change control	Apr 30, 2012 1:20 PM
3	The fact that it would only respond to one command at a time.	Apr 30, 2012 12:22 PM
4	Could not turn and move at same time	Apr 30, 2012 10:43 AM
5	not very fast	Apr 30, 2012 9:55 AM
6	Discretized directional choices	Apr 30, 2012 8:50 AM
7	less fun than gesture and tilt	Apr 29, 2012 2:00 PM
8	a little mundane	Apr 28, 2012 5:17 PM
9	Not pressing the right button because I was looking at the robot instead	Apr 28, 2012 11:51 AM
10	only takes one command at a time.	Apr 28, 2012 9:53 AM
11	Nothing. This was my favorite one!	Apr 27, 2012 8:29 PM
12	Turning, I had to stop and turn	Apr 27, 2012 12:50 PM
13	The controls were not sensitive at all.	Apr 27, 2012 11:47 AM
14	Could not turn and move at same time	Apr 26, 2012 1:30 PM
15	The robot was slower because the control options weren't seamless	Apr 25, 2012 10:10 PM

Page 3, Q30. What was your favorite part about this control scheme?		
1	smooth motion control	Apr 30, 2012 2:05 PM
2	Intuitive and smooth, continuous variance to actions	Apr 30, 2012 1:22 PM
3	The sensitivity of the controller based on you motion	Apr 30, 2012 12:24 PM
4	Smooth, responsive controls. Akin to using a Wii-mote. Could make very subtle motions.	Apr 30, 2012 10:44 AM
5	vibration alerting to when not moving straight	Apr 30, 2012 9:56 AM
6	Full control	Apr 30, 2012 8:52 AM
7	fun	Apr 29, 2012 2:03 PM
8	fun, logical	Apr 28, 2012 5:20 PM
9	Being able to turn while moving forwards	Apr 28, 2012 11:52 AM
10	can perform multiple directions at the same time	Apr 28, 2012 9:54 AM
11	Moving in a straight line gave me a sense of accomplishment as I was pitiful at turning.	Apr 27, 2012 8:32 PM
12	The sensitivity of the controller - didn't have to necessarily stop to make turns	Apr 27, 2012 12:52 PM
13	It was very natural.	Apr 27, 2012 11:48 AM
14	Easy to move forward	Apr 26, 2012 1:32 PM
15	The quick speed	Apr 25, 2012 10:10 PM

Page 3, Q31. What was your least favorite part about this control scheme?		
1	easy to lose control of the direction	Apr 30, 2012 2:05 PM
2	Speed not always correct (slower than should've been)	Apr 30, 2012 1:22 PM
3	The responsiveness and accuracy of the controls	Apr 30, 2012 12:24 PM
4	Sometimes hard to stop. Had to reset the controls a few times, breaking fluid run of course.	Apr 30, 2012 10:44 AM
5	hard to turn	Apr 30, 2012 9:56 AM
6	Had to tilt far forward to get full speed	Apr 30, 2012 8:52 AM
7	difficult moving forward while turning	Apr 29, 2012 2:03 PM
8	the fluidity of the controls tended to hinder precision	Apr 28, 2012 5:20 PM
9	It was very easy to accidentally turn left or right while moving straight	Apr 28, 2012 11:52 AM
10	The hand has to be held at an odd angle at all times	Apr 28, 2012 9:54 AM
11	Turning. I felt that the robot was overly sensitive to my movements, and I could never quite get it pointed in the optimal direction to move swiftly through the course.	Apr 27, 2012 8:32 PM
12	Tilting to control the robot sometimes was difficult	Apr 27, 2012 12:52 PM
13	I had to expend a lot of energy to keep the robot going the way I wanted it to.	Apr 27, 2012 11:48 AM
14	awkward to turn and move	Apr 26, 2012 1:32 PM
15	The "tilt" nature of the device made steering slightly difficult because it was difficult to gauge how subtle the movements should be	Apr 25, 2012 10:10 PM

