The Design of a Power Wheelchair Based Computing System for Individuals with Severe Disability

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Abstract: Currently, unfortunately, a computer system designed for power wheelchair users that matches the powerful desktop PC systems found in the market does not exist. To address this situation, we developed a computing system for power wheelchair users to use whenever and wherever they want. For this study, first, data related to power wheelchairs and its users, and current states of the art were analyzed. To investigate user requirements for the computing system, a focus group interview (FGI) was conducted. Based on the outcomes of the FGI as well as the analysis of users, design and technical consideration, we created two types of a computing system which can be installed to power wheelchairs: one type can be used by people who can independently use the system, and the other type can be used by people who need help installing it to the power wheelchair.

Keywords: power wheelchair, computing system, people with severe disability

1. Introduction

1.1. Background and purpose of the research

The market for power wheelchairs has shown tremendous growth in recent years, experiencing annual growth rate in excess of 55%. An estimated 675,000 powered mobility devices including power wheelchairs and scooters are currently in use in the U.S. But for power wheelchair users, carrying and using a computer is a real challenge because their disabilities hinder them from doing it. In this ubiquitous era, such problem hugely impacts their accessibility to information as well as their quality of life. It has been reported that people with disabilities are less than half as likely as their non-disabled counterparts to have access to a computer at home (23.9% vs. 51.7%). The gap in Internet access is even more striking (11.4% vs.31.1%). Although the wide spread use of advanced computing technologies has in general enabled people to access a vast amount of information and knowledge base in a convenient way, persons with disabilities benefit much less from the advances in the computing technologies. With the aim of solving this problem, we pursued design development of power wheelchair based computing system for people with severe disability.

1.2. Method of the research

For this study, first, we tried to understand existing power wheelchairs and the characteristics of power wheelchair users, as well as the cases of wheelchair-mounted computers. Then to identify user needs for designing computing system, we conducted Focus Group Interview (FGI). From the outcomes of the FGI etc., we formulated design directions. Based on the directions, we created renderings and study models. Renderings and study models were made based on the specifications of two Permobile power wheelchairs to which prototypes of the computing system will be attached later. With the study models, we asked users to examine the usability and appearance of them. After user examination, reflecting the feedback from the users, we made mock ups. Though we selected Permobile power wheelchair as the bases of the computing system, we tried the computing system could be compatible with other power wheelchairs.

2. The characteristics of power wheelchair and power wheelchair users

2.1. Power wheelchair

Power wheelchairs are useful for those unable to propel a manual wheelchair or who may need to use a wheelchair for distances or over terrain which would be fatiguing in a manual wheelchair. They may also be used not just by people with 'traditional' mobility impairments, but also by people with cardiovascular and fatigue based conditions. There are many choices of power wheelchairs available offered by a multitude of manufacturers. Basic structure of them consists of frame, driving system, wheels, control system and batteries. Some power wheelchairs come with special features like tilt, recline and elevating seats.

2.2. Power wheelchair users

Power wheelchair users are those who cannot use manual wheelchair with severe cerebral palsy or spinal cord injury etc. Among people with cerebral palsy, those at level one out of 8 levels use power wheelchairs. People in those categories have severe spasms in their legs and arms. Of people with spinal cord injuries, those who were injured in cervical vertebrae, especially those at C4 and C5 level mostly use power wheelchairs. People with SCI at C4 level maneuver power wheelchairs by using input device which operated by mouth. They are not able to keep independent lives without caretakers' aid since it is impossible to use their hands. Unlike people with SCI at C4 level, those at C5 level can move their arms and hands even though the movements are limited. They are able to eat or type with the help of assistive devices.

3. Analysis of wheelchair-mounted computers

3.1. Wheelchair-mounted computers

There were some efforts to develop wheelchair mounted computers like the Synergy PC. The Synergy PC CPU and monitor were packaged in separate, compact units. The CPU was attached to the back of the wheelchair and was powered by the wheelchair battery. The screen, an adapted flat panel display with a small, laptop-like VGA or CGA screen, could be mounted on the wheelchair lap tray. This Synergy PC was developed as an Alternative and Augmented Communication (AAC) system and was commercially available from Adaptive Innovations. Although this one was closest to our proposed system, it couldn't survive to evolve into the general purpose computing system and was discontinued in 1999. We can imagine several reasons why it may not have survived: insufficient technologies; immature market; marketing and design strategies; and etc. Compared to 12 years ago, the new technologies of these days such as broad band wireless internet, Bluetooth, high performance CPU, and more diverse options for I/O devices provides a different environment to develop more efficient wheelchair-mounted computers. Jim and Tom Finch demonstrated a computer system integrated with a power wheelchair in which the computer was controlled by a QuadJoy mouth-operated joystick and voice recognition. The microphone used for voice recognition could access both the wheelchair-mounted laptop and, via wireless transmitter, a desktop computer at the user's home. The mounted laptop was a regular one, not designed for harsh outdoor environments. The system utilized wireless networking and telecommunication. Another wheelchair-mounted computer system is the Mercury. The Mercury is also designed primarily as an AAC system, but is also compatible with standard keyboards and pointing devices. It is designed to mount to a wheelchair, and receive power from the wheelchair battery. Because it was designed as a dedicated AAC device though it is Window XP-based computer, it is not adaptive for the general purposes of the PC by active users.

