Needs and Usability Assessment of a New User Interface for Lower Extremity Medical Exoskeleton Robots

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***Abstract*— This paper presents an evaluation and recommendations for the improvement of the user interface (UI) of medical exoskeleton robots for people with mobility disorders. Existing UIs of currently available medical exoskeletons lack the flexibility to serve a diverse user group who require more customization. A UI prototype consisting of a glove with buttons attached on fingertips, and a display module for user feedback and/or instruction was developed and evaluated. For the evaluation of this UI prototype, multiple usability tests, guerrilla tests, interviews, and surveys were conducted with several crutch and manual wheelchair users. Finally, a set of final Glove UI design recommendations is illustrated based on the test subjects and interviewees' feedback; finger glove, two buttons, singleton walking method, and adjustable display position. A more thorough evaluation on this improved UI with more potential users of medical exoskeletons with various physical abilities remains as future work.**

Keywords-Design for people with disabilities; User interface design; Exoskeleton; Glove Interface

I. Introduction

By the numbers, there are 700,000 new stroke patients every year, and 265,000 individuals suffering from spinal cord injuries in the United States [1]. These factors are the leading causes of mobility disabilities, which lead thousands of patients to use a wheelchair as their main mobility aid for the rest of their lives. However, due to the nature of a human body, the long-term usage of a wheelchair with prolonged sitting and immobilization of the limbs brings secondary diseases. Common examples of these secondary injuries are urinary tract infections, blood clots, reduction in cardiovascular functioning, decreased bone mineral density, and osteoporosis [2]. It is widely accepted in the field that postponing the use of wheelchairs will delay the onset of secondary injuries and diseases [3], [4], [5], [6]. It has been also shown that being upright and ambulatory has significant benefits to the human body, such as increased circulation, improved bladder and bowel functioning, and an overall feeling of well-being [2], [7].

Lower extremity medical exoskeleton technology can be beneficial for many wheelchair users. Through its ability to enable walking and standing upright, this technology can prevent secondary injuries as well as provide independence in the daily lives of those patients.

This paper presents the background of medical exoskeleton technologies, operating schemes, development and evaluation of UI prototype, result and recommendation for future work.

II. Background of Medical Exoskelteon Technologies and Overview of Their UIs

A. State-of-the-art medical exoskeletons

Powered medical exoskeleton devices that enable a user to stand and walk are available on the market with the price range of \$100,000 - \$150,000. There are Rex from Rex Bionics in New Zealand, ReWalk™ by Argo Medical Technologies in Israel, and Ekso™, developed by Ekso Bionics. These mobile, powered medical exoskeletons are made for rehabilitation or for walking outside the clinic. They have 4 to 10 powered joints aligned to the patient's biological joints. These powered joints are pre-programmed to mimic the human gait, which ambulate the wearer in a similar manner of natural walking when the user commands. Rex has a joystick-type UI located on the arm rest. Rex does not require crutches or a walker since it has self-balancing structure with powered ankles, knees, and hips [8]. ReWalk™ has powered knees and hips, and executes steps by sensing the tilt of the user's torso [9]. Ekso™ also has powered knees and hips, and has an operating method, which determines user intent using multiple sensors on the pilot's arms and crutches to estimate the user's pose and executes steps, as well as manual actuating via buttons on the crutches or walker for initial trainings [10]. AUSTIN, developed in Robotics and Human Engineering Lab in University of California at Berkeley, has a hip-knee coupled gait generation mechanism derived by powered hip joints, operated by a button-integrated UI on the crutch or walker handle [11].

B. User interface of medical exoskeletons

These state-of-art exoskeleton robots for patients with mobility disorders have two kinds of user input receiving systems; 1) sensing user intent from the wearer's posture, 2)

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getting explicit commands from the wearer via joysticks or buttons. The first method has an advantage of requiring minimal effort from the user to issue commands. However, due to the limited mobility and muscle control of this user segment, this implicit UI has the potential risk of misinterpreting the operator's posture, which may cause falling. Studies have shown that the *implicit* UI of ReWalk™ results in a unique pattern of control for walking in individuals with spinal cord injuries, while patients with lower level injuries have better walking performances and also progress rapidly [12]. Having *explicit* UIs such as the systems used in Rex and AUSTIN requires more user effort in commanding steps via joysticks or buttons. However, this appears to minimize the risk of mistriggering due to the pilot's incomplete motor control due to the injuries. However, their device-coupled UI design (see Fig. 1) results in limited usability when used among different users with different hand/finger sizes.

