DESIGN OF A HANDS-FREE CONTROL SYSTEM FOR DEVICE MANIPULATION

FINAL REPORT

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1.0 CONTEXT

Every interaction between a human and a machine is performed through an interface. Almost every interface requires the physical manipulation of the interface. Keyboards, touch screens and steering wheels are all examples of interfaces requiring physical manipulation. In many cases, the user experience, usability or operator safety is impaired by the need for a physical input device. Without the interface, the device is useless - a car with steering mechanism, a computer that does not allow user input. This "one size fits all" approach to human-machine interaction has created over dependency and inefficiency.

At the simplest level, the necessity of a generic hand-operated physical input device prevents and able-bodied operator from performing additional tasks simultaneously. An easy example of this is driving a car. A car has a variety of physical input devices. The steering wheel requires the driver to provide directional instruction via hand movement. Manipulation of pedals controls the speed of the vehicle. Radio and heat controls require manipulation of buttons and knobs. Additional complexity is added if headlights, windshield wipers, or a lane change is required. Adding additional controls requires adding an additional physical input device which in turn continues to increase the driver's workload. This snowball effect of a multitude of physical input devices is seen in a huge array of machines and multiplies when a user is asked to operate multiple devices at the same time. Jets, cars and drones are designed to maximize the workload of a single operator, but adding an additional task often pushes the operator past a safe limit.

In other systems, the physical interface renders the system unusable for a subset of users. An electric wheelchair with a joystick to control its speed and direction can make a huge difference in the independence and quality of life for a large portion of the physically disabled persons, however, the same device would be useless for a paralyzed person but it requires physical input the operator cannot provide.

1.1 HUMAN-MACHINE INTERFACES

A Human-Machine Interface (HMI) is any interface facilitating interaction between human and machine. HMIs have greatly advanced since the beginnings of computing. Original HMIs were driven by single-selection menus. Since then, HMI has progressed to mouse - keyboard controlled interfaces, and now to touch screen interfaces.

Figure 1 displays the cyclic nature of HMIs. As shown, the system is driven by user input. The human user, however is entirely reliant on the HMI to provide input to the system [1].

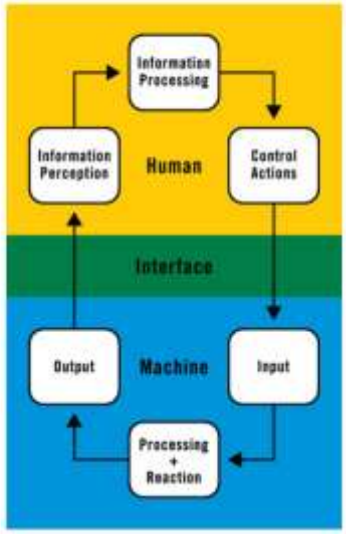


Figure 1 Human Machine Interface [1]

In many cases, the system will require constant attention and input from the user to provide small corrections as the system performs functions. In these cases, repeated actions can create additional stress on the user.

Examples of human-machine interfaces are plentiful in everyday life. A steering wheel is required for a user to manipulate a motor vehicle; a touch pad on a garage door enables a user to open or close the door. A computer relies on two physical human machine interfaces- a mouse and keyboard- to gather data from a user. All of these systems follow the same process outlined in the case study diagram shown in Figure 2. The figure depicts the HMI of an RC Car. As shown, the user's commands and mental model for the intended movement are essentially useless without the physical interface - in this case a remote control.

Figure 2 HMI of an RC Car

These interfaces are largely successful for users with full control of motor functions. However, in persons without control over motor functions, systems where an operator must quickly switch between control interfaces or complex systems requiring a large amount of user input, these systems are inefficient or unusable.

1.2 Alternatives To Current Control Interfaces

A number of alternatives to traditional control systems are in various stages of use. Table 1 gives 6 examples of alternatives to a physical control interface.

Table 1 Alternative Control Systems

[1] Voice Control 	[2] Eye Tracking Software 	[3] Muscle Contraction Detection 
[4] Head Movement/ Gyroscope 	[5] Predictive Analytics 	[6] BCI Interface 

Each of the control interfaces in Table 1 has unique benefits and challenges. Voice control is a popular hands-free control method which works well in systems without huge risk, in systems with minimal background noise and in systems without strict time constraints. Voice control is not effective in systems where the operator is under a large amount of stress or where a missed command has serious ramifications [2].

Eye tracking software is a very effective human-computer interface and has been proven to give a user a level of control comparable to using a mouse. Eye tracking software, however, has been much less effective outside of interaction with a stationary computer screen [3]. Muscle contraction detection is a growing technology especially in providing an operator with control over a prosthetic limb. This technology relies on a functioning nervous system and muscle system in the operator [4].

Gyroscopes has been built into a variety of headset devices to allow a user to control the motion of a device by tilting their head in accordance with mapped signals. This technology provides a limited number of possible commands, and very little fine grain control.

Predictive analytics, as used in the Google Self-Driving car, work to distance or remove the human operator from the system. While this technology is not specifically a control interface, it is important to consider that the human operator may not be necessary for more than a start command [5].

The final grid section shows a brain-computer interface (BCI). Brain-computer interfaces are largely considered to have the highest potential of the interface options. However, this technology is largely still developing [6].

2.0 MOTIVATION

Our team is contributing towards work to create a hands-free controller which can be seamlessly applied to any number of end devices. This effort has been motivated a group of potential users with very few other options. According to a 2012 study performed by the Christopher and Donna Reeve Foundation, 1.9% of the American population identifies as paralyzed. Of these 5,596,000 people, 2,909,920 people identify as "unable to move" or "a lot of difficulty" performing any motion [7].

For these persons, even devices specifically created to help persons with physical disabilities are rendered useless as long as the user is required to perform physical motion to use the device.

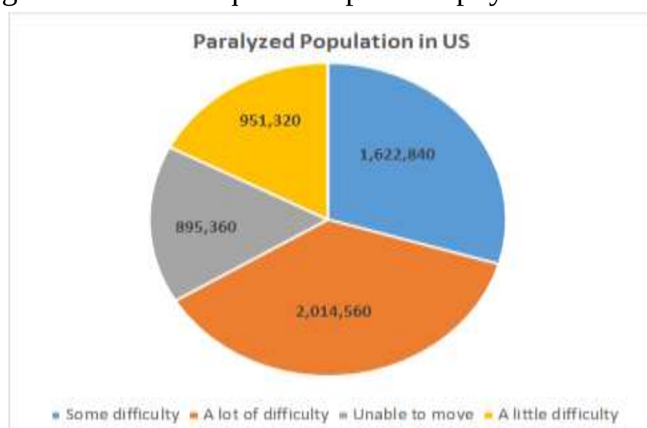


Figure 3 Paralyzed Population in the US

3.0 PROBLEM DEFINITION

3.1 GAP DEFINITION

Currently, almost every human-machine interaction must occur through a physical interface. The necessity of physical movement of the control interface is a highly limiting factor is the system usability and user workload. For the 2,909,920 severely paralyzed persons in America, the necessity of physical motion to operate a device renders the system unusable [7].

3.2 PROBLEM STATEMENT

Paralyzed persons are unable to use robotic aid devices which require physical movement to control.

3.3 NEED STATEMENT

Paralyzed persons need an alternative interface device which will allow them to manipulate a robotic aid device without requiring physical motion from the operator.

3.4 SCOPE

Before a new control interface can be selected for the robotic aid, we must examine the maneuvers which the robot will need to perform. This project will perform a simulation to collect and analyze the data crucial to creating a hands-free control interface.

3.5 STAKEHOLDERS

The main stakeholders for this system are: the physically disabled, the people who want to use EEG as a control method, insurance companies, the general public, the Health and Human Services and Food and Drug Administration, and various industries. Table 1 shows the possible effects of EEG to the stakeholders and their tensions.

Table 2 Stakeholders

Stakeholder	Effect of EEG	Tensions
Physically Disabled	• Improve ease of daily tasks and/or function as an adequate substitute	• Cost issues • Reliability issues • Possible uneasiness/distrust of EEG
EEG Control System Users	• Provide alternative to manual task • Potential to provide the most efficient way to complete a task	• Cost issues • Reliability issues • Possible uneasiness/distrust of EEG
Insurance	• Change policies • Create possible new fields for insurance	• Competition with current insurance if an EEG product becomes preferred
Industries	• Change/Improve EEG design • Create EEG compatible products	• Competition to non-EEG market
HHS and FDA	• Possible regulations update/change	• Possible tension if EEG is found to contain negative effects

3.5.1 Physically Disabled Persons

According to the United States census, approximately 19.9 million have difficulty lifting and grasping objects. If our system proves to be an effective control system for a robotic arm, it could provide support for this demographic.