3.2. Input/output devices

For individuals with disability, many of whom have difficulty positioning a computer and turning it on using traditional methods, access to the system is particularly important. Bluesky Design Inc. is developing a powered device mounting and positioning system which enables individuals with severe physical limitations to reposition devices independently from a bed, wheelchair, or workstation via switch, joystick, or voice input. This kind of mounting system can be applied to deploy the monitor at the power wheelchair. Most people with quadriplegia have limited upper extremity fine motor control, compromising their ability to control standard computer input devices. However, there are many alternative input devices which allow individuals to control through means other than a standard keyboard or pointing device. Examples include: Alternative keyboards-featuring larger-or smaller-than-standard keys or keyboards, alternative key configurations, and keyboards for use with one hand; Electronic pointing devices-used to control the cursor on the screen without use of hands. Devices used include ultrasound, infrared beams, eye movements, nerve signals, or brain waves; Voice Recognition-allowing completely hands-free typing using only voice; Sip-and-puff systems-activated by inhaling or exhaling; Wands and sticks-worn on the head, held in the mouth or strapped to the chin and used to press keys on the keyboard; Joysticks-manipulated by hand, feet, chin, etc. and used to control the cursor on screen; Trackballs-movable balls on top of a base that can be used to move the cursor on the screen; Touch screens-allow direct selection or activation of the computer by touching the screen, making it easier to select an option directly rather than through a mouse movement or keyboard. These input devices can be applied to the individual on the wheelchair when customized in accordance to his/her physical function for the use of the wheelchair worn computing system.

4. Focus Group Interview

To investigate user requirements for the computing system, FGI was conducted. A focus group which consisted of 15 power wheelchair users was recruited. Among them people with spinal cord injuries (SCI) were 12 and those with cerebral palsy (CP) were 3. Participants aged from 20 to 40 and were very active in social life. The group members were interviewed about the needs and usages of computing systems and what features must be considered as a top priority for the development of a power wheelchair based computing system. For participants' understanding of the computing system, we showed the pictures of rough prototypes of it which had been made before the FGI. In regards to the needs and usages of computing system, all participants except one person with CP responded the computing system will improve their access to information through computers. The participant with CP insisted for him iPad, which is compact and operated by pushing touch screen, was enough to get necessary information. Regarding features to be considered for the development of the computing system, a variety of responses were presented. Among the participants, two of them responded 'a power supply system exclusive for the computer-besides the power from wheelchair battery-should be provided'. They worried that the use of a computing system could harm the battery capacity of a power wheelchair.

Figure 1.The scene of FGI secession

Of the participants, there were those who responded that 'easy access to the computing system' and 'easy use of input and output connection' was top priority. Easy access and easy use of computers is an important feature not only for the disabled but also the non-disabled, but to power wheelchair users it is especially true since they have limitations to use their hands. There were also participants who prioritized ‘easy adjustment of the monitor angle and position’ and ‘easy use of computer power switch’. There were opinions that the computing system ‘should not cause problems when they are getting on or off wheelchairs’, ‘should be compatible with other wheelchairs’ and ‘should be durable and weather protective for outdoor use’.

5. Design of the computing system

5.1. Design concepts

From the outcomes of the FGI as well as the studies of current state of the art, characteristics of power wheelchairs and power wheelchair users, we formulated design directions. Based on the design directions, various design ideas of computing system were developed. As a result, two types of a computing system which can be installed to power wheelchairs were presented in rendering presentation: one type which can be used by people who can independently use the system, the other type for people who need caretakers’ help to install it to the computing system. The computing system consists of: (1) Input/output (I/O) unit, and (2) CPU unit. We identified the first type, which we call ‘pocket type’, is good for quadriplegic who can use the upper limb at least as much as people with SCI at C5 level. On the other hand, the second type, ‘tray type’, is proper for people whose hand function is very limited like a person with SCI at the C4 and higher level. Figure 2 shows the pocket type computing system. This system was designed for quadriplegic who can use the upper limb at least as much as people with SCI at C5 level. It is possible for users to take the display out and put it back automatically by pressing a button. It has a feature that allows users to access to the computer whenever and wherever they want and hide the display easily without other’s assistance when they don’t need it.