Page 4, Q39. What was your favorite part about this control scheme?		
1	no buttons that needed to be pressed	Apr 30, 2012 2:06 PM
2	Continuous action until stop or another action is given	Apr 30, 2012 1:24 PM
3	The controls became very intuitive and natural quickly	Apr 30, 2012 12:25 PM
4	Novelty.	Apr 30, 2012 10:46 AM
5	nothing	Apr 30, 2012 9:57 AM
6	Empowerment from making big gestures	Apr 30, 2012 8:54 AM
7	Most Fun	Apr 29, 2012 2:04 PM
8	N/A	Apr 28, 2012 5:24 PM
9	Pretending the controller was a magic wand	Apr 28, 2012 11:53 AM
10	the concept was interesting	Apr 28, 2012 9:55 AM
11	Similarly to the Tilt, I felt best when approaching a smooth part of the course so that I can move it in a straight line; however, I still had trouble stopping and starting the robot.	Apr 27, 2012 8:34 PM
12	Using hand gestures instead of buttons on a phone or gamepad	Apr 27, 2012 12:54 PM
13	It was easy to maintain control in a straight line.	Apr 27, 2012 11:49 AM
14	did not have to hold down any buttons or continuously do a motion	Apr 26, 2012 1:32 PM
15	The quick speed	Apr 25, 2012 10:10 PM

Page 4, Q40. What was your least favorite part about this control scheme?		
1	did not always respond to what seems to be the appropriate gestures	Apr 30, 2012 2:06 PM
2	Right-turn and left-turn are not symmetric: arm doesn't rotate as well in one direction so signaling is harder	Apr 30, 2012 1:24 PM
3	The turning wasn't as responsive and accurate	Apr 30, 2012 12:25 PM
4	Difficult to have total control of robot slave. Gestures were tiring. Gesture did not always yield the desired action from my robot slave.	Apr 30, 2012 10:46 AM
5	hard to turn, I felt that I had to gesture very strongly to make it move	Apr 30, 2012 9:57 AM
6	Relatively very difficult to maintain control	Apr 30, 2012 8:54 AM
7	Hardest to learn	Apr 29, 2012 2:04 PM
8	it was frustratingly disconnected and touchy	Apr 28, 2012 5:24 PM
9	The gestures took too long to affect the robot's movement	Apr 28, 2012 11:53 AM
10	the lag between each command and the action	Apr 28, 2012 9:55 AM
11	Stopping!! This was the most difficult robot to stop because you actually had to press a button or make a motion rather than release control of a different movement. I found it incredibly difficult and frustrating while journeying through the course.	Apr 27, 2012 8:34 PM
12	Sometimes the controller wasn't very sensitive when switching between directions	Apr 27, 2012 12:54 PM
13	The presence of the stop button did not mesh well with the gesturing aspect.	Apr 27, 2012 11:49 AM
14	Controls were unresponsive	Apr 26, 2012 1:32 PM
15	The unfamiliar gestures made it difficult to control the robot, in general	Apr 25, 2012 10:10 PM

Page 5, Q48. What was your favorite part about this control scheme?		
1	most intuitive	Apr 30, 2012 2:07 PM
2	Continuous forward motion possible with direction override	Apr 30, 2012 1:26 PM
3	It was a controller that I was familiar with and found easy to pickup quickly	Apr 30, 2012 12:27 PM
4	Familiar control scheme, like playing a video game or controlling an RC car. Very easy to turn while moving forward, easy to get precise turns	Apr 30, 2012 10:47 AM
5	triggers for gas and brake	Apr 30, 2012 9:58 AM
6	familiarity with control (from video games)	Apr 30, 2012 8:56 AM
7	easiest to learn	Apr 29, 2012 2:05 PM
8	the distinct difference between forward/backward controls and side to side controls	Apr 28, 2012 5:27 PM
9	It was easy to look at the robot and not worry about the controller because of the physical relationship with the buttons and sticks	Apr 28, 2012 11:54 AM
10	easy to understand	Apr 28, 2012 9:56 AM
11	I felt very in control of the robot with this scheme. I felt that the movements, much like with the D-Pad controller, were intuitive and easy to remember and utilize during the race.	Apr 27, 2012 8:37 PM
12	It was very similar to playing video games - easy to control and familiar	Apr 27, 2012 12:56 PM
13	The use of a game controller felt very natural to me.	Apr 27, 2012 11:50 AM
14	Easy to turn and move at same time	Apr 26, 2012 1:33 PM
15	The familiarity and stability of the controls. Also, using both hands was helpful in controlling the robot.	Apr 25, 2012 10:11 PM

