DESIGN OF A HANDS-FREE CONTROL SYSTEM FOR DEVICE MANIPULATION

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***Abstract*— Almost every device we interact with relies the use of a physical control interface in order for the user to command the system. This "one-size fits all approach" to control interfacing prevents the almost 3 million severely paralyzed persons from being able to operate even devices specifically created to help physically disabled persons. Robotic aids have been developed to move physical assets for severely physically disabled person, but a control interface which can support the needs of this population while providing the flexibility and accuracy necessary has not been created. Several alternative control systems have been developed, including eye tracking software, voice commands, predictive analytics and the beginnings of brain-computer interfacing. In order for a successful control interface to be created, a developer would need data and statistical analysis on the specific motions performed by each part of the robot, and the distribution of time necessary to complete a task.**

The project team has (will) created a simulation to demonstrate the movement of a virtual robot as it undertakes a specific task. The simulation provided a random start location, random object to pick up and set end location. The simulated robot will travel from the start location, to the location of the object, pick up the object and bring it to the end location.

Index terms - *HMI, Human Machine Interaction, EEG, BCI*

INTRODUCTION

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.

The required 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 because the user simply cannot provide input in the required format.

This project sets the framework for the development of a hands-free alternative to the standard control interface. This effort has been motivated a group of potential users with very few other options interface 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. 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.

CONTEXT

I. *Human-Machine Interaction*

A Human-Machine Interface (HMI) is any interface facilitating interaction between human and machine. Figure 1 shows the interface as a crucial layer connecting the human and the machine. Without the interface layer, the two entities are incompatible- the human has no capability to receive information from the system and the machine has no opportunity to solicit input from the user [1].

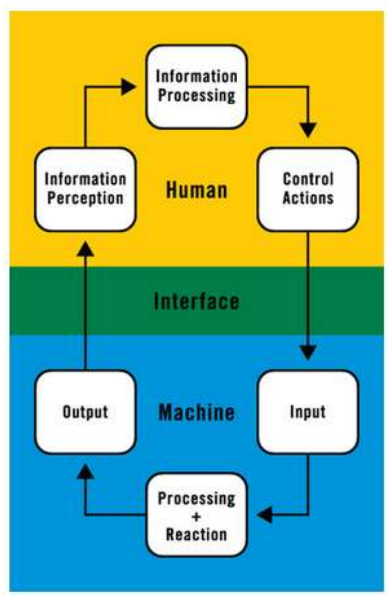

Figure 1 Human-Machine Interaction [1]

II. *Alternatives for Current Control Interface*

The concept of replacing the traditional control interface with one that does not require physical input from the user is not new. There are several interface methods in various stages of use or development which employ the concept of hands-free interfacing. However, current hands-free interface methods have unique benefits and challenges.

The most common hands-free interface method is voice control. Voice controlled devices, as many of us have experienced, allow users to access menu based control systems fairly accurately. The challenge associated with voice control is in the ability to recognize speech. Severely paralyzed persons, as we have focused on, frequently struggle to annunciate words. In situations of high stress, or large amounts of background noise, voice control interfaces are known to miss-interpret, or completely miss, commands [2].

Eye tracking software is known to be an effective method for interacting with a computer, with a degree of control very similar to a mouse and keyboard system. However, this interface is rarely applicable outside of a human-computer system [3]. Muscle contraction detection devices and gyroscope devices are both used for persons with some level of control over physical motion or muscle contraction.

Predictive analytics are used to completely remove the human operator from the inner workings of the control interface. An example of predicative analytics as used for a control interface is seen in the Google Self-driving car. These vehicle requires an input parameter for the user but otherwise removes the user from the system [4].

Brain-computer interfacing (BCI) is increasingly being realized as a potential interface method. While technology remains years out from successfully implementing a reliable, accurate BCI interface, groundwork to understand the challenges and requirements of such a system is being performed. Despite the low technological readiness level (TRL), this technology is regarded as having very high potential [5].

STAKEHOLDER ANALYSIS

It is expected that a wide array of industries will express interest in a hands-free control interface provided the system can perform at or above the accuracy and reliability of the current physical interface. For this analysis, we will focus predominantly on users of the hands-free interface geared towards severely paralyzed persons, as this group would be the first "real-world" test and integration of the interface system.

It is expected that the output of this project will predominantly interest those with the market share in producing alternative control devices. This project will provide data and insight crucial to creating a successful interface.

I. Severely Paralyzed Persons

This group makes up both the primary users for the system and the motivation for this project. The needs and safety of the paralyzed persons are considered the highest requirement throughout this project.