Figure 2.Design proposals of pocket type computing system.

Figure 3 shows the tray type computing system. This system was devised for tetraplegic whose hand function is very limited like person with SCI at the C4 and higher level. The LCD display is incorporated into the tray. The wheelchair users can use it as just a tray when they don't use the computer and can let the display pop up from the tray when they need to use the computer. We excluded the keyboard and mouse because the person with SCI at C4 and higher level cannot use the keyboard and mouse. They can connect their own alternative pointing devices such as Integra mouse, sip-n-puff, and mouse stick with touch screen. This tray type system could be installed on various brands of power wheelchair regardless of the frame structure of the power wheelchairs. We figured out how to operate both types. Followings are the procedures of operating both types.

Figure 3.Design proposals of tray type computing system.

Table1.Steps of operating the computing system

Step	Pocket type	Tray type
1	A power wheelchair user push an operation button to pull a monitor from a compartment	A caretaker connects a monitor to a power wheelchair
2	The monitor moves forward and rotate in a 270 degree arc	The caretaker opens the monitor of a computer
3	The user open the monitor with hand	The caretaker turns on the power of the monitor
4	The user push the power button of the monitor	The caretaker connects an input device to the monitor
5	The user use the computer	A power wheelchair user uses the computer
6	The user close the monitor with hand	The user turns off the power
7	The user push the operation button	The caretaker closes the monitor and disconnects the monitor from the wheelchair.

8	The monitor returns into the compartment	The caretaker put the monitor into a bag attached to the back of the wheelchair

5.2. User evaluation with study models

Using design ideas which were shown in Figure 2 and 3, we made full scale study models of the pocket type and the tray type. We attached them to two existing power wheelchairs. Then we asked two participants to check the usability of those models as well as the appearance of them. Followings are the results of user evaluation.

5.2.1. Pocket type

It appeared that the monitor needs a supplementary connecter near the controls of the wheelchair to prevent the swaying of it while in use. It was suggested that the location of input/output port be moved to the left of monitor because in the proposed location, inserting or pulling things such as USB to or from the port is interfered with a keyboard. It was also identified that, for people who cannot use fingers easily for their disabilities, opening and closing the monitor with their closed hands should be considered.(Figure 4)

Figure 4.User evaluation with a pocket type study model

5.2.2. Tray type

As a result of assessing a tray type study model, it appeared that users feel most convenient when the height of the tray is the same as those of the armrests and the distance between the tray and the user is around 5cm. It also appeared that the location of the space for laying a cup or a beverage should be moved toward upper part of the tray so that it cannot interfere with eating or reading. It was found that, unlike the monitor part, the part on the right hand side of the tray should not be moved to prevent things such as a beverage from falling out even when users open the monitor.

Figure 5.User evaluation with a pocket type study model

5.3. Results

We made the mockups of two types of computing system with the feedbacks of user evaluation of the study models. Followings are the main features of designs.

5.3.1. Pocket type

With adopting 13 inch LCD monitor, the weight and the size are minimized. Users can operate the pocket type computing system by pushing buttons on the above of the pocket compartment which is attached to the left hand side of the wheelchair seat. Once the users push the buttons, the monitor moves forward from the compartment and rotates in a 270 degree arc and stop in front of the users. A support bar is connected to the monitor part from the controls to prevent its swaying. CPU and battery unit is attached to the back of the seat.

Figure 6.The mock up of the pocket type

5.3.2. Tray type

Once the tray type is connected to the pipes beneath armrests and the display is opened from it by caretakers, a user can start using it as a computer. By connecting his or her own input device such as Integra mouse, the user is able to use the computer. Unlike the pocket type in which the display moves forward from the compartment and stop in front of users with the help of motors, in the tray type, operations such as connecting or disconnecting the tray to the wheelchair and opening or closing the display from it are done by caretakers. For the use as a tray, the space for a cup and beverage etc. is placed on the right of it. Also, the top of the tray is indented to prevent things from falling out. The input/output port is installed on the opposite side of the controller to avoid the interference with it.

Figure 7.The mock up of the tray type

6. Conclusions

In this study, we have presented mock ups for the two types of the computing system. The pocket type is one in which a LCD computer display comes out of a pocket shape compartment and places right in front of a user to be used by him or her without any help from other person. On the other hand, in tray type, the LCD display is placed on the tray with the top of it open. It can be used as a normal tray when the user does not use it. In both types, CPU unit is located in the rear of the power wheelchair. The CPU unit houses the power supply, optional battery, the main board (with the CPU, memory, I/O bridge chips and various RF transceivers), and the hard disk drive. Though the computing systems were installed to Permobile power wheelchair, they could be compatible with most power wheelchairs. We expect that the use of proposed system will enhance power wheelchair users' accessibility to information in computing environment.

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