Design of a Hands-Free Interface for Robot Object Relocation for Paralyzed Individuals

Kassidy Kenney, Kimberly Harrington, Angelo Huan, Muhammad Sungkar
George Mason University, kkenney3@gmu.edu, kharrin2@gmu.edu, ahuan@gmu.edu, msungkar@gmu.edu

***Abstract*—All devices we interact with rely on a physical control interface in order for the user to command the system. The current "one-size fits all approach" to control-interfacing prevents nearly three million severely paralyzed consumers in the United States from being able to operate devices. This shortcoming even applies to technologies specifically designed to assist paralyzed persons. This paper describes the design of a Hands-free Interface for object relocation using a robot for paralyzed individuals. The design requirements were developed for a hands-free robotic-aid to be operated by an individual who is paralyzed using a three-degree of freedom kinematic simulation of 500 "fetch-and-deliver" tasks (consisting of random start and finish locations and arbitrary object to pick) for a robotic aid in a domestic setting. A simulation was used to determine that six unique commands were necessary for platform movement. An automated arm and gripper function is proposed for arm and gripper control. A utility vs. life-cycle cost analysis was conducted on the following three design alternatives for hands-free platform commands: eye-tracking, brain-computer interface (BCI), and voice-commands. The utility function includes attributes such as capability, performance, proportion of paralyzed persons physically capable of using the interface, and technology readiness level (TRL). The voice-command method exhibited the highest utility. In a lifecycle cost vs. utility analysis, the voice-command method reveals half the cost of the eye-tracking method.**

Index Terms – HMI, Human Machine Interaction, EEG, BCI

INTRODUCTION

According to a 2012 study performed by the Christopher and Donna Reeve Foundation, 1.9% of the American population identify as paralyzed. Of these 5,596,000 people, 2,909,920 indicated they were "unable to move" or "had a lot of difficulty" performing any motion.

Advances in robotics have made feasible inexpensive, reliable robots for relocation of objects in a domestic setting. These robots have the potential to improve the quality of life and reduce costs (e.g. nurse, personal assistant) for this demographic.

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. The dominant form of user-interface for these robots is through a physical user-interface such as joystick. This is a limitation on use of these robots by the demographic that would benefit the most.

This project describes the design of a hands-free alternative to the standard physical-control interface.

CONTEXT

I. Human-Machine Interaction

A Human-Machine Interface (HMI) is any interface facilitating interaction between human and machine (Figure 1). 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 feedback from the user [1].

II. Alternatives for Modern Control Interfaces

The most common hands-free interface method is voice control. Voice-controlled devices, as many 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 individuals, the primary stakeholders in this context, struggle to enunciate words. Also note that in situations of high stress, or large amounts of background noise, voice control interfaces are known to misinterpret, or not recognize commands [2]. This inhibits the use of voice control for the general population in the situations previously described.

Eye tracking software is known to be an effective method for interacting with a computer, as they offer a degree of control very similar to the mouse and keyboard system. The only issue posed is that this interface is hardly applicable outside of human-computer interactions [3]. Muscle contraction detection devices and gyroscope devices are both used for persons with some level of control over physical motion or muscle contraction.

Brain-computer interfacing (BCI) is increasingly being realized as a potential interface method. Despite the low technological readiness level (TRL), this technology is regarded as having very high potential due to the number of consumers it has the ability to support. [5].

STAKEHOLDER ANALYSIS

It is anticipated 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 current physical interfaces. For this analysis, the project's focus is predominantly on users of the hands-free interface, specifically severely paralyzed individuals. This subset of users will benefit the most from the development of the system and they will eventually mark the first “real-world” test and integration of the new interface.

It is expected that the output of this project will interest those with a market share in producing alternative control devices or those invested in general innovative or futuristic technologies. This project will provide crucial data and insight for creating such an interface.

I. Severely Paralyzed Individuals

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

II. Alternative Control System Manufacturers

Alternative control system manufacturers consists of any companies who may produce the technology necessary to assemble the 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 of BCI interfaces. These companies will be interested in the outcome of the simulation of this project and the insight which will drive the design of future products.

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 widespread use. In the case of an alternative control interface, especially for consumers who are physically incapable of extensive motor movement, elaborate demonstration and testing of the system will be performed by government organizations before it will be 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 tensions are identified between stakeholders of the system. The first major tension lies between the government regulators and the alternative control method manufacturers. In the event that a successful hands-free control method is developed, the manufacturers are more concerned with profits from sales and time-constraints than quality control and safety. On the opposing side, government regulators require a lengthy approval process to ensure the product is safe before allowing for public use.