Likewise, approximately 3.6 million people use wheelchairs as a method of transportation. If the system is an effective control system when interfacing with a mobilized platform, it will enhance the ease of use.

The main tension between the physically disabled and the system is the potential distrust. New technology generates skepticism. With a system that can read brain waves and convert to command, issues such as privacy can cause concern.

3.5.2 Interface Users

These are people who may wish to use the system to substitute manual control (such as operating a vehicle). The system is raising interest due to its futuristic outlook and potential for replacing traditional control methods. The possible tensions that can arise are similar to the possible tensions from the physically disabled.

3.5.3 Insurance Companies

Insurance companies are stakeholders due to the inherent liabilities of EEG. Because the system is designed to be used by people without the ability to manipulate devices without physically manipulating them, the system is an integral part of their lives. This would generate a need for insurance for EEG.

Another stakeholder to the system is the current insurance companies. As the EEG device becomes ubiquitous and integratable with other technology, the insurance companies covering the other technologies would have to adjust their policies for EEG. Since the system is targeted towards the physically disabled population, the system can have a huge impact on health insurance and their coverage on control methods for the physically disabled.

3.5.4 Industries

Various industries are potential stakeholders depending on the success of the system. If the EEG system can be integrated with another product, it opens a window of opportunity for these industries. Despite the potential to create an improvement to products, our system can be of conflict to some industries. The system can cause competition between the industries that use EEG versus the ones not using EEG.

3.5.5 Health and Human Services and Food and Drug Administration

The government is interested in protecting the wellbeing of individuals. Specifically the United States Department of Health and Human Services and the Food and Drug Administration, are stakeholders of EEG due to safety concerns. EEG is labeled as a very safe procedure according to the United States Library of Medicine and is used to diagnose seizures, epilepsy, tumors, and other head injuries. However, this only applies to EEG testing, which works by monitoring the brain activity. Our system differs in the sense that a user input is required and is designed to be used in a dynamic environment.

If the system is successful, an Investigational Device Exemption needs to be submitted to the Food and Drug Administration under a nonsignificant risk device to test its safety. Once approved, a clinical study can be conducted.

3.5.6 Stakeholder Tensions

Figure 8 shows the effects of our system to the stakeholders. The main tension that can arise from the system to the control system users and the physically disabled is an unreliability issue. Having a control system operated by solely the brain causes a considerable risk. As previously stated, introducing an integrable Hands-Free Interface to the market can cause competition amongst industries.

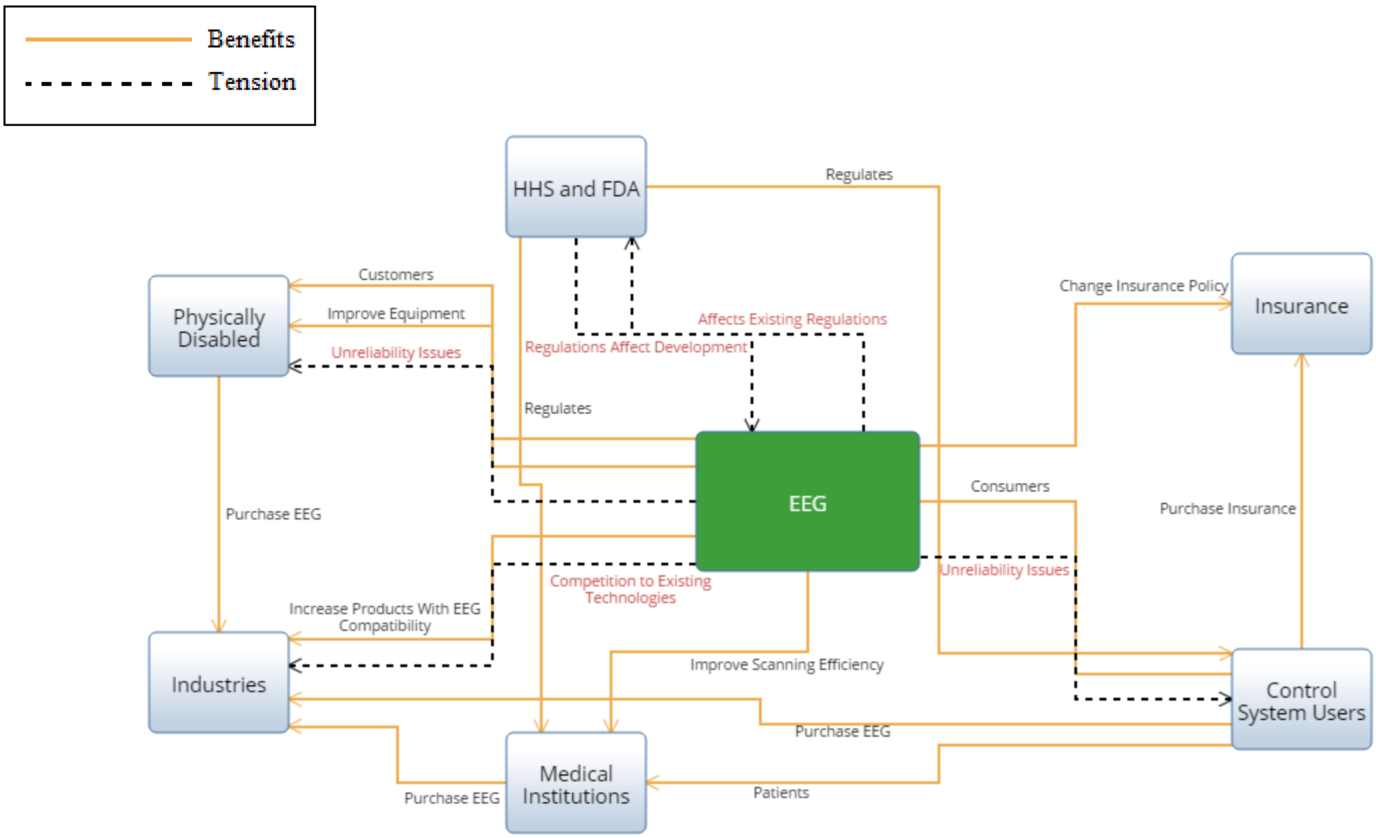


Figure 4 Stakeholder Interaction Diagram

4.0 Approach to the Problem

Before it can be determined which hands-free control method will be most effective, we must define (1) requirements for the hands-free control interface, (2) what maneuvers a robot performs in order to complete the use case, and (3) collect statistics on the frequency, time required and order in which these maneuvers are performed. In order to collect this data, we will have created a sample domestic use case.

End Goal: Use a hands-free interface to control the motion of a robotic aid.

Use Case for Demonstration: A paralyzed person gives direction for a robot to cross a room, pick up a water bottle and return it the operator.

This phase sets the stage for the remainder of the project. The primary deliverable from this Phase is a detailed requirements hierarchy for the hands-free control interface. The phase also includes documenting known challenges for hands-free control.

5.0 Systems Design

5.1 Concept of operations

A paralyzed person cannot perform many basic tasks as they require physical motion. A robotic aid can perform these tasks, provided a control interface is developed so that the paralyzed person can direct the movement of the robot.

A robotic aid, under the control of the operator, will cross a room, pick up an object and return to the operator.

5.1.1 Basic Operational Steps

The below set of steps is required in order for the robotic aid to fulfill its task:

1. Pivot to face object
2. Move forward
3. Stop at the table
4. Raise arm above table
5. Open hand
6. Move forward
7. Grasp object
8. Raise arm

9. Pivot to face user
10. Move forward
11. Stop in front of use
12. Pivot to face user
13. Adjust arm height
14. Open hand/ release object