In this paper, a glove type user-coupled human-machine interface prototype with tactile and visual feedback is discussed for a next generation *explicit* UI for medical exoskeletons. We present an evaluation of this UI prototype, including interviews, guerilla tests, surveys, and usability testing on people with mobility disorder. The evaluation preparation, methodologies, and results are discussed.

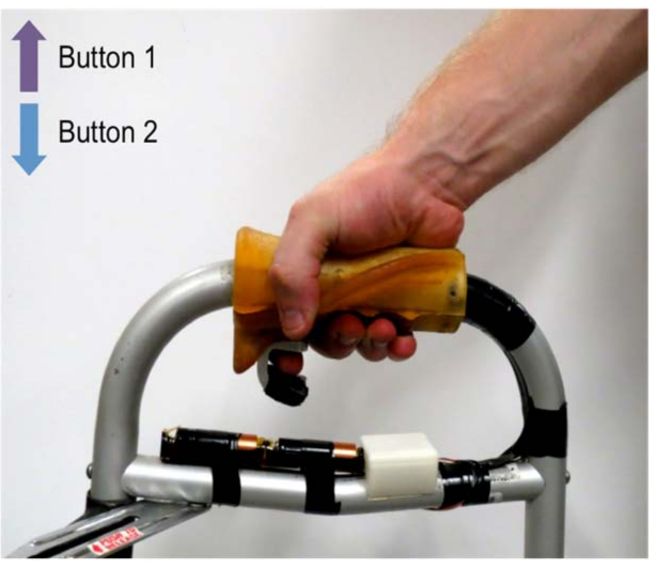

Figure 1. An example of device-coupled UI attached on a walker. The user can trigger the button upward or downward for two different commands. The comfort of this UI is highly dependent on the users' hand size.

III. SCHEMATICS OF EXPLICIT USER INTERFACE FOR MEDICAL EXOSKELETONS

The explicit UI of medical exoskeletons switches the state of the machine from one state to the other when the user issues commands via buttons. There are four different states of the medical exoskeleton; left leg forward, right leg forward, feet together (standing up), and seated down.

With the walking scheme shown in Fig. 2, it is clear that at least two buttons - the simplest way of giving two different signals - are required for the user to switch from a state to the other state. For example, when the user is wearing an exoskeleton with his feet together, he/she can either press button #1 to start walking by moving his/her left leg forward, or click button #2 to sit down. Here, it is assumed that the user can sit down only when his/her feet are together, and the user only goes to "feet together" state from "seated down" state, not to left or right leg forward state. Obviously, there is more than just one way of mapping these button functions, and more than one implementation for the number of buttons the UI can have. One of the goals of this study is to find out the potential users' most preferred mapping which will contribute to the decision on long-term adoption of the device along with the hardware design of the UI.

For this study, two different walking operation schemes, i.e., methods of mapping buttons are suggested and evaluated: *Singleton* and *Alternating*. In the Singleton method (see Fig. 3 (a)), the user presses the same button for each step; for example, the user presses button A for the first step → user presses button A again to make the second step → (continue) → user presses button B to stand up (feet together) → user presses button B again to sit down.

The alternating method (see Fig. 3 (b)) designates different buttons for stepping forward with different legs. For example, in an alternating scheme, the user presses button A for the left step

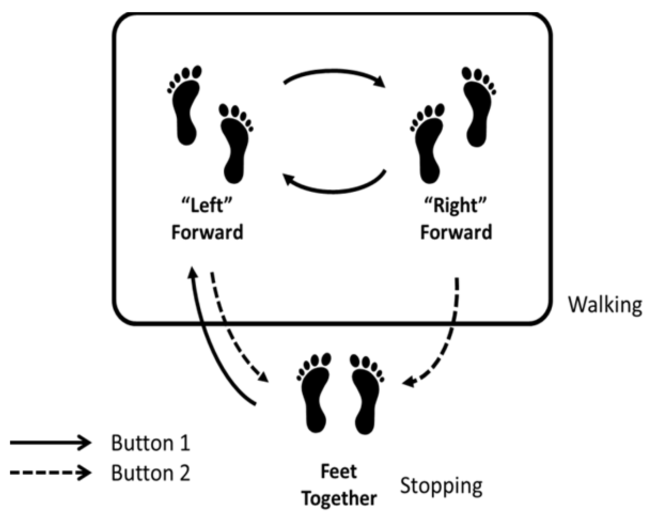

Figure 2. An example of a walking scheme. In this scheme above, the user stands up and starts walking by pressing button 1, and ends operation by pressing button 2.