The second major tension is between the primary users and the manufacturers. People are generally resistant to unfamiliar technology, especially entirely new systems. Manufacturers would need to ensure reliability, ease of use, and would ultimately need extensive demonstration so that users may quickly build trust in the new interface.

GAP DEFINITION

The necessity of physical movement of the control interface is a highly limiting factor is the system usability and user workload. For the 2,900,000 severely paralyzed persons in America, the necessity of physical motion to operate a device interface renders the system unusable. A “win-win” scenario is to create a hands-free control system interface which can match the quality and cost of a traditional interface.

PROBLEM STATEMENT

The 2 million severely paralyzed individuals in the US require a technology to enable them to relocate objects without requiring physical interaction. This design has the potential to assist users in other daily activities that ordinarily rely on physical input, such as navigating a wheelchair.

CONOPS

A paralyzed person who cannot perform basic motor tasks would be benefited by the assistance of a robot in order to pick up an item. The person will use a hands free control system in order to fluidly navigate the robot in a domestic environment. The robot is composed of a mobile platform, an arm, and a gripper. The platform can perform functions such as move forward, pivot to the correct direction, and stop. The arm can adjust its elevation and rotation. The gripper can clamp and open.

IMPLEMENTATION OF THE HFCS

I. HFCS Requirements

To support the task of controlling a robot in a domestic setting the HFCS shall:

1. Be operable in real-time
2. Operate without tactile user input.
3. Provide the flexibility required for a full set of “fetch and return” tasks to be performed.
4. Differentiate between and execute a set of commands.
5. Require down time for no more than 2 hours a week.
6. Perform at or above a 95% accuracy threshold.

II. Robot Command Simulation

To determine the commands and the degree of accuracy needed to perform the task a simulation of “fetch and return” tasks in a domestic setting was developed. The simulation shall provide the number of commands, type of command and command frequency and accuracy commanded for fetch and return tasks to be completed.

The fetch and return tasks were simulated as performed by the Kuka YouBot [6]. The Kuka Youbot is a configurable robot consisting of an omnidirectional platform, with a zero turning radius, an arm with 5 joints and a gripper. This robot was selected because the fine grain control of the arm allows for many fetch and return tasks to be feasible. The Kuka Youbot is modeled in a package integrable with VRep, a Virtual Robotics Simulator [7]. The VRep simulator can interface with Matlab, to provide a common modeling language.

The simulation contains 2 components - one for the 2-dimensional platform motion required to navigate from a start location to a fetch location, and one for the 3-dimensional motion required for the arm and gripper to lift the desired object. For the 2-dimensional platform movement, the angle of each turn and the distance traveled between each turn will be recorded. For the 3-dimensional movement, the degree of movement of each arm joint will be recorded.

III. Simulation Algorithm in 2-Dimensions

The simulation for platform movement in 2 dimensions requires an input map marking the obstacles in a given room. Figure I shows a sample input map. In addition, 2 arrays of coordinates must also be provided. One array contains feasible start and finish locations and the other array contains feasible fetch locations.

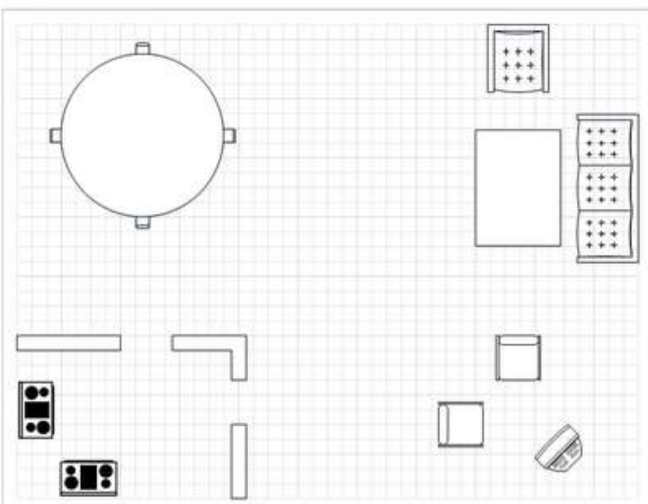

FIGURE I
SAMPLE INPUT MAP

The simulation begins by randomly selecting a start point, fetch point and finish point from the given arrays. The simulation uses the input map and the d* shortest path algorithm to calculate the prefer route from start to fetch point and from fetch point to finish location.

The simulation output is a folder containing a jpg map with the shortest route highlighted, a graph of degree of turn vs frequency and a graph of distance traveled vs frequency.

