Heinrich C. Mayr, Martin Pinzger (Hrsg.): INFORMATIK 2016,
Lecture Notes in Informatics (LNI), Gesellschaft für Informatik, Bonn 2016 2127

μ-Force Control - A Device for Controlling Power Wheelchairs for Severely Mobility Impaired Persons

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Abstract: A new device for the control of power wheelchairs is introduced. Besides a speech recognition module its main component consists in two force sensors, shaped to match the hands of the user. The sensors are able to measure slightest pressures executed by the thumbs. Commonly, mobility impaired persons control a power wheelchair via a joystick. This requires the ability to execute distinct movements of the fingers or hands. In case the impairments are more severe and affect also the upper limbs, the possibility of wheelchair control via a joystick might not exist. Such persons in mind, a concept has been developed in which minimal muscular forces suffice to control a power wheelchair. A prototype of the device has been constructed that measures and combines the pressures from both thumbs and translates them to direction and speed of the wheelchair. It has been tested under reality conditions in various indoor and outdoor scenarios.

Keywords: biomedical equipment, assistive devices, wheelchairs

1 Introduction

There are many different forms of diseases that lead to movement-limiting disabilities with similar endings: the persons cannot move individual body parts or even the whole body. Finally, they are confined to a wheelchair. Among common causation of such disabilities are types of muscular dystrophy and neuromuscular diseases. Muscular dystrophy is a group of inherited diseases that are characterized by weakness and wasting away of muscle tissue. They are commonly caused by mutations in the genetic material. The most well known of the muscular dystrophies are the Duchenne muscular dystrophy (DMD) and the Becker muscular dystrophy (BMD). Neuromuscular diseases comprise a large number of different ailments that impair directly or indirectly nerves or neuromuscular junctions. While these diseases may have many different reasons, the result is often the same: the persons end up in a wheelchair.

Mobility is essential for handicapped people. It allows them to take part in social life. A power wheelchair is an important tool to provide handicapped people with some autonomy. In early stages of neuromuscular diseases a regular joystick is often sufficient to control the wheelchair. But with progressive weakening of muscles it becomes increasingly difficult to move the joystick. In this case a mini joystick is commonly the only option to retain control. It needs a force of 10 grams and the ability to move the thumb and the pointer finger in a small radius of approximately $5-10\,mm$. If the force and the freedom of movement is decreasing further, the impaired person will be able to use the joystick

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for fewer directions (e. g., only forward). Afterwards, this input device is getting more and more useless. For keeping the ability of driving power wheelchairs in this situation, an alternative control approach is needed. Without it, affected people would not be able to go to school or university, to work or to meet other people.

2 Related Work

Commercially available input devices for power wheelchairs are mostly proportional devices like the mini joystick. They need distinct movements of limbs in order to operate. Further common input devices are shown in [WR15]. Examples are joysticks, touchpads, tablets, foot controls, head arrays and sip/puff controls. Future directions are going to isometric input devices and smart wheelchairs. Isometric joysticks [DCC10] are alternatives to traditional proportional joysticks. They sense force exerted on them and do not change position perceptively when a subject applies force . Smart Wheelchairs [Ta13, Tr13] consist of a power wheelchair and a personal computer with sensors. The personal computer interacts with the user and allows to control the wheelchair functions. Based on smart wheelchairs, there are projects of alternatives using brain computer interfaces [In11], myoelectric signals [OOH10], eye tracking [EGP16, Fo11, WSP10] as well as pressure sensitive touchpads [CHK14]. However, many of these systems are very expensive or their development is time-consuming.

3 μ-Force Control

The μ-Force Control is a new approach keeping the ability of driving power wheelchairs even with the a very small residual muscle strength. In comparison to other existing systems it has two essential advantages: it only requires minimum muscle strength, and unlike the interaction with a mini-joystick, the fingers do not have to be moved.