Page 5, Q49. What was your least favorite part about this control scheme?		
1	less than ideal integration of turning / moving	Apr 30, 2012 2:07 PM
2	All-or-nothing joystick detection range	Apr 30, 2012 1:26 PM
3	The fact that the controls were not sensitive to touch or pressure and that you could only give one command at a time.	Apr 30, 2012 12:27 PM
4	Controller malfunctioned at start of third lap, ending test run.	Apr 30, 2012 10:47 AM
5	it was hard to turn while moving	Apr 30, 2012 9:58 AM
6	it went out of control at the end (anomaly?)	Apr 30, 2012 8:56 AM
7	least fun	Apr 29, 2012 2:05 PM
8	i would have preferred to be able to make progressive movement while also turning.	Apr 28, 2012 5:27 PM
9	Not being able to turn while moving forward	Apr 28, 2012 11:54 AM
10	so many buttons	Apr 28, 2012 9:56 AM
11	The robot turned more sharply/forcefully when I commanded it than it did with the D-Pad, so I couldn't make my turns as subtly as I would have preferred. Moreover, in order to complete the turning motion, one very much has to fully push the joystick. It will not respond to light movement.	Apr 27, 2012 8:37 PM
12	Gas and Backward controls were separate from the turn control/button - They could've all been on the same joystick button	Apr 27, 2012 12:56 PM
13	The controls were not sensitive at all; the robot was incapable of making small turns at the level I needed.	Apr 27, 2012 11:50 AM
14	Hard to control degree of turn	Apr 26, 2012 1:33 PM
15	It was somewhat slower.	Apr 25, 2012 10:11 PM

Institutional Review Board Forms

This is the protocol approved by the University of Pennsylvania Institutional Review Board. The experiments were only conducted after approval from the IRB was obtained.

University of Pennsylvania
Office of Regulatory Affairs
3624 Market St., Suite 301 S
Philadelphia, PA 19104-6006
Ph: 215-573-2540/ Fax: 215-573-9438
INSTITUTIONAL REVIEW BOARD
(Federalwide Assurance # 00004028)

24-Apr-2012

Norman I Badler
Attn: Lauren Frazier
badler@seas.upenn.edu
lfrazier@seas.upenn.edu

PRINCIPAL INVESTIGATOR	: Norman I Badler
TITLE	: Evaluation of Gesture-Based Controls for Robotic Systems
SPONSORING AGENCY	: Department Of The Army
PROTOCOL #	: 815432
REVIEW BOARD	: IRB #8

Dear Dr. Badler:

The documents noted below, for the above-referenced protocol, were reviewed by Dr. Emma Meagher, Executive Chair of the IRB (or her authorized designee) using the expedited procedure set forth in 45 CFR 46.110 and approved on 23-Apr-2012.

_HS-ERA Modification Request, submitted 04/20/12 [confirmation code: iifjjjj]
_Modification Summary, uploaded 04/20/12
_Imaging Release Form, uploaded 04/20/12
_Consent Form, uploaded 04/20/12
_Questionnaire, uploaded 04/20/12
_Email Correspondence, dated 04/20/12

If you have any questions about the information in this letter, please contact the IRB administrative staff. Contact information is available at our website: http://www.upenn.edu/regulatoryaffairs.

Thank you for your cooperation.