II. Alternative Control System Manufacturers

The Alternative Control System Manufacturers are made up of all of the companies who produce technology in support of a hands-free interface. This includes companies researching and developing improved voice command algorithms, those creating muscle contraction devices to operate prosthetic limbs and those beginning to delve into the capabilities and possibilities for BCI interfaces. These companies will be interested in the outcome of the simulation in this project and in the insight which can drive the design of their products in the future.

III. Government Regulators – US Department of Health and Human Services

The US Department of Health and Human Services is responsible for ensuring that products marketed to US citizens are safe for use. In the case of an alternative control interface, especially for a physically vulnerable group, extensive demonstration and testing of the system will be performed by government organizations before it is considered safe for the general public.

IV. Other Stakeholders

These include insurance companies, national defense sector organizations interested in applying hands-free control interfaces to their systems and the users and manufacturers of current control interfaces.

V. Stakeholder Tensions

Two crucial tensions have been identified between stakeholders of the system. The first major tension is between the government regulators and the Alternative Control Method Manufacturers. In the case that a successful hands-free control method is created, the manufacturers would want it to be declared safe and reliable as soon as possible, where are government regulators would want the make sure the product is safe before recommending them for public use.

The second major tension would be between the primary users and the manufacturers. People are generally resistant to new technology and change, especially in new systems. The manufacturers would need to ensure reliability, easy use and extensive demonstration so that the users quickly build trust in the new interface.

GAP DEFINITION

Currently, almost every human-machine interaction must occur through a physical interface. For the 2,909,920 severely paralyzed persons in America, the necessity of physical motion to operate a device renders the system unusable. This prevents these persons from using robotic aids, electric wheelchairs and other devices.

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.

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.

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.

I. Functional Diagram

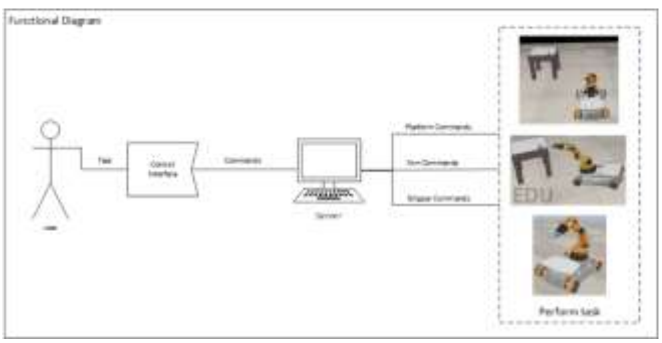

Figure 2 Functional Diagram

The Figure 2 summarizes the use of the system. A user will give commands to a robotic aid. These commands will be separated into commands for the arm, gripper and platform of the robotic aid.

II. Use Case Diagram

Figure 3 demonstrates the intended use of the system. The robot, after being given instruction, will travel to the location of the object, pick up the object and bring it to the user of the system.

This use case will be simulated and run a large number of times in order to generate to data necessary for analysis.

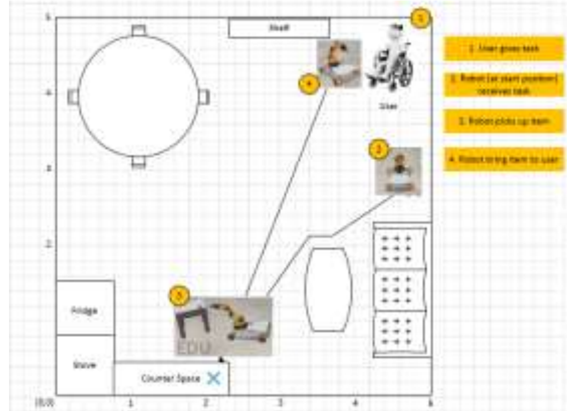

Figure 3 Use Case Diagram

III. 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.

SIMULATION OF ROBOTIC 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

I. Simulation Environment

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.

Twenty start positions have been identified, as well at twenty fetch items. The end position has been identified and will stay the same for each trial. Figure 4 shows the 10 of the start positions and 1 end position. Figure 5 shows the 10 of the fetch points. It is important to notice that the start and end positions are (x,y) coordinates for the location of the center of the robot while the fetch location includes a z coordinate as most items are located on furniture.