3.1 Hardware

Figure 1 illustrates the components of the proposed system in comparison to system utilizing a mini joystick. The μ-Force Control combines isometric input devices [DCC10] and smart wheelchairs [Ta13, Tr13] and needs no distinct movements of limbs but only minimal force of the thumbs. It consists of two force sensors (each one per thumb). The 3-D form of the sensors has been designed to match the hand form of the user. Of course every person has different requirements to the 3-D hand form of the sensors. The sensors' shape of the μ-Force Control can be customized to meet these requirements. In case of the presented prototype, the 3-D hand forms were modeled with a 3-D software and created with a 3-D printer.

The sensors are connected to an Intel Nuc personal computer running Microsoft Windows 10. For connecting the personal computer to the control of the power wheelchair, a serial

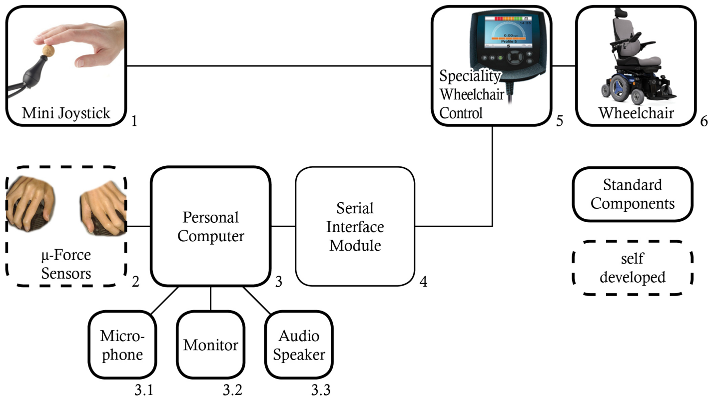

Fig. 1: Comparison of components of a system with a mini joystick (1,5,6) and the components of the μ-Force Control (2-6). The complete system is more complex than described in this paper. For example, it comprises a microphone for interaction via speech recognition.
(Image sources: Christoffer Steen[a], mini joystick / Curtiss-Wright Industrial Group[b], R-net Omni speciality wheelchair control / Permobil[c], wheelchair.)

[a] http://kristoffersteen.dk
[b] http://www.cw-industrialgroup.com/Products/Mobility-Vehicle-Solutions/R-net/Omni-Control-Interface.aspx
[c] http://countries.permobil.com/Austria/Produkter/Alla_modeller/M400-3G-corpus/

interface module is used [In11]. The fully functional prototype of the μ-Force Control is attached on a *Permobil m400* wheelchair with an *R-Net Omni* speciality wheelchair control (see Figure 3). The μ-Force Control application reads the sensor data and calculates the output for the wheelchair. The software allows to calibrate the sensors according to the force of the user.

3.2 Interaction

Pressing the left thumb turns the wheelchair right and vice versa. A light pressure with both thumbs selects the driving direction forward or backward and pressing both thumbs with a slightly stronger pressure accelerates the wheelchair in the current direction. However, controlling the wheelchair solely based on the pressure of the finger is – regardless of the calibration – not accurate enough. Therefore, a 7 inch touch-sensitive USB-screen with a resolution of $1024 \times 600\,px$ is used to generate an additional visual feedback. With the help of visual feedback through the driving vector (see Figure 2), a suitable coordination of the pressure of both thumbs is possible. Additionally, auditive feedback is emitted via speaker. This is done for important events, e. g., when the driving direction is changed, a calibration is started or done, or if any of the connected devices (microphone, force sensors, etc.) loses connection. Outside, if strong sunlight makes the display difficult to read, an auditory feedback is quite reasonable in addition to the visual feedback.

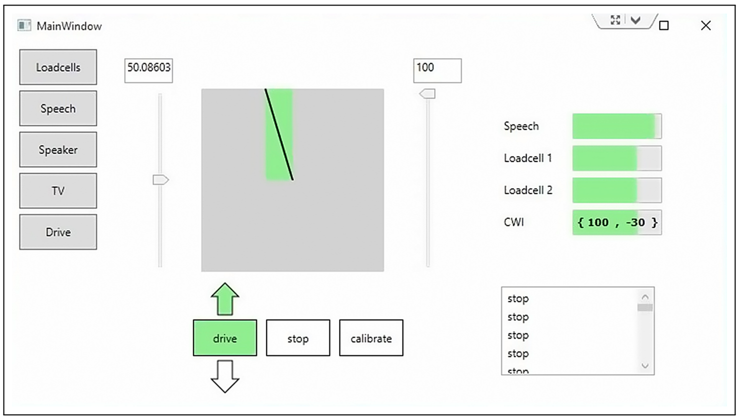

Fig. 2: This figure shows a screenshot of the graphical user interface with the driving vector indication (shown in the gray square at the center), the driving direction (bottom left), the system status (top right), and a speech input history of control commands (bottom right).

