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Augmenting Intuitiveness with Wheelchair Interface Using Nintendo Wiimote

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ABSTRACT

The natural interaction aspects of the user interface are more significant in the devices of impaired users than the devices of healthy users. This work investigates three controls as the wheelchair controllers according to the design and physicality principles; conventional joystick, isometric joystick, and quad-directional button. Our aim is to provide further ease of use to the impaired whilst strengthening link between embedded software engineering and human-computer interaction. We conclude that an improved multi-function interface design by using Nintendo's Wiimote quad-directional button is more intuitive, flexible and natural to use.

KEYWORDS

Physicality; embedded software; wheelchair controller; user interface design; natural interaction.

1 INTRODUCTION

Impaired people are more sensitive to the user interfaces (UIs) of their assistive tools and devices. This limitation must be considered at the design time of these devices. Among assistive tools for impaired people, the mobility assistive tools are heavily used. In US alone, approximately 4 million people use assistive wheeled mobility devices, with about 17% using electric power wheelchairs [27]. A wheelchair can have different types of UIs based on various factors including the power source, that is, hand-driven; hand-power-driven; or intelligently/sensor-power-driven. The hand-power-driven wheelchairs use various controllers including; joystick, trackball, head array, touch pads and various types of buttons and switches.

The natural interaction is the combination of human innate abilities and the physical visceral qualities in the artefacts [1]. The visceral quality is that physical aspect of device which recruits our natural human abilities [2]. Physicality as defined by Donald A. Norman [3] is "the return to mechanical controls, coupled with intelligent, embedded processors and communication". The importance of physicality is evident from many examples. The notational and social aspects of physical artefacts cannot be ignored in agile software development [4]. Pilots of commercial airlines use papers for many purposes including managing attention [5]. Physical representations are difficult to ignore than digital reminders [6]. McKinnon [7] states, "(Some software) helps you effortlessly create new ideas, break them down, arrange them, colour code them but most importantly - print them out to use them as technology in their own right".

There are two popular types of joystick; conventional joystick (CJ) and isometric joystick (IJ). The difference between the two is that when the user exerts force, CJ moves itself significantly whilst IJ does not move itself. IJ as a pointing device has been used in various laptops, computer mice, and desktop keyboards. It occupies little space providing only single finger operation. Different brands have different names for IJ including TrackPoint by IBM/Lenovo, PointStick by HP, NX Point by NEC, Pointing Stick by Sony and Unicomp, StickPoint or QuickPoint by Fujitsu, Track Stick by Dell, AccuPoint by Toshiba, and FineTrack by Acer.

Nintendo's Wii is presently the largest selling video game around the world [18], [19]. The controller of the game is called Wii remote or Wiimote. The reason behind using Nintendo's Wiimote for wheelchair interface is its better interaction capabilities. It has more flexibility and scalability than conventional components used in wheelchair interface. Wiimote has a quad-directional button (QDB) also called control pad, eight other buttons, 3D motion sensing, and pointing functions for input purpose and a speaker, rumble pack, and four LEDs for sound, tactile, and visual feedback, respectively. In this work we investigate and compare the design principles of CJ, IJ, and QDB.

This paper is organized as follows. The next section describes motivation and related work followed by introduction of physicality principles and then introduction of controllers. Subsequently we compare the physical and logical mappings of three controllers. Before discussions and conclusion we analyse the three controllers according to design and physicality principles.

2 MOTIVATION AND RELATED WORK

Among the vast application areas of embedded software systems, we look into the interface design of assistance devices for physically impaired people. Wheeled mobility devices are heavily used tools by the impaired people around the world. Although a lot of work has been done in the past on the solutions for the impaired people but the specific area of interface design of controllers has not yet received appropriate attention. In order to have a deep understanding of the requirements-availabilities relationship, we investigate the problems and solutions of firstly blind impaired people, and secondly the mobility impaired people. In this way we can be better able to design a natural interface for wheelchair users keeping in mind that blind users also need to interact with the wheelchair.

For our study, we also visited hospitals, impaired people's care centers, interviewed impaired children and their caregiver staff, and observed the ways in which impaired people interact with their wheelchairs to gain first-hand knowledge of their needs. The impairment that leads to the use of wheelchair may be caused by many diseases or injuries of spinal, muscular, brain, legs or feet.