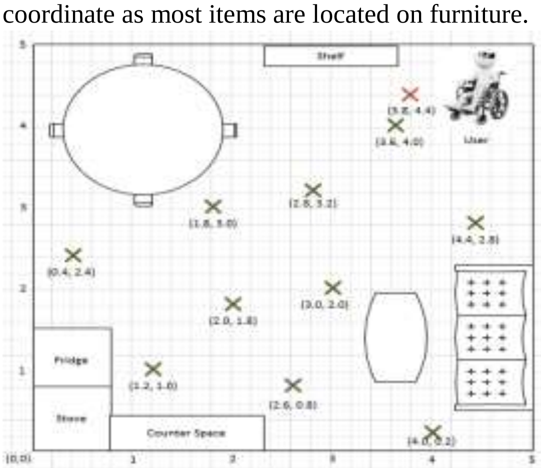

Figure 4 Start and End Positions

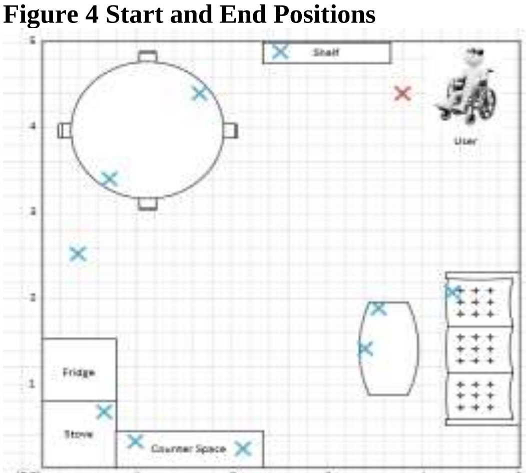

Figure 5 Fetch Points

II. 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 [6].

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 [7].

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 [8].

III. Useful VREP Functions

The VREP simulation includes Path Planning module. 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 [9].

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 [10].

IV. Input-Output Diagram

Figure 6 shows the input, output and controls of the system. The robot velocity, virtual robot, end position and environment will remain constant for each trial. The system will assign a random start point and fetch point before each trial. The system will output task macro statistics, maneuver and quantities, platform and displacement statistics and arm displacement statistics.

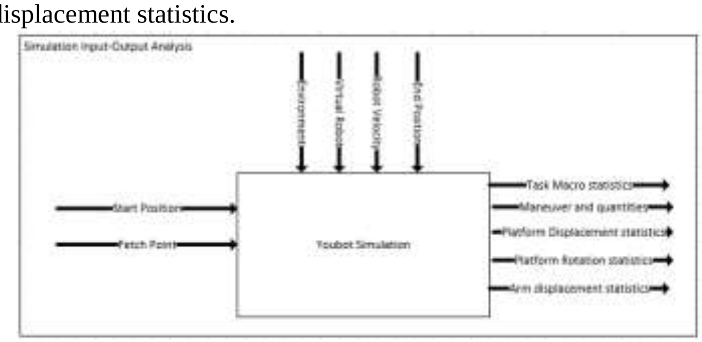

Figure 6 Input - Output Diagram

V. Statistics to be Recorded

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)

RESULTS

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RECOMMENDATIONS

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REFERENCES

[1] "Human Factors and Medical Devices." U.S. Food and Drug Administration. U.S. Food and Drug Administration, n.d. Web. 19 Nov. 2015.

[2] B. Shneiderman, 'The limits of speech recognition', *Communications of the ACM*, vol. 43, no. 9, pp. 63-65, 2000.

[3] Eyetracking.com, 'Powerful eye tracking software developed for researchers', 2015. [Online]. Available: http://www.eyetracking.com/Software. [Accessed: 04- Nov- 2015].

[4] Google Self-Driving Car Project, 'Google Self-Driving Car Project', 2015. [Online]. Available: https://www.google.com/selfdrivingcar/how/. [Accessed: 09- Dec- 2015].B. Smith, "An approach to graphs of linear forms (Unpublished work style)," unpublished.

[5] J. Wolpaw and D. McFarland, 'Control of a two-dimensional movement signal by a noninvasive brain-computer interface in humans', *Proceedings of the National Academy of Sciences*, vol. 101, no. 51, pp. 17849-17854, 2004.

[6] "YouBot." YouBot Store. Kuka, n.d. Web. 19 Nov. 2015.

[7] R. Detry, 'TRS: An Open-source Recipe for Teaching (and Learning) Robotics with a Simulator', *Ulgrobotics.github.io*, 2015. [Online]. Available: http://ulgrobotics.github.io/trs/project.html. [Accessed: 09- Dec- 2015]. G. R. Faulhaber, "Design of service systems with priority reservation," in *Conf. Rec. 1995 IEEE Int. Conf. Communications,* pp. 3–8.

[8] Coppeliarobotics.com, 'Child scripts', 2015. [Online]. Available: http://www.coppeliarobotics.com/helpFiles/en/childScripts.htm. [Accessed: 09- Dec- 2015].

[9] Coppeliarobotics.com, 'Path planning', 2015. [Online]. Available: http://www.coppeliarobotics.com/helpFiles/en/pathPlanningModule.htm. [Accessed: 09- Dec- 2015].

[10] Coppeliarobotics.com, 'Vision sensors', 2015. [Online]. Available: http://www.coppeliarobotics.com/helpFiles/en/visionSensors.htm. [Accessed: 09- Dec- 2015].