5.1.2 Use Case Diagram

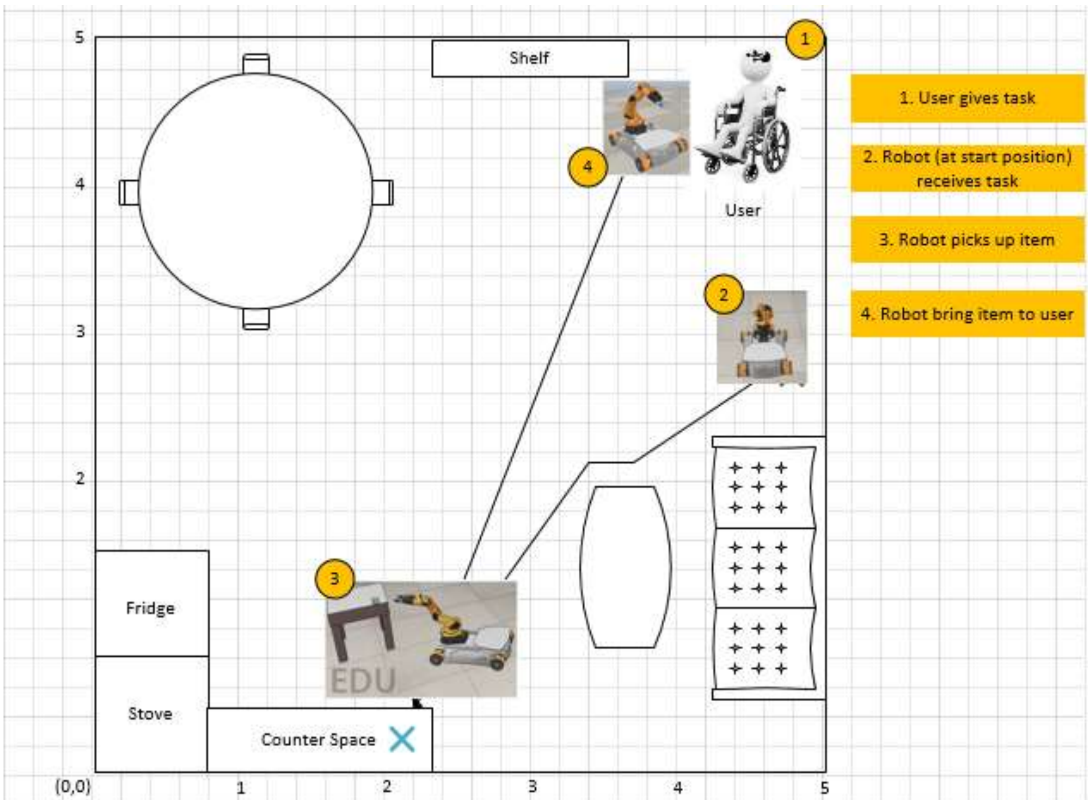


Figure 5 Use Case Diagram

5.1.3 Mission Requirements

A set of high level mission requirements has been generated for the operational concept.

R.0 The HFCS shall be operable without physical user input.
R.1 The HFCS shall direct the motion of a simulated robot in 3 dimensions.
R.2 The robot shall perform motion directed by HFCS.
R.3 The HFCS shall direct the movement of the simulated robot arm.
R.4 The robot arm shall perform movement directed by HFCS

R.5 The HFCS shall not harm the user in any way.
R.6 The HFCS shall provide flexibility for use for a variety of functions.
R.7 The HFCS system shall operate in real-time.

5.2 Functional Diagram

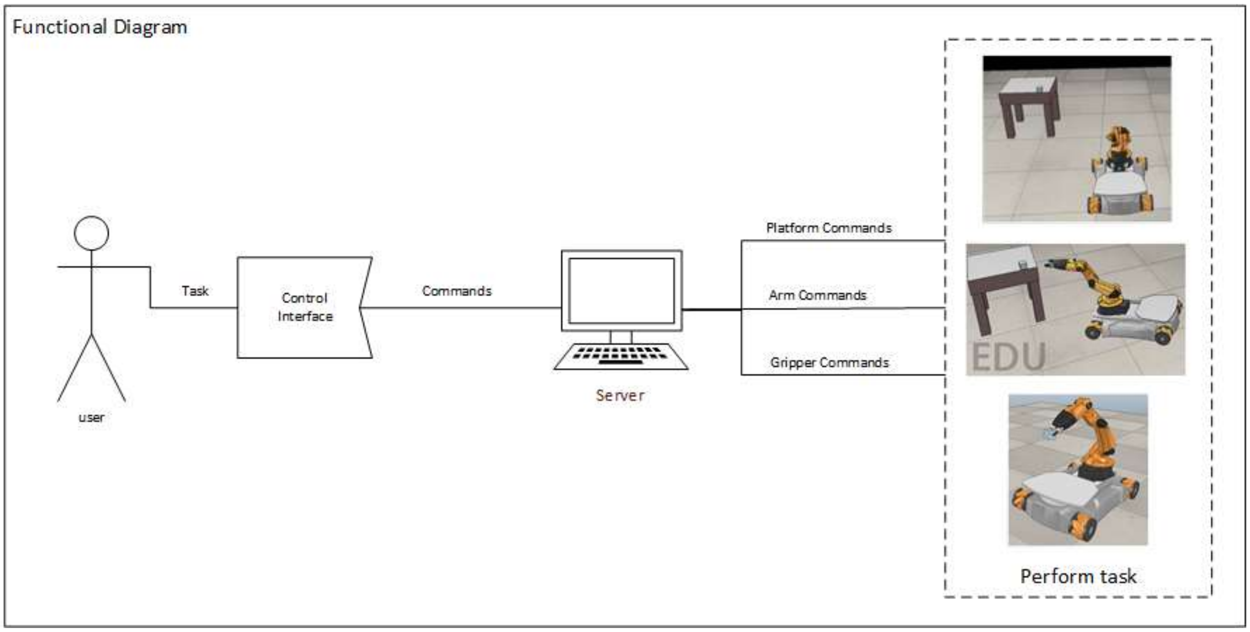


Figure 6 Functional Diagram

5.3 Requirements Decomposition (Mission and Functional)

The mission requirements listed in section 5.1.2 have been decomposed into functional requirements. This decomposition is reflected below. These quantitative values in these requirements may be revised after the simulation is run and analyzed.

R.0 The HFCS shall be operable without physical user input.
R.1 The HFCS shall direct the motion of a robot in 2 dimensions.
R.1.1 The HFCS shall direct the robot to move forward.
R.1.2 The HFCS shall direct the robot to pivot left.
R.1.3 The HFCS shall direct the robot to pivot right.
R.2 The robot shall perform motion directed by HFCS.
R.2.1 The robot shall move forward upon command.
R.2.2 The robot shall pivot left upon command.
R.2.3 The robot shall pivot right upon command.
R.3 The HFCS shall direct the movement of the robot arm.

R.3.1 The HFCS shall direct the arm to raise.
R.3.2 The HFCS shall direct the arm to lower.
R.3.3 The HFCS shall direct the hand to open.
R.3.4 The HFCS shall direct the hand to close.
R.4 The robot arm shall perform movement directed by HFCS
R.4.1 The robot arm shall raise upon command
R.4.2 The robot arm shall lower upon command.
R.4.3 The robot arm shall open upon command.
R.4.4 The robot arm shall close upon command.
R.5 The HFCS shall not harm the user in any way.
R.5.1 The HFCS shall employ only non-invasive technology.
R.5.2 The HFCS shall weigh less than 25 lbs.
R.5.3 The HFCS shall be worn by an operator with head size min = 19 inches, max = 25 inches.
R.5.4 The HFCS shall not impair the operator's ability to move their limbs or neck.
R.5.5 The HFCS shall not impair the operator's ability move from one location to the next.
R.5.6 The robot shall employ automatic collision avoidance.
R.5.7 The robot shall employ an automatic stop function if signal is lost.
R.6 The HFCS shall provide flexibility for use for a variety of functions.
R.6.1 The robot shall have a total radius of 8 inches.
R.6.2 The robot shall be able to grasp an object up to 4 feet off the ground.
R.6.3 The robot shall be able to grasp an object up to 3 inches away from the edge of a table.
R.6.4 The robot shall be able to lift an object up to diameter 5 inches.
R.6.5 The robot shall be able to lift an object up to 5 lbs.
R.6.7 The robot shall be able to transport up to 25 lbs.
R.6.8 The HFCS shall operate for a minimum of 3 hours before recharging is required.
R.6.9 The robot shall operate for a minimum of 3 hours before recharging is required.
R.6.10 The HFCS shall broadcast signal to 20 ft radius of system.
R.7 The HFCS system shall operate in real-time.
R.7.1 The HFCS shall direct the robot within 2 seconds of user command.
R.7.2 The robot shall perform motion within 1 second of HFCS direction.
R.7.3 The HFCS shall correctly identify 75% of user commands.

5.4 HANDS-FREE CONTROL INTERFACE CHALLENGES

A major design detail in a control system is the concept of control versus trajectory. In a trajectory based system, the end position of the device is provided as an input, and the device navigates to the end point without further instruction from the user. In a command based system, the user navigates the device as it moves towards the end point; the user must continuously supply input in order for the device to reach its end point. It is likely that a hands-free control interface would fall in the midpoint of the spectrum from trajectory based to command based systems. The level of automation provided will largely depend on the user's ability to specify and end-point, and the amount of automated movement the robot is capable of performing before a correction by the user is necessary.