Sincerely,

IRB Administrator

Modification

Basic Info	
Confirmation Number:	**iifjjjj**
Protocol Number:	**815432**
Created By:	**FRAZIER, LAUREN E**
Principal Investigator:	**BADLER, NORMAN I**
Protocol Title:	**Evaluation of Gesture-Based Controls for Robotic Systems**
Short Title:	**Gesture-Based Controls for Robotic Systems**
Protocol Description:	**In this thesis, I propose the use of smartphones for gesture-based control of robotic systems. The proposed controller will be evaluated by performing a set of carefully designed human factors experiments and computing a set of metrics (e.g. time taken to complete tasks) to measure the efficacy of the gesture-based control system.**
Submission Type:	**Social and Biological Sciences**

PennERA Protocol Status

Approved

Resubmission*
Yes

Are you submitting a Modification to this protocol?*

Yes

Current Status of Study

Study Status

Study has not begun (no subjects entered)

If study is currently in progress, please enter the following

Number of subjects enrolled at Penn since the study was initiated

0

Actual enrollment at participating centers

0

If study is closed to further enrollment, please enter the following

Number of subjects in therapy or intervention

0

Number of subjects in long-term follow-up only

0

IRB Determination
If the change represents more than minimal risk to subjects, it must be reviewed and approved by the IRB at a convened meeting. For a modification to be considered more than minimal risk, the proposed change would increase the risk of discomfort or decrease benefit. The IRB must review and approve the proposed change at a convened meeting before the change can be implemented unless the change is necessary to eliminate an immediate hazard to the research participants. In the case of a change implemented to eliminate an immediate hazard to participants, the IRB will review the change to determine that it is consistent with ensuring the participant′s continued welfare. Examples: Convened Board Increase in target enrollment for investigator initiated research or potential Phase I research Expanding inclusion or removing exclusion criteria where the new population may be at increased risk Revised risk information with active participants Minor risk revisions that may affect a subject′s willingness to continue to participate Expedited Review Increase in target enrollment at Penn where overall enrollment target is not exceeded or potentially sponsored research Expanding inclusion or removing exclusion where the new population has the same expected risk as the previous, based on similarities of condition Revised risk information with subjects in long-term follow-up Minor risk revisions with no subjects enrolled to date ** For track changes: turn on the reviewing toolbar (view ⇒ toolbars ⇒ reviewing). You can accept all changes from current point forward by clicking the arrow next to Accept Change icon in toolbar, and then clicking Accept All Changes in Document. Use either balloons with tracked changes OR-- to format for underlines (for additions) and strikethrough (for deletions) Either (1) click Show (in the reviewing toolbar) ⇒ options ⇒ "unclick use balloons in print and web layout" -- OR -- (2) use ctrl-U (for underline), and format ⇒ font ⇒ strikethrough (for strikethrough).
Expedited Review

Modification Summary
Please describe any required modification to the protocol. If you are using this form to submit an exception or report a deviation, enter 'N/A' in the box below.
Small changes to make wording more clear in several places.

Risk / Benefit
Does this amendment alter the Risk/Benefit profile of the study?
No

Change in Consent
Has there been a change in the consent documents?
Yes

If YES, please choose from the options below regarding re-consenting

Our site does not plan to obtain re-consent

Deviations

Are you reporting a deviation to this protocol?*

No

Exceptions

Are you reporting an exception to this protocol?*

No

Protocol Details

Resubmission*
Yes

Study Personnel

Principal Investigator

Name:	**BADLER, NORMAN I**
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Pager:	
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HS Training Completed:	**Yes**
Training Expiration Date:	**08/28/2012**
Name of course completed :	**CITI Protection of Human Subjects Research Training - ORA**

Study Contacts

Name:	**FRAZIER, LAUREN E**
Dept / School / Div:	**1300 - School of Engineering**
Campus Address Mail Code	
Address:	**RM 1109 SANSEAST 3600 CHESTNUT STREET MB 1030**
City State Zip:	**PHILADELPHIA PA 19104-6106**
Phone:	**215-369-0266**
Fax:	
Pager:	
Email:	**lfrazier@seas.upenn.edu**
HS Training Completed:	**No**
Training Expiration Date:	
Name of course completed :	

Other Investigator

None

Responsible Org (Department/School/Division):

1303 - Computer and Information Science

Key Study Personnel

Name:	**KAPADIA, MUBBASIR T**
Department/School/Division:	**Computer and Information Science**
HS Training Completed:	**No**
Training Expiration Date:	
Name of course completed:	