Recently some efforts have been made to bridge the gap between software engineering and human-computer interaction and to provide ease to the embedded software developers. Kim et al. [25] have proposed a user behavioral analysis framework for the ubiquitous embedded systems. Bujnowski et al. [8] empirically analysed the use of tactile system to guide the visually impaired people during walk. Although they used tactile vibrators on subject's one arm only, still their results showed that tactile feedback is more comprehensible to the blind. This work can be enhanced easily by increasing the directions from three to five or even more. At each arm, small duration vibration would mean turn left 45^o, and long vibration would mean turn left 90^o, while vibration on each arm simultaneously would mean to move forward. The study by Hara et al. [9] has also proved that the tactile feedback is better than audio, especially in outdoor's possibly noisy environment. The results of Shah et al. [10] have also confirmed the former studies. Based on these studies among many others it can be concluded that the tactile sense of visually impaired people is more sensitive and better than audio feedback.

Ivanchenko et al. [11] have proposed a computer vision based solution. A camera and high speed computing device for graphical processing of images made the system costly besides other flaws. This approach targets the visually impaired users who may have additional mobility difficulties. This system engages an arm of user all the time which is laborious especially for an impaired person. It is difficult for fixed camera to monitor the free moving cane. Lastly, the computer vision program needs improvement by categorizing the friends and foes among obstacles. Kuno et al. [12] have come up with even costlier wheelchair interface solution having multiple cameras, high speed computing machines for image processing, and automated control of wheelchair. The solution has overwhelmed the user with many controlling points and strict limitations on head movement for the user. Any slight movement of head for communication with some person or for enjoying the environment will result in the unintentional change of direction of wheelchair that may end up in an accident. The system is designed in a way that the back camera tracks and follows the movement of caregiver. However, the back camera can interpret any pedestrian as caregiver because authors have not designed anything to identify the caregiver. As the caregiver control has priority over user control, in case of wrong selection of caregiver the user is helpless especially at a busy place like market. This system indicates a lot of enhancements to be made on the interface of the system besides functionality. Abascal et al. [13] have proposed a mobile interface for the patients of quadriplegia (who are unable to use their arms and legs) that is low cost, automatic, and requires less effort by the user. It also takes into account the activeness of user for rehabilitation purposes. The user can select the available paths after scanning a matrix of icons, with a pushbutton or a joystick. To select a destination the user is provided with a hierarchical map model due to compact menu-based display. The presented entries for the destination to the user are optimized by two ways. First, only the reachable destinations from the current point are displayed to reduce the time and effort of user in selection. Second, the displayed options are ordered based on the frequency of selection by the user. However, the user interface needs enhancement. In all the discussed scenarios we have found spaces for improvement in the user interface.

Duran et al. [32] proposes the use of wiimote instead of joystick for holonomic wheelchair control by exploiting Wiimote's 3D sensor movement facility using gestures. Authors want to reduce the interaction with the wheelchair controller to reduce mental workload and introduce relaxed interaction. The aim is to remove the limitation of using buttons or knobs to facilitate the riders with specific kind of cognitive and physical disabilities. Hand manipulations holding wiimote are translated into the displacements of wheelchair. The system consists of wiimote, laptop or PC, Bluetooth dongle and holonomic robotic wheelchair. The three wiimote movements are translated into three wheelchair movements; pitch, yaw and roll to move forward/stop, turn right/left, and steering right/left, respectively. In comparison tests it is proved that wiimote control requires less movements and hence more intuitive than joystick controller.

3 INTRODUCING THE DESIGN AND PHYSICALITY PRINCIPLES

The physicality principles have not yet applied on the wheelchair interface to introduce natural interaction. Embedded software developers emphasized on functionality by providing multiple complex interfaces simultaneously for a single chair whilst ignoring the usability and fluid interaction aspects, completely. Users like a naturally used device no matter how simple it is but dislike a very sophisticated device having poor interaction. We briefly discuss here the design and physicality principles for natural interaction. We will evaluate the existing controller and compare with other controllers according to these principles in detail in section 7.

If a control expresses its underlying logical state by its physical state then this control holds the property of exposed state. For example, simple on-off light switches. If the physical appearance does not express the logical state then it is called hidden state. For example, twist control of a speaker. The directness of effect property is directly proportional to the action performed. A small push results in small movement and a large push results in large movement. Locality of effect means the result of an action should be there and then. A control having bounce back effect maintains a state until operated then either stays or returns back to its initial physical state. For example, push button. Cultural influence indicates the frequency of usage in a society. Affordance is the number of action options perceived by the user. Compliant interaction shows the symmetrical aspect of interaction between user and system. Physical and mental requirements are the amount of physical and cognitive efforts, respectively that are needed to perform an operation while interacting with a control.