The simulation begins by randomly selecting a start point, fetch point and finish point from the given arrays. The simulation uses the input map and the d* shortest path algorithm to calculate the prefer route from start to fetch point and from fetch point to finish location.

The simulation output is a folder containing a jpg map with the shortest route highlighted, a graph of degree of turn vs frequency and a graph of distance traveled vs frequency.

IV. Simulation Algorithm in 3-Dimensions

The movement of the Youbot arm was modeled using the Robotics Toolbox for Matlab, a plugin published by Peter Corke [7], which provides functions to measure and record the movement of the simulated Youbot. The Robotics Toolbox contains a function which outputs the change in displacement of each arm joint necessary for the gripper to select an item.

V. Simulation Output

Simulation output in 2 dimensions shows the number of maneuvers performed and distances traveled for 50 runs of the simulation. Figure 2 shows the output for distance traveled before turning.

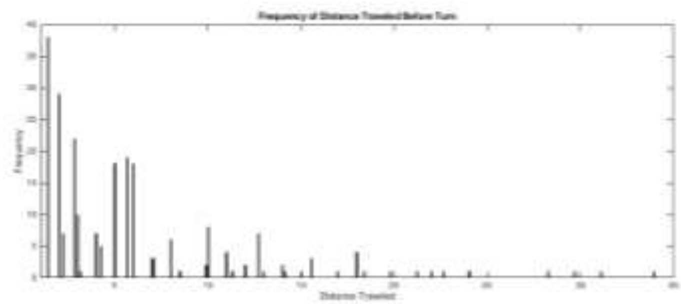

FIGURE II
DISTANCE BETWEEN TURNS

Figure II shows the frequency and degree of each turn performed for 50 simulation runs.

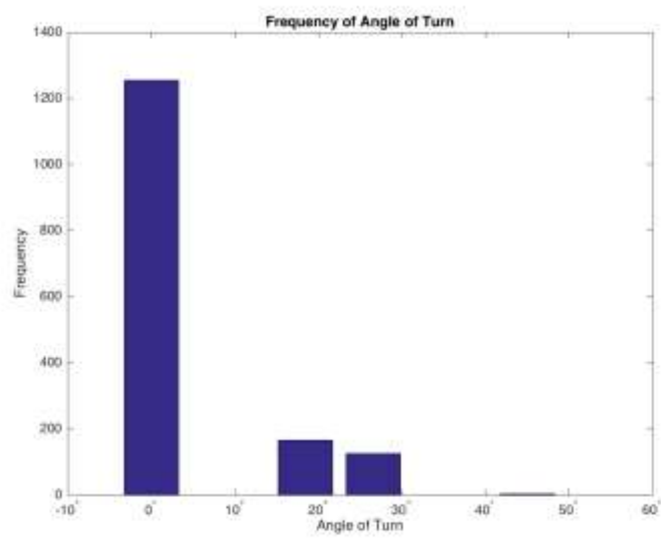

FIGURE III
FREQUENCY AND DEGREE OF TURNS

VI. Simulation Results

The simulation results showed that the platform will require 6 basic commands: turn left, turn right, start forward movement, stop all motion. All turns can be performed in 10 degree increments, meaning to turn left 30 degrees, the user would give the turn left command 3 times.

The simulation results showed that control of the arm is requires highly precise adjustments in the angle of each of the 5 arm joints. The simulation showed that there is no overarching pattern in the configuration of the arm, and rather the movement of each joint is based entirely on the height of the object and the distance the object is from the edge of the surface.

These findings have led to the addition of requirements for a new capability - autonomous grasping of a selected object. Because of the level of detail and precision needed for the robot to grasp an object, it is necessary to automate some of the actions required for the arm and gripper motion. The project team proposes a function which presents the user with an array of the objects in the robot's view, and allows the use to select an object. Once an object is selected, the robot will autonomously grasp the selected object.

These findings provide the data necessary to complete the requirements set initially discussed in the HFCS Requirements section. The following requirements have been added to the system specification:

- The HFCS shall execute between 4 platform commands.
  - The HFCS shall employ a start forward movement command for platform movement.
  - The HFCS shall employ a stop all motion command for platform movement.
  - The HFCS shall provide direction for the platform to turn right in 10 degree intervals.
  - The HFCS shall provide direction for the platform to turn left in 10 degree intervals.
- The HFCS shall perform autonomous grasping of a selected object.
  - The HFCS shall allow the user to select a desired object in its line of sight.
  - The HFCS shall configure arm as necessary to grasp selected object.
  - The HFCS shall autonomously grasp a selected object.
  - The HFCS shall execute a "Release object" function.