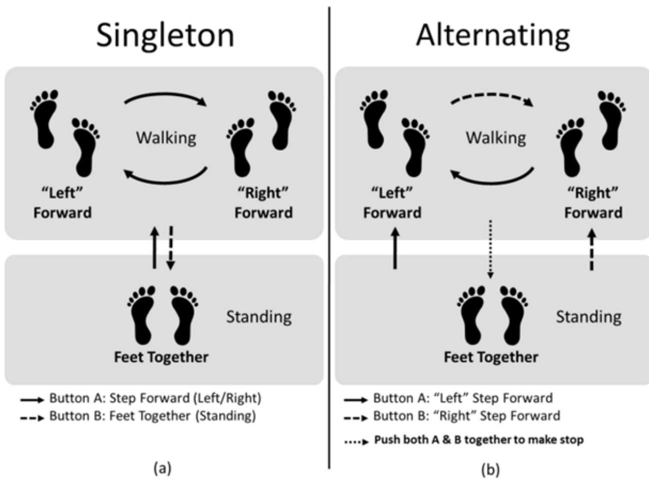

Figure 3. Two different walking schemes. (a) The Singleton method uses the same button for steping forward (b) The Alternating method maps two different buttons for stepping each leg forward.

→ presses button B to make the right step → button A to make the left step again → (continue) → user presses both buttons two times in a row to bring the feet together and sit down.

IV. PROTOTYPING

Several versions of prototypes have been developed to simulate the UI and elicit feedback from potential users during this testing phase. A "glove UI" featuring a glove with buttons attached on fingertips and an LED display mounted on the inside of the wrist (See Fig. 4) was prototyped as a suggested next generation UI design for medical exoskeletons.

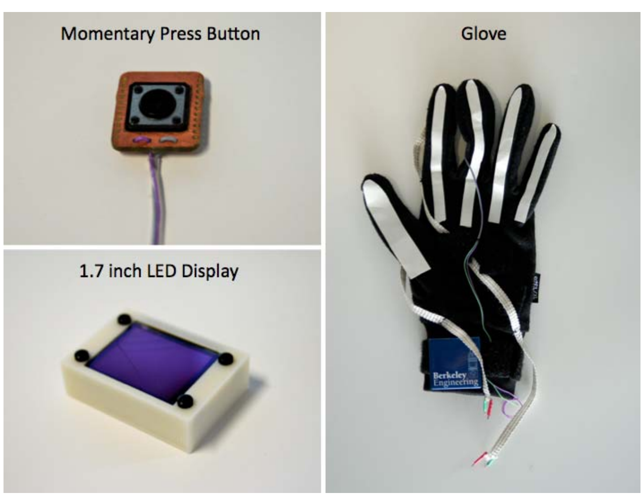

Figure 4. The three components of the glove user interface

Fig. 5 shows a wheelchair user wearing the refined prototype after pre-testing.

This new UI concept is designed to overcome the shortcomings of the other user interfaces of the state-of-art medical exoskeletons, including accommodating different users' hand sizes and gripping preferences, and providing visual feedback to the user via a monitoring display.

Figure 5. A subject wearing the prototype.

Information shown on the monitor includes On/Off status, battery life, and quick instructions for the exoskeleton operation.

V. RESEARCH METHODOLOGIES

A. *Summary of Research Methodologies*

Our data are collected from pre-testing, interviews, guerilla testing, surveys, and usability tests with eight subjects on our target user segment.

B. *Pre-testing*

The first prototype of the glove UI was tested at Berkeley Robotics and Human Engineering Lab by their medical exoskeleton test pilots. This pre-testing was used to revise our interview and usability test strategies according to the feedback from actual exoskeleton test pilots prior to testing the prototype with potential users who have never been exposed to this technology. While conducting a pre-testing, we found several improvements from our design. Given the distinctiveness of the potential user group, feedback from actual test pilots from Robotics and Human Engineering Lab was immensely valuable.