Disclosure of Financial Interests*
Does any person who is responsible for the design, conduct, or reporting of this research protocol have a **FINANCIAL INTEREST**?
No

Certification
I have reviewed the *Financial Disclosure and Presumptively Prohibited Conflicts for Faculty Participating in Clinical Trials* and the *Financial Disclosure Policy for Research and Sponsored Projects* with all persons who are responsible for the design, conduct, or reporting of this research; and all required Disclosures have been attached to this application.
Yes

Social and Biological Sciences

Study Instruments
Discuss the particulars of the research instruments, questionnaires and other evaluation instruments in detail. Provide validation documentation and or procedures to be used to validate instruments. For well know and generally accepted test instruments the detail here can be brief. More detail may be required for a novel or new instrument. For ethnographic studies identify any study instruments to be used (i.e. for deception studies) and describe in detail where, when and how the study will be conducted and who or what are the subjects of study. Note: For more information on how to conduct ethical and valid ethnographic research, follow the link For oral histories or interviews provide the general framework for questioning and means of data collection. If interviews or groups settings are to be audio taped or video taped describe in detail the conditions under which it will take place. Include a copy of any novel or new test instruments with the IRB submission.
Hardware: A Roomba robotic vacuum cleaner, an Android phone, and a XBOX gamepad controller will be used in the study, as well as some tape/craft materials to create an obstacle course for the robot. Participants will use the gamepad and smartphone to navigate the Roomba robot in the obstacle course. Video Recording: The participants will be video taped while performing the experiment which will be used to compute quantitative metrics to evaluate the efficiency of the controllers. We will observe metrics like number of times the subject looks down at the controls, number of times the subject verbally acknowledges a mistake, etc. Having a video recording means that we could analyze those metrics offline, after the experiment. The video will not be made public and will not be associated with the subject's name. Evaluation: After performing the experiment, subjects will be administered a questionnaire to help us determine their subjective experience during the experiment. They will be questioned about their experience with video games and other control systems to ensure that the independent variable was the only contributing factor to the differences in their results. The questionnaire will use a 5-level Likert scale. Attached is a copy of the questionnaire. Finally, subjects will be asked if they would like to allow us to use the images we took of them during the study as more than data -- potentially in a paper we write, or on slides or on our website. They will be asked to sign a consent form if they agree, but will be told that none of their other participation will be affected by their choice, either way we will use their data, unless they choose to withdraw from the study. Although we will maintain a list of the subjects' names during and after the study, we will not associate the individual set of responses from any particular subject in any personally identifiable way.

Group Modifications
Describe necessary changes that will or have been made to the study instruments for different groups.
N/A: No groups

Method for Assigning Subjects to Groups
Describe how subjects will be randomized to groups.
N/A: No groups

Administration of Surveys and/or Process
Describe the approximate time and frequency for administering surveys and/or evaluations. For surveys, questionnaires and evaluations presented to groups and in settings such as high schools, focus group sessions or community treatment centers explain how the process will be administered and who will oversee the process. For instance, discuss the potential issues of having teachers and other school personnel administer instruments to minors who are students especially if the content is sensitive in nature. Describe the procedure for audio and videotaping individual interviews and/or focus groups and the storage of the tapes. For instance, if audio tape recording is to be used in a classroom setting, describe how this will be managed if individuals in the class are not participating in the study. Explain if the research involves the review of records (including public databases or registries) with identifiable private information. If so, describe the type of information gathered from the records and if identifiers will be collected and retained with the data after it is retrieved. Describe the kinds of identifiers to be obtained, (i.e. names, social security numbers) and how long the identifiers will be retained and justification for use.
Before subjects begin, they will sign a consent form and be briefed on the way to use each controller. Approx. 15 min. Each subject will navigate a robot through an obstacle course several times (once for each control scheme). The experiment itself should take approx. 20 minutes. After the experiment, the subject will complete one questionnaire (~15 minutes) after he/she finishes with the robot. All video footage will be stored on a hard drive. No other records will be reviewed. Total time: 50 minutes.