All requirements, including those derived from the simulation, have been included as measures in the utility analysis.

DESIGN ALTERNATIVES

Several interface alternatives exist which fit all requirements for the system. These alternatives are brain-computer interface (BCI), eye movement tracking, and voice command. Similar alternatives, such as muscle contraction detection, were not selected because these interfaces require physical movement which the targeted user group cannot provide.

I. Brain-Computer Interfacing

A brain-computer interface is a system that connects the brain with an external machine that interprets the thoughts of the brain as commands. In a noninvasive brain-computer interface, an electrode is placed on the head of the user [10]. These electrodes detect the electrical activity of the brain, and an external machine uses these as commands. In an invasive brain-computer interface, the electrodes are placed in the grey matter of the brain. In order for the external machine to accurately interpret the electrical signals as input, the user has to calibrate it by repetitively thinking of the same thoughts.

The largest advantage to BCI technology is seen as its universal application- regardless of physical functioning, users will be able to interact with a BCI. The shortcoming of BCI is seen as a function of its technical readiness level (TRL). The low TRL contributes to a lack of usability.

II. Eye Tracking

In an eye-movement tracking system, a machine is attached on the user's head. This machine uses infrared to scan the pupil. The machine tracks the reflection of the eye as input. This machine requires calibration, but is more stable than brain-computer interface.

The advantage of the eye-tracking software is seen in its time-sensitivity and it's TRL. This means the alternative could be immediately integrated into the system. Eye-tracking software does pose a risk of false-positives, as a user's fixation with an image may be interpreted as selection.

III. Voice Commands

Voice commands use a software to interpret a user's verbal words into commands. When a user speaks, he/she emits vibrations in the form of waves and the software converts these waves to executable commands by using a built-in library of commands. Calibration is usually optional and is used for the system to be more accurate.

The advantage to voice command software is seen in the user's familiarity with the interface format. Voice commands software does, however, struggle in environments with large amounts of background noise and requires some calibration time for maximum accuracy.

IV. Utility Model

Analysis of alternative utility was driven by four weighted categories. These categories were decomposed into weighted measures. The swing weights method was used to determine an overall weight for each measure. Weights are shown in Table I.

TABLE I
UTILITY MODEL WEIGHTS

Goal	Category Weight	Measures	Measure Weight	W
Capabilities	0.5	# of Commands	0.7	
		Time Sensitivity	0.3	
TRL	0.1	TRL	1	
Usability	0.2	User Population	0.75	
		New User Time	0.25	
Performance	0.2	Accuracy	0.4	
		Maintainability	0.2	
		Reliability	0.4	

Each alternative was scored based on reviewed journal articles and other available data [11] [12] [13]. The utility score was calculated via the equation $\Sigma w_i * s_i$, where w_i is the measure weight and s_i is the alternative's score for the measure.

Voice command (0.812) ranks the highest, followed by eye-tracking (0.804), then BCI (0.536). Utility is shown in Figure IV.

The Utility vs Cost for each alternative is shown In Figure V. The higher utility does not correlate with a higher price for the alternative.

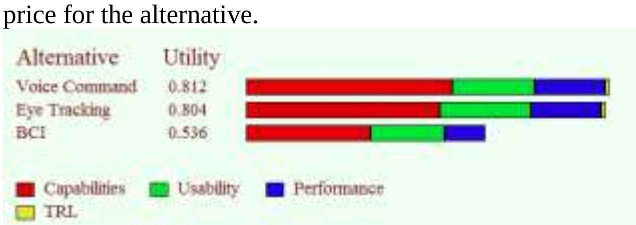

FIGURE IV
UTILITY OF ALTERNATIVES

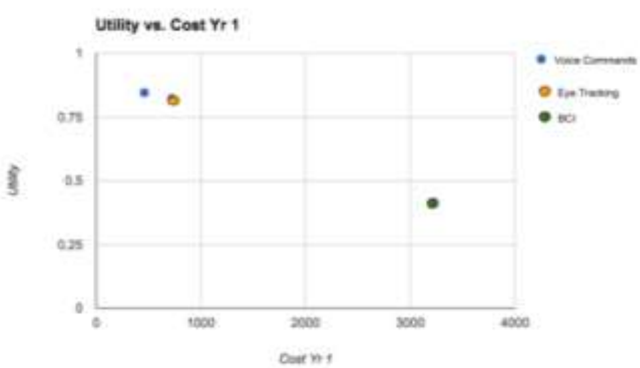

FIGURE V
UTILITY VS COST

Sensitivity Analysis

Sensitivity analysis was performed using the Logical Decision Making Software [14]. Figure 6 shows that as the weight of reliability attribute is increased, eye tracking becomes a better alternative than voice commands.