3.3 Software

Figure 2 shows a screenshot of the graphical user interface which can be controlled via speech recognition. The sliders on the left and right of the gray area show the measured force of the sensors. The driving vector shown in this box (black line in green rectangle) is calculated from these two values. Visible changes of the driving vector occur only when exceeding a certain value, e. g., 20% of the maximal pressure. The moving direction (bottom left on Figure 2) is flipped by pressing (and releasing) both sensors with a power below this threshold. If *drive* is activated, the values of the driving vector are sent to the wheelchair. The wheelchair is turned to the right/left by pressing the opposite thumb. When pressing both thumbs, the wheelchair is accelerated. If *stop* is activated, no control commands will be send to the wheelchair. Instead, the force values will be used to control the mouse of the computer. The calibration procedure is started by activating the button *calibrate*. Then the sensors must be pushed with minimal and maximal force within 10 seconds. The bar indicators shown at the top right of Figure 2 give an overview of the current measured pressure of the sensors (*Loadcell 1/2*) and feedback on the status of the speech recognition and the computer wheelchair interface (CWI). Finally, the text-box at the bottom right on Figure 2 gives feedback on already used commands.

In combination with the other menus on the left side, it is possible to modify parameters of sensors (Figure 2), configure the speech recognition and the speaker. Further, the software allows the user to control all wheelchair functions including seat actuators and light.

4 Evaluation

The first author of this paper suffers from Duchenne muscular dystrophy and has developed the described prototype according to his own needs. In a period of continuous developing and testing he was able to operate Y-Force Control in various indoor and outdoor scenarios under realtime conditions. The insights gained from these field studies have been incorporated in the development of the control device. Following real world scenarios have been tested:

Fig. 3: Different indoor and outdoor operation scenarios for the μ-Force Control.

- rooms in the author home (see Figure 3). In this environment, the doors have a standard width of about $80\,cm$. A video showing the accuracy of control in this environment is located here:
  `http://www.fernuni-hagen.de/mci/resources/software/video1.wmv`.
- at work and in public buildings such as shopping malls, restaurants, cafés, or cinemas. Moreover, also elevators in public buildings have been used.
- outdoor scenes. This includes passing through a meadow, covering larger distances ($1.5\,km$) on paved roads (see Figure 3) or shorter distances on cobblestone, and driving onto the ramp of a car loading system. The latter can be watched in a video which is located here:
  `http://www.fernuni-hagen.de/mci/resources/software/video2.wmv`.

Turning around, braking, accelerating, or driving the wheelchair backwards are possible without any major problems. The tested top speed is currently at approximately 6 km/h. Depending on the pavement, more force is needed to compensate for the vibration. Short rest periods or a repositioning of the hands may occasionally be required by an accompanying person. Though a systematic evaluation remains to be done there is already ample evidence, that the prototype of μ-Force Control introduced in this paper represents a significant relief in the everyday life of severely mobility impaired persons.

5 Conclusion

In this paper a new approach to control power wheelchairs for severely mobility impaired persons was proposed. Compared to the common approach of using a joystick, the proposed μ-Force Control approach requires no distinct movement of the fingers but only a minimal force of the thumbs. Thus, finding a good position of the hands is much easier in contrast to systems using a joystick. The latter requires the hand to be positioned precisely. If the hand is too much ahead (behind), a user of the target group is not able to drive backward (forward). In addition, the utilization of standard computer components offers much flexibility. The driving algorithm can be changed to meet special user demands and the application can be extended with eye tracking. In addition, using both hands supports a better sitting posture than one-sided controlled joysticks.

Summarizing, the proposed control device for mobility impaired persons has proven to enhance mobility in various indoor and outdoor scenarios and thus to improve participation in social life.

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