1) *The UI prototype Improvement*

While testing the prototype, we realized that is difficult to discern the hand position of a user who was wearing a black glove, and since a big part of our testing was determining the user's hand position, this was an important oversight. As a result, we taped white stripes to the back of each finger to make them more visible. We added Velcro to the back of the monitoring display so users could reposition the display. Letting the user determine their own ideal location was better than just asking if the display was readable.

2) *The Interview/User Test Setup Improvment*

Interviews with microphone and camera setups were conducted. We added a set of questionnaires to obtain the demographic data of test participants. We added a high-resolution camera (DSLR) to get detailed close-ups of motions while the subjects were testing out our prototype. We also used a microphone to closely record their voice and filter out the background noise.

Throughout the pre-testing, the subjects provided valuable feedback about our test environment and test questions/protocols, which ultimately helped the research preparations in the next steps.

C. Interviews/Guerilla Testing/Surveys

In order to collect information from our potential user segments, we conducted interviews at several locations where people with mobility disorders frequently visit. One of these places is the Ed Roberts Campus and the Center for Independent living located in Berkeley, California. Both guerilla and scheduled interviews were conducted on a wider variety of potential users at this center. A short list of survey questionnaires was also prepared to obtain basic demographic data from the participants before the interviews. Given the relatively small sample size, it was critical to coordinate in-depth interviews immediately followed by the usability test to thoroughly explore opinions on the glove UI prototype.

D. Usability Test

Usability tests were performed on three test subjects with mobility disorder – two crutch users (referred as Subject 1 and 3), and one manual wheelchair user (referred as Subject 2). The goal of this usability test is to find their preferences on the types of glove, the number of buttons, the location of the display, and walking scheme. A brief profile of the test subjects follow:

Subject 1: 30-year-old male, a relatively new crutch user due to his recent injury on his ankle.

Subject 2: 24-year-old male, paralyzed in his lower torso and legs due to car accident five years ago. He has been a manual wheelchair user for last five years.

Subject 3: 34-year-old female, a lifetime cane or single crutch user due to congenital leg abnormalities.

For usability testing, the subjects were given a glove UI prototype shown in Fig. 4, and asked to demonstrate how they would walk with their mobility aid while wearing the glove UI.

1) Grip, Buttons, and Glove Preference

The way patients hold their crutches or walker grips varies widely with hand size, type of mobility aid, and type of grip. Depending on these factors, the user's preference for button locations may differ for ease of use and mistrigger prevention. In testing preferences, subjects were asked to hold the grip of their mobility aid while wearing the glove UI prototype, and find the preferred buttons among the ones attached on fingertips of the glove UI prototype. The subjects were also asked for their opinions on the number and types of buttons. They were asked to choose at least two buttons for the simplest operation, and more buttons for other possible functions or more elaborated exoskeleton maneuver, if desired.

2) Type of Glove

A glove used for a prototype shown in Fig. 4 was provided in this usability test. The subjects were asked for their opinions on the type of glove in terms of the glove material; whether the fabric is too thick or thin, and whether the coverage of the glove over the hand is too much or too little.

3) Display Module Position

The display module has an LED screen, which is capable of displaying various types of information such as the system status, battery life, wireless connectivity, and error diagnostics when applicable. The subjects were asked to find the position of the display module where they could get information at a glance while they operate the exoskeleton. Our assumption here was that the preferred location of the display module would differ according to the type of mobility aid and its grip.

4) UI Scheme, or Walking Method Preference

Two different UI schemes described in section III were explained to the subjects, and the subjects were asked to simulate walking with the two different schemes, using their button preferences from the previous part of usability testing. The subjects were asked to follow each walking schemes in Fig. 4 for three times. After this simulation, the subjects were asked to describe their preferences and opinions on the two different schemes.

