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Haptic control for powered wheelchair driving assistance

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Abstract

For persons with motor disability, wheelchair driving is an essential activity. They should be able to accomplish this task easily and efficiently. However, in some cases, severe motor disabilities may generate symptoms such as tremor and spasma and will thus affect the driving ability of the person. The driving task may then become insecure and exhausting for the wheelchair user. In order to assist these persons in the control of powered wheelchairs, we propose to use haptic control devices that allow to feedback forces to the user's hand. This haptic feedback should allow immediate recognition of the free directions in the near environment and bring in easy and smooth handling of the control device through these free spaces.

We carried out experiments on a simulator using haptic control devices on a powered wheelchair fitted with a range measurement sensor for obstacle detection. Results show strong interindividual differences of driving behavior, the force feedback acting in general positively on the control.

1. Introduction

Powered wheelchairs (PW) helped many disabled persons to overcome their mobility problems, especially nowadays where most cities and buildings have a high level of accessibility. However, in the case of severe motor deficiencies, the control actions become difficult to achieve and may be inaccurate and uncoordinated. Then the person's ability to drive the wheelchair will be limited. To provide help to these persons, the research focused on the development of smart wheelchairs, fitted with autonomous functions such as obstacle avoidance, wall following, narrow passages crossing, etc. [1,2]. To date, no smart wheelchair is available on the market in particular because of reliability and safety issues. On one hand we also notice that the disability level is usually variable among individuals, and, as a consequence, it is difficult to adapt the wheelchair to each person. On the other hand, psychological acceptability problems arise for some persons who don't want to let the wheelchair driving by itself and become apprehensive about it. They actually would rather keep control of the wheelchair all the time. Other persons prefer taking the best advantage of their residual motor skills. Actually there is no study to confirm these points since there is no large-scale use of a particular smart wheelchair model. They are only based upon patients and rehabilitation professional suggestions. For these persons, we propose to use a force feedback joystick to drive the powered wheelchair. This device generates force effects that the user can experience on his hand. In this context, they will help the person to avoid obstacles by feeding back repulsive or resisting forces to his hand if he moves towards them. This driving scheme allows the person to continuously control the wheelchair and will not force him up to perform unwanted motion. We believe that the techni-

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cal and psychological limitations brought by smart wheelchairs will not occur anymore.

Haptic feedback enhanced performances in various control tasks [3,4]. It could be initially considered as an additional source of information compensating for the lack of visual information the user may need to properly perform a control task [5]. Many haptic devices were used in the literature, ranging from force feedback joysticks [6] to motorized wheels [7] or even 3D haptic devices [8]. In a shared control task between a human operator and an automatic controller, the haptic feedback would allow the human to perceive the controller's actions through the force feedback effects and, at the same time, to correct these actions by forcing them back on the control device [7,9]. [10] presents an overview of various shared control schemes using haptic feedback. In remote control of mobile robots, the haptic feedback assistance significantly improves driving performances [8,11]: less collisions with obstacles and an increased distance between the robot and the obstacles with no significant change in navigation time. [12] used haptic feedback for the remote control of a simulated aerial vehicle. They showed that it leads to the same performances while reducing the operator's workload. However, the haptic feedback should be computed thoroughly to take the best advantage of this assistance.

Haptic control also brought assistance in a very natural way to visually impaired persons [13,14], but its use with motor impaired persons remains few and unexplored. Some applications were for rehabilitation purposes, such as posttraumatic rehabilitation [15,16], driving training of wheelchairs for children [17] or adults [18] with motor disability. Only few works which concern the control of powered wheelchairs are referenced in the literature. First research in this context was based on preprogrammed trajectories where the persons were guided to the target position by a haptic feedback [19–21]. Later on, [22,23] implemented a passive haptic feedback assistance on an omnidirectional wheelchair, using two laser rangefinders for obstacle detection. [24,25] used the same assistance for obstacle avoidance and reverse movements in an elevator. A passive haptic feedback consists only of resistive forces generated in the direction of obstacles or cluttered areas. No attractive forces are applied to drive the user to his destination. Another work by [26, 27] used an active haptic feedback to strengthen control actions of elderly persons. However, none of these researches carried out large experimental evaluations of the developed prototype. Only simple L-shaped or U-shaped trajectories were followed in the evaluation process which involved only one healthy person. We can also notice that they were all evaluated on healthy users and none of them assessed the assistive technology on persons with motor disabilities. In another context, a force feedback assistance was implemented on manual wheelchairs using motorized hubs at the wheels axes [1,28], but this assistance could only be used at a lower level of disability. We could also mention the use of various force feedback effects such as vibrations and frictions in order to point out the obstacles positions to the user [29].

Our first works in this field were carried out on a 2D simulator [30]. Results obtained on a panel of healthy persons show that active haptic feedback assistance reduced navigation time and the collisions by smoothing the wheelchair trajectories. These conclusions were confirmed in a second step by experiments carried out on a real instrumented wheelchair [31]. They also related to a panel of healthy people. The objective of this article is to extend these experiments to usual drivers of powered wheelchairs. Indeed, to our knowledge, it is the first time where such assistive technology, a force feedback joystick intended for driving assistance, is assessed with persons with motor disabilities. It is a first series of exploratory tests intended to locate profiles of people for whom the force feedback would improve the driving performances. Experiments were performed using a 3D simulator for safety reasons and also to facilitate the acquisition of quantitative data. In the following we present the results and discussions of these experiments.

2. Methods

2.1. The ViEW simulator

The 3D wheelchair simulator ViEW (Virtual Electrical Wheelchair) designed in our laboratory has several aims. The developed virtual environment can vary according to the application: safe driving training, test of the control skills for example within the framework of a wheelchair prescription, aid for parameterizing wheelchair settings, tests of new features [32,33]. To facilitate the diffusion and the experiments with the simulator in various rehabilitation centers we chose a "software only" development.

To approach as well as possible the behavior of a real wheelchair three different architectures have been modeled: central, traction and propulsion driving wheels (Fig. 1). We used a physical simulation using gravity, friction and torques to rotate the wheels according to the joystick control. In addition we increase the immersion of the user by managing the collisions with the 3D environment and displaying an animated prolongation of his arm in the virtual world (left handed and right handed is also supported) which controls the wheelchair (Fig. 2). Finally we display the performances and parameters of the achieved trajectories: speed, duration, number of collisions.

Our simulator was designed using the software 3DVia Virtools™, for the real-time 3D engine, and 3D Studio max™ for the modeling part. The human machine control interface may be a traditional wheelchair joystick (or a functional equivalent) or a joystick with force feedback like the Microsoft Sidewinder Force Feedback 2 used in this study. Although it is very cumbersome, this hardware was selected for the price, the quality and the power of its force feedback. It was modified to respect in a better way the specific driving position of each child. Fig. 3 presents the system modified as well as the various gripping devices.

The force feedback joystick is self-centered in order to help the user finding easily the stop position of the wheelchair. Based on measurements of distances to obstacles, an algorithm detects the free directions and then feeds back haptic information on