A second challenge is found in the decision between using a control system based off of the user's point of view versus that of the device. For example, left and right controls would be the same for the user and the robot, if the robot is placed directly in front of the user, but facing away from the user. If the robot is turned to face the user, the robot's "left" command would no longer be the same direction as the users intuitive left.

6.0 SIMULATION OF ROBOTIC AID MOVEMENT IN DOMESTIC ENVIRONMENT

A simulation of a robot performing the use case will be generated and automatically run with random start point, end-point and fetch points. Data collect from this simulation will feed performance requirements for the hands-free control interface and allow the developed of the hands-free control interface to make the best judgement as to what interface method should be selected. The statistics will also allow the developer to position the control options to that the options most frequently used will be the most accessible. Lastly, this data will allow the developer to draw conclusions about the level of accuracy required in controlling the robot in order to perform the use case.

Terms for Simulation
Fetch item - an item the virtual robot is instructed to pick up
Fetch point - the location of the fetch item
Task - a randomly generated trip from a start point, to the fetch point, picking up the fetch item and carrying it to an assigned finish point
Start location - initial (x,y) coordinates of the center of the robot's platform
Finish location - final location of the center of the robot's platform

6.1 SIMULATION SET-UP

The simulation will be developed and run on Virtual Robotics Experimentation Platform (VREP). An educational version of this software is available for free on their website, as well as tutorials and user manuals (http://www.coppeliarobotics.com/) [8].

6.1.1 REQUIREMENTS FOR VIRTUAL ROBOT AND SIMULATOR

The following requirements were defined in order to select a virtual robot simulator.

S.0.1 Virtual Robot shall accept input from HFCS.
S.0.1.1 Virtual Robot model shall contain a robot with 3D movement capability
S.0.1.2 Virtual Robot model shall contain a robot capable of grasping and relocating
S.0.1.3 Virtual Robot model shall contain an object to be relocated.
S.0.2 The Virtual Robot model shall allow for scripted iterations.
S.0.3 The Virtual Robot model shall allow for start location to be set.
S.0.4 The Virtual Robot model shall include a path finding function.
S.0.5 The Virtual Robot model shall include an obstacle collision function.
S.0.6 The Virtual Robot model shall run on Windows 7 OS.

6.1.2 Simulation Environment Set-Up

The simulation will be run in a 5 meter by 5 meter room, created in the VREP software. The room will contain 20 "fetch objects" located on shelves, tables, chairs and the floor, all located at a variety of heights and distances from the edge of the surface. Fetch objects will be a variety of shapes and sizes. This room will be held constant after its initial generation. Figure 7 shows the simulation environment. Upon creation of the room, 20 "start points" will be created. The Figure 8 below shows 10 such start points.

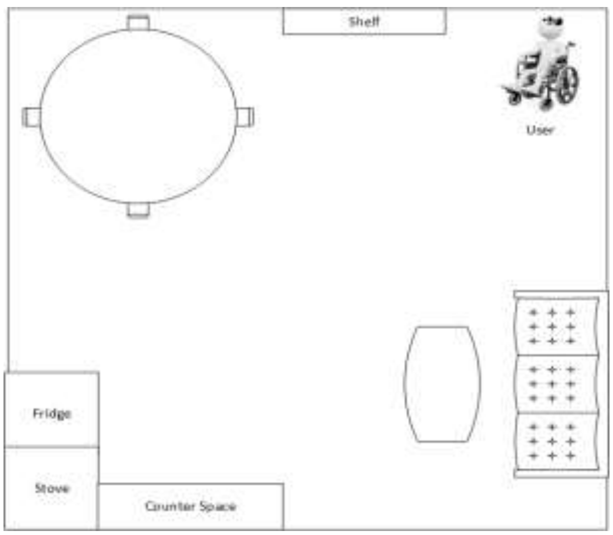


Figure 7 Simulation Environment

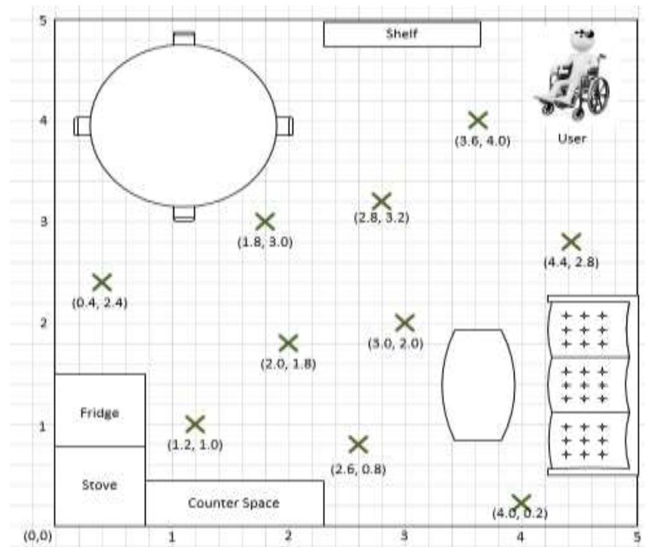


Figure 8 Simulation Start Points

The finish point will always be immediately in front of the user, as shown in Figure 9.

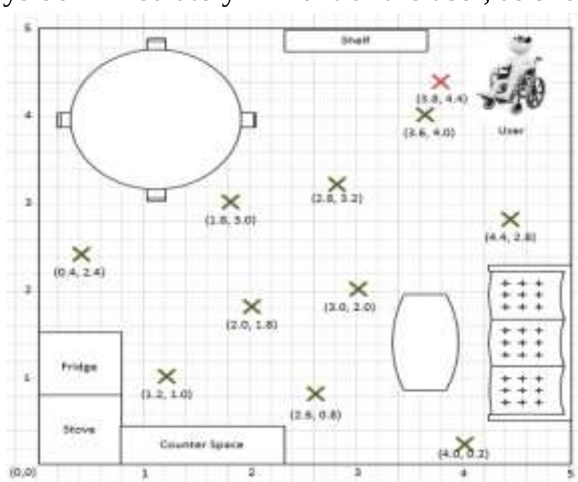


Figure 9 Simulation Start and End Points

Fetch points will be assigned to include a “z” variable (height) in addition to the xy location. For this reason, the majority of the fetch points will be found on the existing furniture in the simulated environment to support this 3rd dimension.

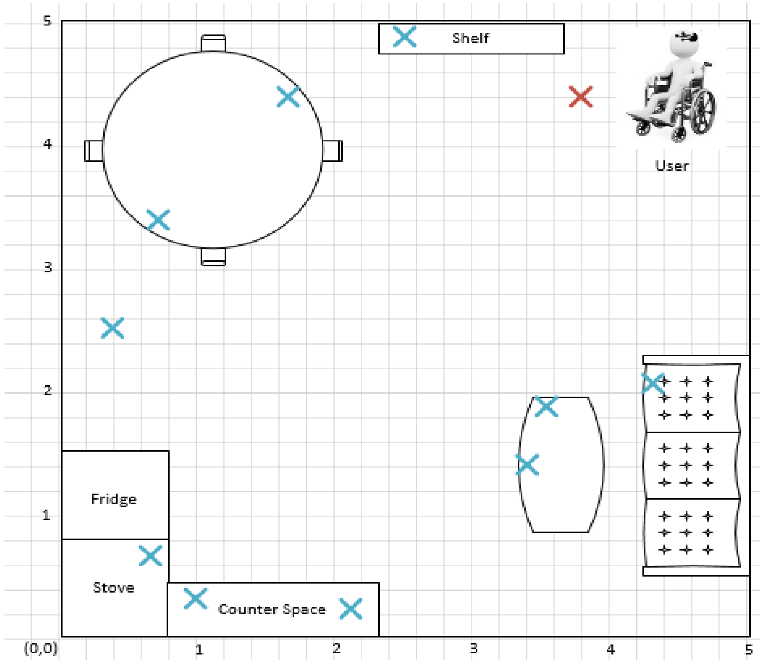


Figure 10 Fetch Points

6.1.3 VIRTUAL ROBOT SET-UP

The robot used for the simulation is the Kuka YouBot. This robot consists of 3 major parts, a platform, an arm, and a gripper at the end of the arm. The platform is capable of omnidirectional movement, zero turn radius turning and has a small surface to place objects. The arm has 5 joints for full 5DoF movement and limited pitch motion. The gripper is a 2 dimensional claw type gripper. The specification for the robot is below [9].