Data Management
Describe how and who manages confidential data, including how and where it will be stored and analyzed. For instance, describe if paper or electronic report forms will be used, how corrections to the report form will be made, how data will be entered into any database, and the person(s) responsible for creating and maintaining the research database. Describe the use of pseudonyms, code numbers and how listing of such identifiers will be kept separate from the research data.
The video data will be stored digitally, on a hard drive. The questionnaires will be taken online (using SurveyMonkey) and stored digitally as well. Subjects will be assigned a number that will be used when transcribing the questionnaire rather than identifying information. The data will only be managed by the PI and primary study contact. Although we will maintain a list of the subjects' names during and after the study, we will not associate the individual set of responses from any particular subject in any personally identifiable way.

Human Source Material*
Does this research include collection or use of human source material (i.e., human blood, blood products, tissues or body fluids)?
No

Medical Information Disclosure*
Does the research proposal involve the use and disclosure of research subject's medical information for research purposes?
No

If the answer is YES, indicate which items is is provided with this submission:

Use of UPHS services*
Does your study require the use of University of Pennsylvania Health System (UPHS) services, tests or procedures* whether considered routine care or strictly for research purposes?
No

Primary Focus*
Other

Protocol Interventions

	Sociobehavioral (i.e. cognitive or behavioral therapy)
	Drug
	Device - therapeutic
	Device - diagnostic (assessing a device for sensitivity or specificity in disease diagnosis)
	Surgical
	Diagnostic test/procedure (research-related diagnostic test or procedure)
	Obtaining human tissue for basic research or biospecimen bank
	Survey instrument
x	**None of the above**

The following documents are currently attached to this item:

There are no documents attached for this item.

Sponsors

Business Administrator

Name:	**WEST, MARK**
Dept / School / Div:	**1322 - Moore Business Offices**
Phone:	**215-898-2442**
Fax:	
Pager:	
Email:	**MWEST@SEAS.UPENN.EDU**

Funding Sponsors

Name:	**DEPARTMENT OF THE ARMY**
Type:	**UPENN Federal**

Project Funding*
Is this project funded by or associated with a grant or contract?
Yes

Sponsor Funding
Is this study funded by an industry sponsor?
No

Status of contract

The following documents are currently attached to this item:

Grant Application (h4.1.doc)

Protocol

Objectives

Overall objectives
Robotic control systems are becoming more common, especially in the military. With military applications, there are lives at stake, so having the most efficient, intuitive control system can make a large difference in the success of a mission and the safety of the soldiers involved. Arm and hand gestures are typical human forms of communication, so applying that to a robotic control system can yield a more intuitive system. Varcholik et. al. describe a gesture based control system that uses the Nintendo Wiimote to determine arm/hand gestures to control a robot. In this thesis, I propose the use of smartphones for gesture-based control of robotic systems. The proposed controller will be evaluated by performing a set of carefully designed human factors experiments and computing a set of metrics (e.g. time taken to complete tasks) to measure the efficacy of the gesture-based control system.

Background
"Interactions and Training with Unmanned Systems and the Nintendo Wiimote" (Varcholik, Barber, and Nicholson) describes a gesture based control system that uses the Nintendo Wiimote to determine arm/hand gestures and control a robot. They then conducted a study where subjects used Wiimote gesture system and a more standard system and filled out a survey to indicate how effective the Wiimote system was as compared to the standard system. This project attempts to do something similar with smartphones by utilizing a framework first proposed by Robert Neßelrath in "TaKG, A Toolkit for Automatic Classification of Gestures".

Study Design

Design
Participants will use a gamepad and a smartphone to guide the robot through an obstacle course. They will first try the gamepad, which will be an XBOX 360 controller. On the smartphone, they will try a button based control scheme, a tilt based control scheme, and a large gesture based control system. The order in which they attempt these will be randomly selected. Some metrics that will be recorded are the speed with which each trial is completed, and the number of times the robot goes outside the boundaries of the obstacle course. At the end, participants will fill out a questionnaire regarding their performance on the obstacle course.