4 CONTROLLERS

The controllers of the wheelchair may include various kinds of joysticks, trackball, head array, touch pads and different type of buttons and switches. We have selected IJ and QDB to be compared with the existing CJ controller. The existing system [15] is a non-commercial wheelchair developed by embedded system students of a university. This wheelchair has triple-user interface; hand-power-controller (with CJ); automatic-power with sensors; and manually by using rim (Fig. 1).

Fig. 1. Subject wheelchair.

We introduce three controllers CJ, IJ, and QDB in subsequent subsections.

4.1 Conventional Joystick

CJ has been widely used as a wheelchair controller. When user applies force on CJ, it moves itself whilst forwarding the user input to the wheelchair as output. In this way, the joystick movement guides user during the interaction. In existing wheelchair [15] CJ is used (Fig. 2).

Fig. 2. Conventional joystick (CJ) mounted on controller box of existing system.

The joystick has a metal stick with hard plastic head. It is 3cm in vertical length or height mounted on a controller box. The controller box holding the joystick is occupying further 3cm height resulting in a total height of 6cm from the wheelchair arm. This occupies a lot of space and reduces the seating and operational space for the user. The clothes of user may stick to the joystick during seating or leaving the chair. This may result in the damage of device. There is no labeling for guidance to indicate any direction. Among 360^o, user cannot predict the operational range of joystick. This is an example of lack of affordance. The joystick is a bounce back control [16] as it returns to its initial position after the release of pressure. However, this CJ has a hidden state property and therefore it needs to have some labeling for the directions [17].

In addition, this joystick needs to be grabbed or grasped with fingers to operate. Whilst we are focusing on the impaired users, among them patients having no fingers may also use this wheelchair, for example leprosy patients. Therefore, this control is approximately unusable or very difficult for the people having no fingers. Another problem of the existing CJ is that it is twistable and rotatable in clockwise and anticlockwise direction, having no logical functionality. The physical-logical mapping is absent here that will only confuse the user. One more limitation of this CJ interface is the introduction of four screws that are holding joystick module inside the controller box. The screws on the box hinder the use of joystick because these are well above the surface. The edges of the screws may injure the user in any unintentional or careless handling of device.

4.2 Isometric Joystick

IJ is a type of joystick that does not move itself but translates the input of user into electronic form and forwards to the underlying system. Therefore, it does not provide any kinesthetic feedback to the user. User only gets a non-visual feedback in the form of feeling back-pressure in exerting force on the joystick. In contrast to CJ, IJ requires less space. It has been frequently used in hand-held devices or mobiles including powered mobility [27], mobile phone [28], and electric power wheelchair [29]. In [29] authors have conducted a comparison study between virtual and real electric powered wheelchair maneuvering using a position sensing joystick and an isometric joystick. In [30] authors have conducted comparison study of three controls for browsing World Wide Web including scrolling and pointing actions. These three controls include mouse with IJ, wheel mouse, and two handed keyboard and mouse. In [31] gestures of isometric joystick are used to enter text in mobile phone (Fig. 3c). IJ is also used with mouse (Fig. 3a) and keyboard (Fig. 3b).

(a) IJ in Keyboard [30]

(b) IJ in Mouse [30]

(c) SC1100 Smartphone augmented by IBM's TrackPoint IJ on front and back [31]

Fig. 3. Some uses of IJ.

Although isometric controls are found less intuitive in start but after gaining experience these may be less fatiguing and result in smoother movements [33]. Vast applicability of IJs in various devices makes it a good candidate to be used in our study. There are few other studies that have used IJ for imddpaired users in mobility assistive devices and compared with conventional joysticks especially for the patients suffering from cerebral palsy, and duchenne muscular dystrophy [34], [35], [36], [37].

However, none of these and other studies have addressed the physicality principles. Motion sensing joysticks have also been used with wheelchairs. Due to desirable features of IJ, currently research is in progress in the area of embedded system to improve IJ. It has been exercised by augmenting IJ with intelligence and control by using the programmed microprocessor [27]. Many shapes or caps of IJs are used for example soft rim (Fig. 4a), soft dome (Fig. 4b), and classic dome (Fig. 4c).

(a) Soft rim (b) Soft dome (c) Classic dome

Fig. 4. Example caps of IJ.

Instead of using different or new controllers for different devices; resulting in learning effort, handling burden, space occupation, cognitive burden on user, time wastage, and difficulty in context switching; least number of controllers should be used (a universal controller as a perfect case). Therefore, we investigate culturally familiar controls for the impaired users.

4.3 Quad-directional Button

Nintendo has recently introduced new design for its game controller (Fig. 5). This game has broken the previous records of sales [18] and currently it is at top position (more than 11,450,000