General characteristics youBot arm		
Serial kinematics	5 axes	
Height	655 mm	
Work envelope	$0.513\ m^3$	
Weight	6.3 kg	
Payload	0.5 kg	
Structure	Magnesium Cast	
Positioning repeatability	1 mm	
Communication	EtherCAT	
Voltage connection	24 V DC	
Drive train power limitable to	80 W	
Axis data	Range	Speed
Axis 1 (A1)	+/- 169°	90 °/s
Axis 2 (A2)	+ 90°/- 65°	90 °/s
Axis 3 (A3)	+ 146°/- 151°	90 °/s
Axis 4 (A4)	+/- 102°	90 °/s
Axis 5 (A5)	+/- 167°	90 °/s
Gripper	Detachable, 2 fingers	
Gripper stroke	20 mm	
Gripper range	70 mm	

General characteristics youBot platform	
Omnidirectional kinematics	4 KUKA omniWheels
Length	580 mm
Width	380 mm
Height	140 mm
Clearance	20 mm
Weight	20 kg
Payload	20 kg
Structure	Steel
Speed	0.8 m/s
Communication	EtherCAT
Voltage connection	24 V DC

General characteristics energy supply
Maintenance-free lead acid rechargeable batteries: 24 V, 5 Ah; Power supply: 200 W
Approximate battery runtime of KUKA youBot mobile manipulator: 90 minutes

General characteristics mini PC
Mini ITX PC-Board with embedded Intel® Atom Dual-Core CPU, 2 GB RAM, 32 GB SSD, USB

Figure 11 YouBot Specification [10]

Figure 12 YouBot Joints [10]

The youBot_gripperPositionTarget function allows the user to set the desired position of the gripper, and the system will adjust the arm accordingly so that the gripper position can be achieved [10].

Summary of Virtual Robot Moving Parts

- Gripper
  - Open
  - Close
- Arm
  - Up / Down
  - Forward / Backward
  - Left / Right
- Platform
  - Forward / Backward
  - Left / Right

Youbot velocity script simulation parameters allow for a minimum and maximum speed to be set for robot movement. These parameters may be utilized to ensure robot travels at the same velocity for each task [11].

6.1.4 Useful VRep Functions

The VREP simulation includes Path Planning module.
(http://www.coppeliarobotics.com/helpFiles/en/pathPlanningModule.htm)
This module requires the input of a start location, a goal position and obstacles (objects the robot should not collide with while completing the task.) Start and goal positions are identified with "dummies" - markers which appear based on the provided input parameters. Obstacles can be any imported shape or item, which are then identified as "obstacles". All non-fetch objects in the room will be identified as obstacles [12].

VRep includes a variety of sensors. The most important included sensor for this simulation will be the vision sensor. An object can be labeled "renderable" when it is created. A renderable object can be detected by the vision sensor. The Youbot robot contains a function to pick up a renderable object, using its vision sensor, provided that the object is in the line of sight of the robot [13].

6.2 Simulation Design

6.2.1 Input-Output Diagram

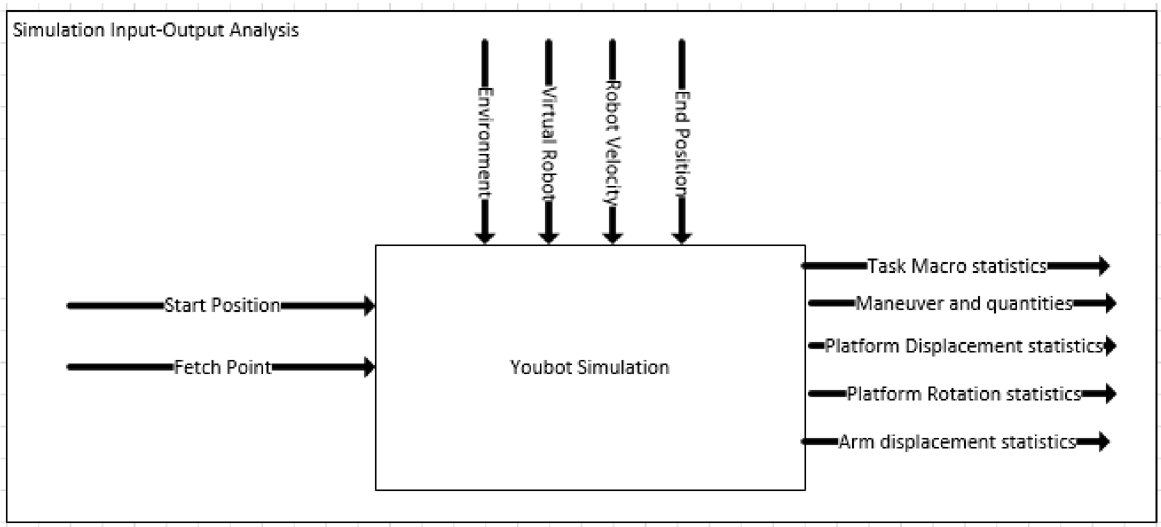


Figure 13 Input-Output Diagram

6.2.2 Example Path from Start location- Fetch location - Finish location

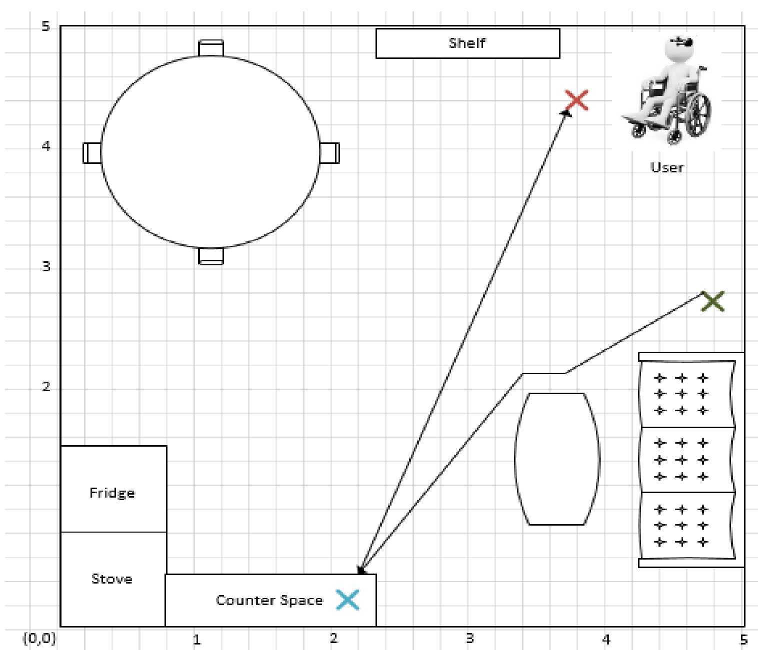


Figure 14 Sample Path

6.3 Simulation Pseudo-code

- Initialize each fetch object by (x,y,z) location.
- Create a list of the fetch objects.
- Create an array of start locations (x,y)
- Create a finish locations (x,y)

- Randomly select one of the fetch objects
- Randomly select a start position

- Create path plan from start location to fetch object
- Create a path plan from fetch object to finish location.

- Set robot location to start location.
- Run path from start location to fetch object
- Adjust robot angle so that the fetch object is in the vision sensor's range and line of sight. (Minimize distance between vision sensor and fetch object)
- Pick up the object
- Run path from fetch object to finish location

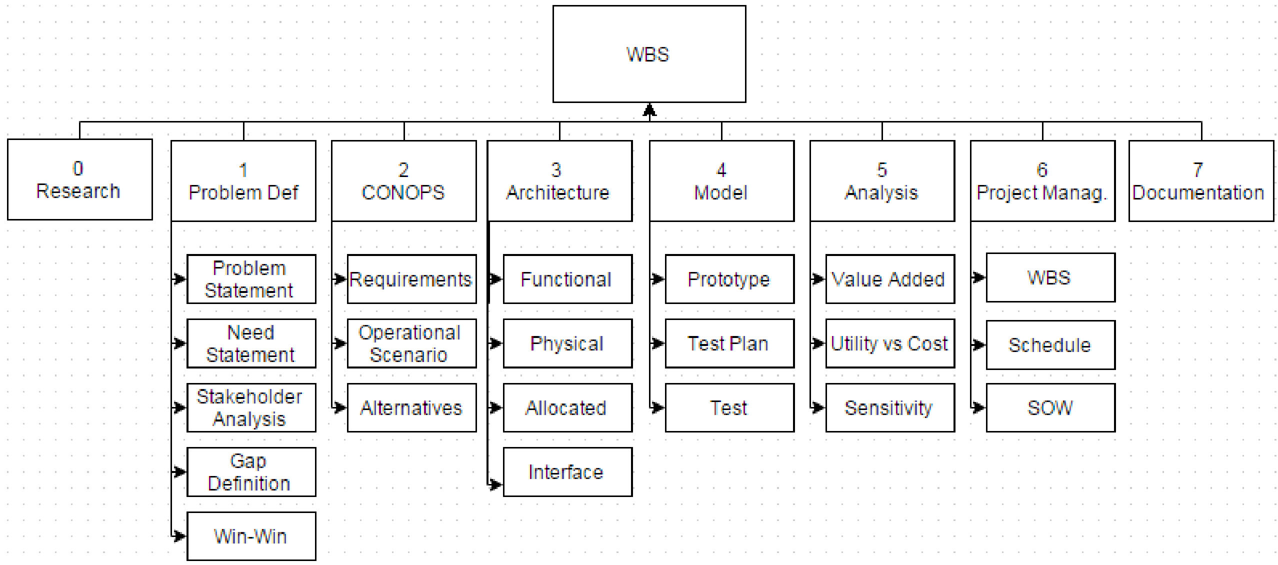
6.4 Statistics to Record per Run

The simulation will be run ~ 1000 times and each of the below data items will be recorded per run. Distributions and statistical analysis run on these statistics will reveal the most common maneuvers performed by the robot.