Study duration
This study is on-going research that will last about one month. Subjects participating in the study will be limited to 1 hour per session, for one session each.

Characteristics of the Study Population

Target population
Adult (college aged) subjects who are physically able enough to move their arms.

Subjects at Penn
30

Subjects at Sites Other than Penn
0

Vulnerable Populations

	Children (refer to SOP 501 for definition of children) Form
	Pregnant women (if the study procedures may affect the condition of the pregnant woman or fetus) Form
	Fetuses and/or Neonates Form
	Prisoners Form
	Other
x	**None of the above populations are included in the research study**

The following documents are currently attached to this item:

There are no documents attached for this item.

Subject recruitment
Posters will be put in campus buildings advertising the study. No referrals necessary.

The following documents are currently attached to this item:

Subject recruitment (flyer_irb.pdf)

Subject compensation*
Will subjects be financially compensated for their participation?
No

The following documents are currently attached to this item:

There are no documents attached for this item.

If there is subject compensation, provide the schedule for compensation per study visit or session and total amount for entire participation, either as text or separate document

N/A

Study Procedures

Procedures
The subject will be briefed on the purpose of the study and introduced to the robot and control equipment. The subject will then perform several trials (in a randomly selected order) using the different control schemes. Their performance will be timed/recorded. After the trials, the subject will fill out a questionnaire about their background and experience during the trials.

The following documents are currently attached to this item:

There are no documents attached for this item.

Analysis Plan
For each trial, we will record the total time taken to finish the trial, the number of fouls (straying outside of the course boundaries). We will also look at the data from the questionnaire, like subjects' rankings of the control schemes, and the video data (e.g., number of times the subject had to look down at the controls, trajectories of hand gestures, times the subject asked for help, times the subject acknowledged making a mistake). The average performance for each control scheme will be determined using arithmetic methods or ANOVA to compare the different control schemes. The analysis of variance would be computed for the average time taken to finish a trial, average number of fouls, average difficulty reported by subjects, etc.

The following documents are currently attached to this item:

There are no documents attached for this item.

Subject Confidentiality
Personal information will be collected on the consent form, and in the form of the videos, but will not be linked to the data. We will be using identifiers for the subjects on the consent , rather than personal information. The consent forms, survey data, and video data will be stored on an encrypted hard drive. After the study is complete, the relevant stills and survey data will be included in a paper (possibly for publication) to be shared with the RCTA. All the original data will then be destroyed by wiping the hard drive.

Data Disclosure
Will the data be disclosed to anyone who is not listed under Personnel?
Mubbasir Kapadia, CIS Postdoc

Data Protection*

	Name
	Street address, city, county, precinct, zip code, and equivalent geocodes
	All elements of dates (except year) for dates directly related to an individual and all ages over 89
	Telephone and fax number
	Electronic mail addresses
	Social security numbers
	Medical record numbers
	Health plan ID numbers
	Account numbers
	Certificate/license numbers
	Vehicle identifiers and serial numbers, including license plate numbers
	Device identifiers/serial numbers
	Web addresses (URLs)
	Internet IP addresses
	Biometric identifiers, incl. finger and voice prints
	Full face photographic images and any comparable images
	Any other unique identifying number, characteristic, or code
x	**None**

Consent

1. Consent Process

Overview
Consent will be obtained through the signing of a form after a subject volunteers for the study. There will be a brief (several minute) waiting period between informing the prospective participant and obtaining the consent. The language understood by the prospective participant is similar to the following: He/she has read and understand this consent form. He/she gives permission for the project personnel to use the images/videos collected as a result of this study for data collection purposes. Anonymity in all publications will be maintained unless he/she gives written consent to use his/her image. He/she does not waive any of his/her legal rights by signing this form. His/her signing of this form does not release the investigator, the sponsor, the institution nor its agents from liability for negligence.

Risk / Benefit

Potential Study Risks
The potential risks in this project are minimal. Possible risks are muscle strains and sprains while gesturing. If this occurs, the study will stop, and the subject can stop or continue at a future time. The electronic devices involved are not expected to cause any physical harm.