VI. RESULTS AND DESIGN RECOMMENDATIONS

Overall, the results of the interviews and usability test appear to reveal the potential user's general preferences on medical exoskeleton UIs. Based on the feedback from the user research participants, design suggestions on four different components of the next generation glove type UI are summarized:

A. Type of Gloves

According to the preferences of usability test subjects and interviewees, adopting a single type of full glove for this application in meeting different kinds of user needs appears to be challenging due to the conflicting preferences among potential users. Manual wheelchair users responded that they generally prefer thick and durable gloves to protect their hands when they use a wheelchair. While a medical exoskeleton is to provide an alternative mobility aid, a wheelchair is still frequently used with medical exoskeleton during trainings and their daily life for easy maneuver and/or long travel. Therefore it appears that providing durable gloves for hand protection in wheelchair use as the glove UI platform would ease the don and doff of exoskeleton use. However, it appears that a full glove itself, even with thin material is not favored by other user groups since it provides unnecessary coverage, which might cause unpleasant heating on the user's hand. Therefore, a finger glove is recommended instead of a full glove. A finger glove satisfies the needs of non-wheelchair users, requires minimal

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hardware, and offers the option of wearing the glove UI on top of wheelchair users' thick gloves.

B. Number of Buttons

All the subjects responded that they liked the tactile feedback of the momentary switches on the prototype. Given the number of states of the machine and the users' desired operation, at least two buttons are required as stated in section III. For more elaborate maneuvering of the machine, using three buttons can be considered. However, it appears that having two buttons is preferred by the potential users due to its simplicity.

C. Walking Operation Scheme

The Singleton method is the preferred walking operation scheme due to its simplicity in operation. A majority of test subjects perceived the Singleton method as more intuitive and easier to operate. The Alternating method was deemed complicated for beginners even though it provides more flexibility. An argument remains to keep the Alternating method as an option for more experienced users. Key quotations from the subjects on these two walking schemes are following;

"I'm thinking about a computer game. Some people prefer using fewer but more intuitive commands, but I like to use more granular ones. But for right now, I like the Singleton option since I am new to this system."

"After a while if it was something that I had to do regularly, like, say, drive a car, it would probably just become second nature because I would train myself to click only one."

D. Display Module Position

Subjects showed different preferences regarding the display module's angle and position. Walker, crutch, and wheelchair users view the display from different angles due to their different grips. Therefore, it is recommended that the display module position stays adjustable with easy attachment methods such as the use of Velcro, for example.

VII. Conclusion

The goal of our research is to evaluate a new glove type UI for medical exoskeletons. A conceptual prototype that contains key components for evaluation was created and evaluated by potential users. Four research methods are used in this research; interviews, guerilla tests, surveys, and usability tests.

Finger glove, two buttons, singleton walking method, and adjustable display position are the final design recommendation based on our research.

- "Finger glove" instead of a whole glove
  This type of glove better facilitates users' different hand sizes, grip preferences, and the glove material.
- Adjustable display position
  Users with different types of walking aid have different preferences on the display module position.
- Two buttons rather than more buttons
  At least two buttons are required for an exoskeleton to provide a simple walking function. Having more buttons would provide more functions. However, potential users would prefer to start learning how to walk with exoskeletons with a minimal and simple interface.
- Singleton walking operation (see Fig. 3 (a))
  Mapping button functions related to the exoskeleton operation rather than the stepping leg appears to more simple and intuitive to use.

TABLE I. SUMMARY OF GLOVE UI DESIGN RECOMMENDATION

Components	Design choices provided to test subjects			
1. Type of Glove	 **Finger Glove**[a]	Vs.	 Whole Glove	
2. Number of Buttons	 **Two Buttons**[a]	*Vs*	 Three Buttons	 One Button
3. Walking Method	**Singleton**[a]	*Vs*	Alternating	
4. Display Position	 **Adjustable**[a]	*Vs*	   Fixed	

a. **Highlighted features are the final design decisions**

Final design recommendations are illustrated in Table I.

VIII. Discussion/Future Work

This study addresses the next generation UI design for medical exoskeletons that can potentially improve their usability and ability to learn. However, current state of the art medical exoskeleton technologies, as well as the outcome of this study, are limited to people who retain a certain level of upper body control, or can use crutches or a walker. Identifying the primary target user groups based on the level of their mobility and physical strength is critical regarding this user group that has a broad range of physical abilities that may affect various aspects of conceptual UI design. Exploring more customizable features to satisfy the needs of a broader range of users, for example, patients with higher-level injuries, remains as future work, along with testing with more test subjects.

We hope that the broader range of users with mobility disorders, other researchers, and practitioners in this field of research can benefit from our recommendations in the near future.

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