1. Start location
2. Fetch item location
3. End location
4. Total time on task
5. Time spent on Path 1
6. Time spent on Path 2
7. Time spent picking up object (frame between Path 1 and Path 2)
8. Total distance traveled
9. # of platform rotations
10. degrees rotated for each rotation
11. # lateral arm movements
12. Arm displacement per movement (cm)

7.0 Project Management

7.1 WBS



7.2 Schedule

High Level

Task Mode	Name	Duration	Start	Finish	Successors
	Project Totals	158.17 days	Mon 9/7/15	Thu 2/18/16	
	Management	50 days	Mon 9/7/15	Wed 10/28/15	
	Research	35.33 days	Mon 9/7/15	Tue 10/13/15	
	CONOPS	7 days	Mon 9/21/15	Mon 9/28/15	10,21,42,25
	Design Alternatives	6.67 days	Mon 10/5/15	Mon 10/12/15	
	Originating Requirements	3.33 days	Tue 10/6/15	Fri 10/9/15	10
	Design	17.5 days	Mon 10/12/15	Thu 10/29/15	31,52,44,30
	Simulation	53.33 days	Thu 10/29/15	Thu 12/24/15	
	Test	26.67 days	Wed 12/16/15	Wed 1/13/16	
	Analysis	31.67 days	Wed 1/13/16	Tue 2/16/16	
	Presentations	35.33 days	Mon 9/28/15	Tue 11/3/15	
	Documentation	102.17 days	Wed 11/4/15	Thu 2/18/16	

7.2.1 Detailed Schedule

		Task Mode	Name	Duration	Start	Finish	Successors
1			**Project Totals**	**158.17 days**	**Mon 9/7/15**	**Thu 2/18/16**	
2			**Management**	**50 days**	**Mon 9/7/15**	**Ved 10/28/15**	
7			**Research**	**35.33 days**	**Mon 9/7/15**	**Tue 10/13/15**	
8			Initial Project R	60 hrs	Mon 9/7/15	Wed 9/16/15	11,9,2
9			EEG Research	20 hrs	Wed 9/16/15	Mon 9/21/15	10,12,18
10			VREP Simulatio	20 hrs	Fri 10/9/15	Tue 10/13/15	31,30
11			**CONOPS**	**7 days**	**Mon 9/21/15**	**Mon 9/28/15**	**10,21,42,25**
12			Context	20 hrs	Mon 9/21/15	Wed 9/23/15	13
13			Problem/Need/	10 hrs	Wed 9/23/15	Thu 9/24/15	15,14
14			Stakeholders	10 hrs	Fri 9/25/15	Mon 9/28/15	15
15			Win-Win	2 hrs	Mon 9/28/15	Mon 9/28/15	17
16			**Design Alternatives**	**6.67 days**	**Mon 10/5/15**	**Mon 10/12/15**	
17			Hands-Free Opt	2 hrs	Mon 10/5/15	Mon 10/5/15	18,21
18			Headset Altern	8 hrs	Mon 10/5/15	Tue 10/6/15	25,21
19			Simulators	10 hrs	Fri 10/9/15	Mon 10/12/15	31,25,30
20			**Originating Requirements**	**3.33 days**	**Tue 10/6/15**	**Fri 10/9/15**	**10**
21			Mission Req	5 hrs	Tue 10/6/15	Wed 10/7/15	35,22,25
22			Functional Requ	5 hrs	Wed 10/7/15	Wed 10/7/15	23,25
23			Simulation Req	10 hrs	Thu 10/8/15	Fri 10/9/15	32,35,19
24			**Design**	**17.5 days**	**Mon 10/12/15**	**Thu 10/29/15**	**31,52,44,30**
25			Preliminary Dra	15 days	Mon 10/12/15	Tue 10/27/15	26
26			Functional Arch	5 hrs	Tue 10/27/15	Ved 10/28/15	27
27			Physical Archite	5 hrs	Wed 10/28/15	Ved 10/28/15	28
28			Interface Archit	5 hrs	Thu 10/29/15	Thu 10/29/15	
29			**Simulation**	**53.33 days**	**Thu 10/29/15**	**Thu 12/24/15**	
34			**Test**	**26.67 days**	**Wed 12/16/15**	**Wed 1/13/16**	
35			Develop test pl	40 hrs	Wed 12/16/15	Ved 12/23/15	36
36			Perform test ac	110 hrs	Thu 12/24/15	Wed 1/13/16	38,39
37			**Analysis**	**31.67 days**	**Wed 1/13/16**	**Tue 2/16/16**	
41			**Presentations**	**35.33 days**	**Mon 9/28/15**	**Tue 11/3/15**	
46			**Documentation**	**102.17 days**	**Wed 11/4/15**	**Thu 2/18/16**	
54							

7.2.2 Critical Path Analysis

Name	Duration	Start	Finish	Successors
Management	50 days	Mon 9/7/15	Wed 10/28/15	
Research	35.33 days	Mon 9/7/15	Tue 10/13/15	
CONOPS	7 days	Mon 9/21/15	Mon 9/28/15	10,21,42,25
Design Alternatives	6.67 days	Mon 10/5/15	Mon 10/12/15	
Originating Requirements	3.33 days	Tue 10/6/15	Fri 10/9/15	10
Mission Req	5 hrs	Tue 10/6/15	Wed 10/7/15	35,22,25
Functional Requ	5 hrs	Wed 10/7/15	Wed 10/7/15	23,25
Simulation Req	10 hrs	Thu 10/8/15	Fri 10/9/15	32,35,19
Design	17.5 days	Mon 10/12/15	Thu 10/29/15	31,52,44,30
Preliminary Dra	15 days	Mon 10/12/15	Tue 10/27/15	26
Functional Arch	5 hrs	Tue 10/27/15	Wed 10/28/15	27
Physical Archite	5 hrs	Wed 10/28/15	Wed 10/28/15	28
Interface Archit	5 hrs	Thu 10/29/15	Thu 10/29/15	
Simulation	53.33 days	Thu 10/29/15	Thu 12/24/15	
Test	26.67 days	Wed 12/16/15	Wed 1/13/16	
Develop test pl	40 hrs	Wed 12/16/15	Wed 12/23/15	36
Perform test ac	110 hrs	Thu 12/24/15	Wed 1/13/16	38,39
Analysis	31.67 days	Wed 1/13/16	Tue 2/16/16	
Presentations	35.33 days	Mon 9/28/15	Tue 11/3/15	
Documentation	102.17 days	Wed 11/4/15	Thu 2/18/16	

7.3 BUDGET

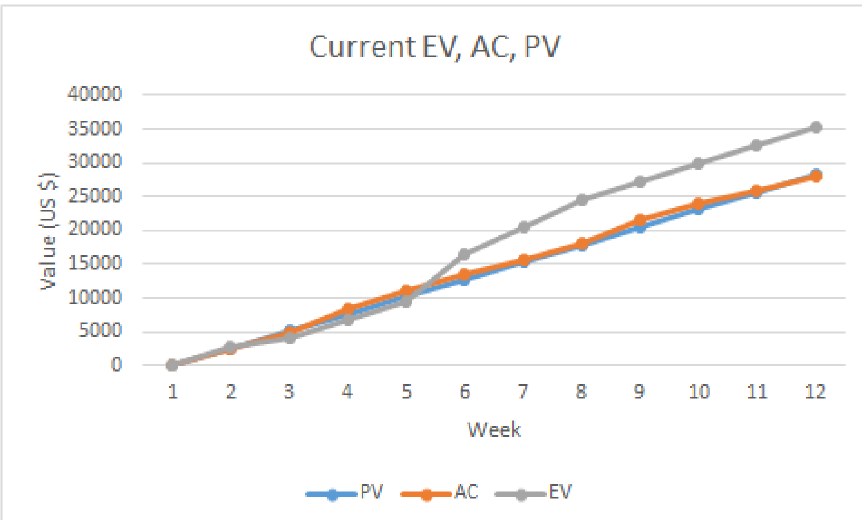
- Labor cost - $40/ hr
- Hourly rate - $85.40
  - GMU Overhead rate 2.13
- Planned hours - 1,576
- Planned Equipment cost - $400
- Planned Budget = $134,990.00