Potential Study Benefits
There are no direct benefits to the subject for choosing to participate in this study. However, participation could contribute to the understanding of gesture-based control systems, which could benefit the subject indirectly and may help other people in the future.

Risk / Benefit Assessment
The potential benefits outweigh the potential risks of the study. The risks are minimal, and the benefit could lead to technology that could be widely used, or used to save lives in the future.

General Attachments

The following documents are currently attached to this item:

Informed consent form (consent_form.doc)

Additional forms (imageconsentform.doc)

Questionnaires (questionnaire.doc)

Additional forms (citi_completion_report_mubbasir.pdf)

Additional forms (reply_doc.pdf)

Additional forms (citicompletionreportlfrazier.pdf)

University of Pennsylvania
Center for Human Modeling and Simulation
Norman I. Badler, Professor, Computer and Information Science, 215-898-5862
3330 Walnut St., Philadelphia, PA 19104-6389

Consent Form

Evaluation of Gesture-Based Control for Robotic Systems

PURPOSE
The purpose of this study is to measure the efficacy of different gesture-based control systems. You will test several control systems by navigating a robot through an obstacle course. The overarching goal of this work is to determine which control schemes are the best for soldiers who work with mobile robots. Should you choose to participate, we will videotape your participation for data collection purposes. The images of you collected during the study will not be redistributed without your written consent. You will be asked to complete a brief questionnaire at the end. Your total time is not expected to exceed 1 hour. The study will take place in the SIG Center within Penn Engineering. This research is sponsored by the Department of Defense and is subject to review by the Army Human Research Protections Office.

RISKS
The potential risks in this project are minimal. Possible risks are muscle strains and sprains while gesturing. If this occurs, the study will stop, and you can stop or continue at a future time. The electronic devices involved are not expected to cause any physical harm.

EXCLUSION CRITERIA
If you have a condition or injury such that you do not have a full range of wrist, elbow, or shoulder motion, you should not participate in this study.

BENEFITS
There are no direct benefits to you if you choose to participate in this study. However your participation could contribute to the understanding of gesture-based control systems, which could benefit you indirectly and may help other people in the future.

CONFIDENTIALITY
Every attempt will be made by the investigators to maintain all information collected in this study strictly confidential, except as may be required by court order or law. Data from the questionnaire answers may be stored on computers but will not be associated with your name. Authorized representatives of the University of Pennsylvania, including members of the Institutional Review Board (IRB), a committee charged with protecting the rights and welfare of research subjects, may be provided access to research records that identify you by name. If any publication or presentations results from this research, you will not be identified by name.

WITHDRAWAL
Your decision to take part in this study is a voluntary one. You may terminate your participation anytime without prejudice to present or future care or services at the University of Pennsylvania.

ALTERNATIVES TO PARTICIPATION
The alternative to being in this study is to not be in this study.

SUBJECT'S RIGHTS

Should you wish further information regarding your rights as a research subject at the University of Pennsylvania, you may contact the Director of Regulatory Affairs at 215-898-2614.

If you have any questions about the study you may contact the principal investigator (Dr. Norman Badler), listed on the first page of this document.

By signing below, the subject asserts that:

He/she has read and understands this consent form.

He/she gives permission for the project personnel to use the images/videos collected as a result of this study for data collection purposes. Anonymity in all publications will be maintained unless he/she gives written consent to use his/her image.

He/she does not waive any of his/her legal rights by signing this form.

His/her signing of this form does not release the investigator, the sponsor, the institution nor its agents from liability for negligence.

________________________________	________________________________
Signature of subject	Signature of person obtaining consent
________________________________	________________________________
Print name of subject	Print name of person obtaining consent

This consent form follows federal regulations. Specifically, Title 45 (Public Welfare), Department Of Health and Human Services, National Institutes Of Health, Office For Protection From Research Risks, Part 46 (Protection Of Human Subjects). These regulations can be found at http://ohrp.osophs.dhhs.gov/humansubjects/ guidance/45cfr46.htm, specifically sections 46.116 and 46.117.