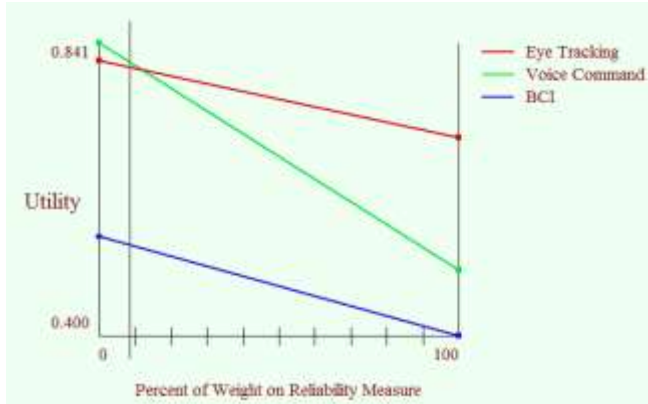

FIGURE VI
SENSITIVITY ANALYSIS ON RELIABILITY

In order for the eye tracking software alternative to match the utility of the voice command alternative, the total utility of the eye tracking method would need to increase by .06. This could be achieved by a 2 point increase in accuracy or reliability. In order for BCI to reach the utility of the voice command method, the utility of the BCI alternative would need to increase by 0.276. This could be achieved by a 5 point increase in each of the following: Number of Commands, Time Sensitivity, TRL, New User Time, Accuracy and Reliability.

Recommendations

"Fetch-and-carry" robots have the potential to improve the quality of life or paralyzed individuals. A user-interface that is not dependent on physical actions could provide 2.9M paralyzed people with limited or no physical movement, access to these robots.

From this analysis, it has been shown that the alternative for a HFCS with highest utility is voice command technology and that an autonomous arm and gripper function will increase usability. A sensitivity analysis, concluded that in an environment where reliability is of increased importance, a HFCS utilizing eye tracking software may be the preferable alternative.

In order for BCI technology to become a competitive alternative, major improvements in performance and capabilities would be necessary. It is likely that as the TRL level catches up to that of the other alternatives, BCI will become a more feasible alternative.

Business Case

According to a 2014 New York Times article, more than 1.3 million new in-home caregivers will be needed within the next decade []. In-home caregivers are paid an average of $20, and almost 75% of in-home care is paid for but Medicare and Medicaid []. This is significant in that it is highly unlikely that the salary of in-home caregivers will rise to make it a more desirable job.

The robotic aid of object relocation can be marketed to in-home caregivers as a supplement to the current 24/7 in-home care.

ACKNOWLEDGEMENTS

The Project Team would like to our sponsors at General Dynamics Mission Systems – Mike DiMichele and Nathan Cushing. In addition, we would like to thank Professor Sherry and Mr. Bahram Youseffi.

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] J. H. Medicine, "Electroencephalogram (EEG)," Johns Hopkins Medicine, [Online]. Available: http://www.hopkinsmedicine.org/healthlibrary/test_procedures/neurological/electroencephalogram_eeg_92,P07655/. [Accessed 23 March 2016].

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

[11] Crone, Nathan E., and Nitish V. Thakor. "Demonstration of a Semi-Autonomous Hybrid Brain-Machine Interface Using Human Intracranial EEG, Eye Tracking, and Computer Vision to Control a Robotic Upper Limb Prosthetic." IEEE Trans. Neural Syst. Rehabil. Eng. IEEE Transactions on Neural Systems and Rehabilitation Engineering (2014): 1-13. IEEE Xplore. Web. 2 Feb. 2016.

[12] Kayagil, T., O. Bai, P. Lin, S. Furlani, S. Vorbach, and M. Hallett. "Binary EEG Control for Two-Dimensional Cursor Movement: An Online Approach."2007 IEEE/ICME International Conference on Complex Medical Engineering (2007): 1-4. IEEE Xplore. Web.

[13] Interact-AS User Guide: Enabling Communications for the Deaf and Hard of Hearing Communities. Publication no. Version 4.0. Nortfield: SpeechGear, 2010. Web.

[14] Logical Decisions. Logical Decisions: Software for More Effective Decisions. Vers. 7.2. Logical Decisions, 1016. Web. 1 Feb. 2016.