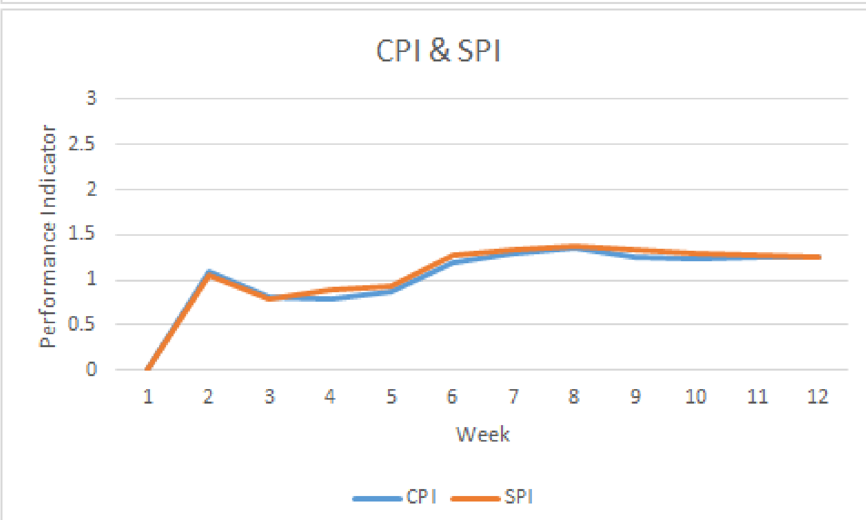
7.3.1 BUDGET TRACKING

Budget Calculations Weeks 1 through Week 12

'V) or Budgeted Cost of Work Scheduled (BCWS)														
Task Name	Budgeted Hours	TBC	8/31/2015	9/7/2015	9/14/2015	9/21/2015	9/28/2015	10/5/2015	10/12/2015	10/19/2015	10/26/2015	11/2/2015	11/9/2015	11/16/2015
			1	2	3	4	5	6	7	8	9	10	11	12
Management	135	$11,529.00	$0.00	$597.60	$341.60	$683.20	$341.60	$512.40	$341.60	$85.40	$256.20	$170.80	$85.40	$170.80
Research	100	$8,540.00	$0.00	$1,793.40	$1,750.70	$1,451.80	$1,195.60	$1,110.20	$768.60	$512.40	$512.40	$597.80	$341.60	$427.00
CONOPS	50	$4,270.00	$0.00	$85.40	$256.20	$341.60	$0.00	$85.40	$85.40	$0.00	$170.80	$341.60	$85.40	$0.00
Originating Requ	20	$1,708.00	$0.00	$0.00	$0.00	$0.00	$0.00	$170.80	$512.40	$427.00	$0.00	$341.60	$0.00	$0.00
Design Alternati	20	$1,708.00	$0.00	$0.00	$170.80	$170.80	$85.40	$170.80	$170.80	$0.00	$170.80	$170.80	$0.00	$0.00
Analysis	210	$17,934.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$170.80	$0.00	$256.20	$170.80	$0.00	$0.00
Test	150	$12,810.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Design	40	$3,416.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$768.60	$170.80	$170.80	$0.00
Simulation	320	$27,328.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$427.00	$683.20	$1,366.40
Testing		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Presentations	200	$17,080.00	$0.00	$0.00	$0.00	$854.00	$854.00	$597.80	$0.00	$854.00	$341.60	$85.40	$427.00	$0.00
Documentation	350	$29,890.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$597.80	$1,024.80	$0.00	$0.00	$256.20
Competitions		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Budgeted H	1595	136,213	0	30	30	30	30	30	30	30	30	30	30	30
Total Budgeted Cost			$0.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00	$2,562.00
		PV	$0.00	$2,476.60	$2,519.30	$3,501.40	$2,476.60	$2,647.40	$2,049.60	$2,476.60	$3,501.40	$2,476.60	$1,793.40	$2,220.40
		Week	1	2	3	4	5	6	7	8	9	10	11	12

7.4 Status





7.5 RISKS

Risk #	Foreseeable Risk	Mitigation Strategies
1	Delivery of Equipment	1a. Order equipment asap
2	Data Collection - quality of equipment, data quality	2a. Careful review of equipment reviews before ordering 2b. Research data collection techniques
3	Access to raw data	3a. Contact equipment company 3b. Find contacts within Mason community
4	Data analysis timeline driven by data collection/ equipment	4a. Develop test plan in line with system architecture 4b. Closely monitor progress towards project completion.

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APPENDIX 1 SIMULATION DESIGN FOR EEG AND YOUBOT

The main purpose of the virtual simulation is to demonstrate that we can perform actions with the EEG. The preliminary prototype of the HFCS will be demonstrated using the V-REP Virtual Simulator, as detailed in Section 1.3.

The robot used is the Kuka YouBot. The robot consists of 3 major parts, a platform, an arm, and a gripper at the end of the arm. The platform is capable of omnidirectional movement, zero turn radius turning and has a small surface to place objects. The arm has 5 joints for full 5DoF movement and limited pitch motion. The gripper is a 2 dimensional claw type gripper.

The initial prototype of the system uses keyboard commands to demonstrate that we can get the robot to move:

Platform:

- Move forwards – Up arrow key
- Move backwards – Down arrow key
- Turn left – Left arrow key
- Turn right – Right arrow key

Arm:

- X axis displacement – A and D keys
- Y axis displacement – W and S keys
- Z axis displacement – Q and E keys
- Gripper open/close toggle – Space key

In order to simplify user complexity, we created a function move all the joints of the arm according to the X, Y, Z position of the gripper. Each joint has a limited range of motion similar to how a real limb is.

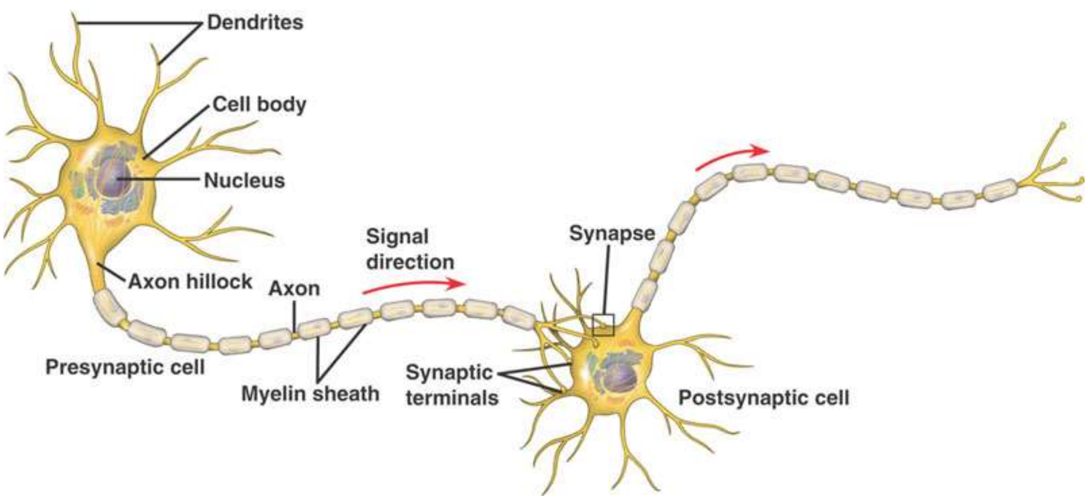
This training set will allow for demonstration that the control system is applicable to moving a wheelchair. After the initial prototype is developed and tested via demonstration, a second subset of motions will be developed to demonstrate the applicability of the hands-free control system to using a robot to aid a physically disabled person. We may need to simplify the number of controls more, such as using the same controls to control the arm displacement and the platform and use a toggle to switch between the control of each.

APPENDIX 2 DESIGN OF HANDS-FREE CONTROLLER WITH BCI INTERFACE

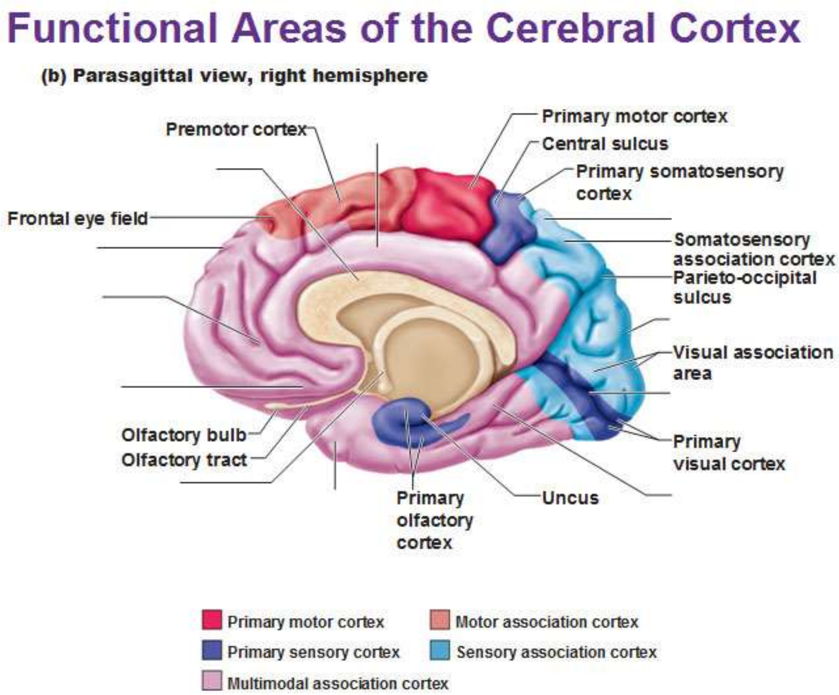
1.1 BRAIN MACHINE INTERFACES

Brain-machine interfaces (BMI) eliminate the need for the physical control device seen in the human-machine interfaces described in Section 1.1.1. Brain-machine interfaces very much a developing technology. The ability to begin research into brain-machine interfacing has been made possible by advances in machine learning, computing power and our understanding of the human brain, however, this technology is still at a technological readiness level of 3.

The human brain is made up of hundreds of millions of neurons. Neurons are nerve cells which can process and transfer information, when "excited". Neurons enter an excited state when they are connected to other neurons at specific transfer points referred to as synapses.These chains of excited neurons, referred to as neural networks, produce electrical signals and heat when transferring information. Information is transferred between the neurons on chains called axoms. Figure 4 shows an axon connecting two neurons at synapses, and an electrical signal being transferred along the axon.



The electrical signal produced by the transfer of information can be sensed on the outermost layer of the brain, referred to as the cortex. Different segments of the brain map to different functions. Figure 5 maps the segments of the brain to their function, for example, the top left segment, shaded red and labeled the primary motor cortex is responsible for the command messages controlling the physical motion of the body.



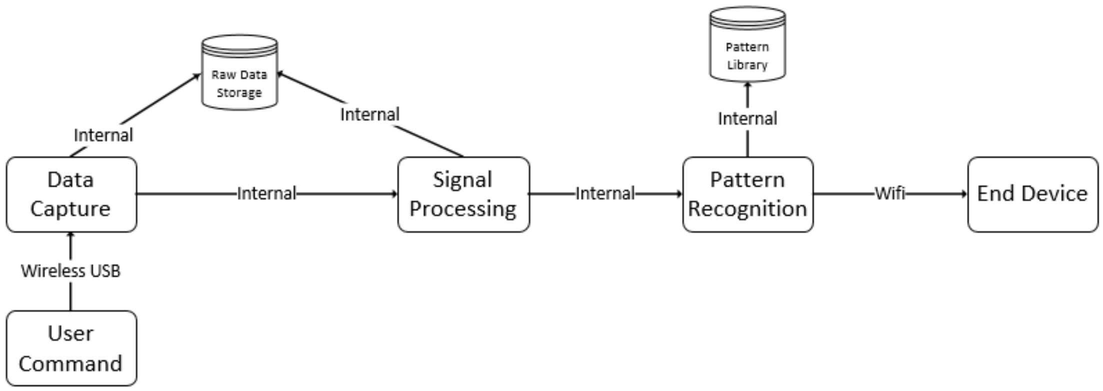
This modern understanding of the brain as an electrical control system has provided a crucial component to the development of brain-computer interfaces. Because the electrical signals commanding the physical control of the human body are measurable from the outer cortex of the brain, it is reasonable that these signals can be used to control a mechanical device.

1.2 ELECTROENCEPHALOGRAPHY

A normally functioning brain communicates by transmitting a series of electrical signals, referred to as impulses. This electrical activity can be measured and recorded through a process called electroencephalogy (EEG).

The waveforms shown in Figure 6 allow scientists and doctors to categorize the signals as a step towards identifying the thought that mapped to the waveform. Brain waves, as shown in the EEG output, usually fall into one of 4 major categories- alpha, beta, theta and delta waves. Each major category is distinguished by the frequency at which the brain waves are transmitted and have been mapped to specific emotions or behaviors. For example, beta waves are commonly associated with anxiety. While the basic waveforms seen in an EEG frequently allow doctors to diagnose neurological disorders, the EEG also records bursts of energy, responses to stimuli and unique waveform.

Advancements in data science and machine learning have made huge advancements in our ability to map specific motor controls to their respective brain signal output. The ability to identify the wave form that maps to a specific control, “look down” for example, gives us the ability to create a control system based on conscious thought.



1.3 TECHNOLOGY

Until very recently, brain activity could only be measured through invasive procedures. Two procedures were available to retrieve this data. In the most invasive procedure, a chip in the grey matter of the brain; in the partially invasive procedure, a chip was placed in the skull but on the outside of the brain. While these procedures yielded very accurate data, the invasive and potentially dangerous nature of the procedure prevented the advancement of EEG research.

However, recently a number of noninvasive methods to measure brain signals have been developed. The most common of these methods is seen in the medical profession, where a series of individual sensors are applied to the outside of the skull, as shown in Figure 7.

This method, while invasive, is still labor intensive and requires a large amount of preparation and calibration time. An alternative to the sensor method has been developed in the form of the EEG headset. This headset is comprised of an adjustable plastic frame supporting a series of sensors. While the headset does not match the level of data accuracy seen in invasive procedures, the data is frequently sufficient for non-medical purposes. As this technology continues to expand, it is expected that the accuracy of non-invasive headsets will improve.

1.4 CURRENT USES

Research into EEG began during World War II in an effort to evaluate fighter pilots for pre-existing neurological diseases. Today, the majority of the applications of EEG technology and leading EEG research remain in medical fields. EEG tests are regularly prescribed in an effort to evaluate a patient for risk of seizure disorders such as epilepsy. EEG tests can also reveal neurological disease creating sleep or stress disorders. A current study at Massachusetts General Hospital is being performed to evaluate the use of EEG to monitor the brain function of patients under anesthesia or in a coma.

The increased availability of EEG headsets has lead to research into uses for EEG data in commercial fields. The study of neuromarketing focuses on the consumer's conscious and subconscious reaction to a product. The application of EEG to this field has allowed researchers to assign quantitative values to a user's subconscious reactions. A hallmark study of this field compared a consumer's reaction to Coke versus Pepsi. In a blind taste test, reactions and EEG data yielded very little difference between the two products. In a second test, the users were able to see the packaging of the beverage and results showed a strong preference towards Coke products. This study showed that marketing and a consumer's perception of a product can affect the user's subconscious reaction to the product.

In military organizations, the application of EEG technology has the potential to reduce the user workload in command and control systems. A current project undertaken at University of California, Irvine is investigating the potential to revolutionize the way soldiers communicate through "Imagined Speech." Because soldiers are trained to communicate in very concise, specific terms, researchers believe these terms may create specific patterns in EEG output. The ability to recognize short key terms for communication is the same capability which will allow for EEG data to be used in a control system.

1.5 EMOTIV

Emotiv is a highly accredited bioinformatics company based in southern California. Their main goal is to promote the research of the human brain and stimulate public interest in bioinformatics. In addition to performing research, they offer many varieties of EEG headset products. Particularly, the standard EPOC headset comes equipped with fourteen passive EEG channels, wireless capabilities, and a software development kit created by the company. The EPOC+ variation includes all of these components, among bluetooth, and nine inertial sensors. For the purpose of this project, we purchased the standard EPOC headset with the raw data package. The raw data option will provide further insight to the finite signals that are emitted from the brain. This will enable a more accurate diagnosis of the flaws involved with utilizing EEG as a control system.