Force Feedback Joystick Control of a Powered Wheelchair: Preliminary Study *

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Abstract – *An evaluation of a force feedback joystick for a powered wheelchair is performed. Our aim is to determine if the force feedback joystick enhances the driving performance of persons with severe disabilities. A Microsoft® Sidewinder™ Force Feedback joystick 2 is used with a computer simulation system for the evaluation phase of the study. The factor used to determine the feedback force of the joystick is the displacement vectors of sixteen sensors to the nearest obstacles. The preliminary results on persons without disability show that there are fewer collisions when the force feedback algorithm is activated compared to their performance when the algorithm is not activated. All test subjects agreed that when the force feedback algorithm is activated, the wheelchair guidance is easier in corridor displacement. Moreover, some subjects found it easier for door crossing.*

Keywords: Assistive technology, powered wheelchair, human-machine interaction, force-feedback joystick.

1 Introduction

Many varieties of input devices and control interfaces have been developed for powered wheelchairs to satisfy diverse needs for disabled people [6]. However, for some people with severe motor disabilities, it is impossible to use these powered wheelchairs [9, 13].

At the end of eighteenths, some research groups have used the term "smart" to describe their powered wheelchair [3, 15]. They wanted to give the powered wheelchair more capacities in identifying the environment and then extracting from it useful information which will be used later to achieve autonomous or semi- autonomous movements like, for example, obstacle avoidance, door crossing, approaching and automatic following of planned trajectories (see for example [2, 10, 17]). Unfortunately those smart wheelchair prototypes are only available in research centers and they are not commercialized for disabled people. There are several reasons for this, the most important one is the security factor the smart wheelchairs being intended for people with severe disabilities.

For good reliability, a complete set of sophisticated environment sensors and a heavy information processing must be used. However, this needs more money to realize such smart wheelchairs. One way to overcome this problem of security is to introduce the assistive driving mode. In this case, the driver provides the desired speed and direction while the smart wheelchair tries to find a valid trajectory: a trajectory without obstacles [11]. In this mode, the driver has the possibility to stop, restart the wheelchair or to modify the desired speed and direction. However, the actual speed and direction are determined by the control logic and not by the driver, which may disrupt the driver in certain situations. This approach has been used at Michigan University where the smart wheelchair follows a free direction closest to the desired one [16]. One disadvantage of this approach is the difficulty of realizing some actions like pushing a door or approaching an obstacle.

Another approach based on the use of a force feedback joystick has been developed to help disabled peoples to drive a powered wheelchair. The force feedback law is a linear function of the distance between the wheelchair and the closest obstacles. In this case, the driver is completely master of the wheelchair and the control logic only makes the feedback joystick less or more difficult to go in some direction, i.e. the control law only changes the joystick compliance according to the environment. This approach has been used in [8] for a virtual environment and in [5, 14] for a completely known environment.

In this work, the later approach will be adopted. However, the force feedback law is not simply a linear function of the distance between the wheelchair and the closest obstacles, but it is also a function of the driver behavior and the unknown environment structure.

The first step in this work will be done in virtual environment using a real time computer simulation (like for example the one proposed by [12]). The advantages of this computer simulation are the possibility of testing:
1- different control algorithms for powered wheelchair,
2- different force feedback control laws for the joystick,
3- different environment configurations and
4- different driver behaviors.

In the second step, the validated approaches in the simulation step will be applied in real environment using a powered Push^{TM} wheelchair equipped with sixteen ultrasonic sensors, an odometric measurement system and a control system. The wheelchair is available at the Laboratory of Automatic and Cooperative Systems (LASC), University of Metz in France. It has been initially used in 1989 in the VAHM project (see [4] for more details).

The paper is organized as follows: Section 2 describes the force feedback methodology used in this preliminary study. In Section 3, the computer simulation configuration is detailed. Section 4 is devoted to the application of the proposed methodology and the results. Conclusion and future work are given in Section 5.

2 Force feedback methodology

In this section, the Human-Wheelchair system adopted in this work is detailed as well as the force feedback algorithm.

2.1 Human-Wheelchair system

The human-wheelchair system considered in this paper is shown in Figure 1.

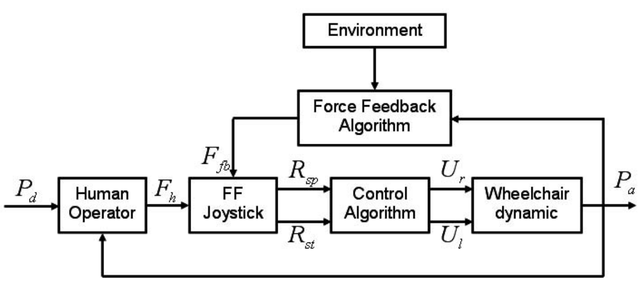

Figure 1: Block diagram of the system

In Figure 1, P_d is the desired path, P_a is the actual path, F_h is the force applied by the human operator, F_{fb} is the feedback force applied by the control system, R_{sp} and R_{st} are the desired speed and direction respectively and U_r and U_l are the applied commands to the right and left wheel motors respectively.

In this configuration, the human operator applies a force on the input joystick in order to drive the wheelchair to the desired position P_d. The position of the joystick is interpreted as desired speed and direction according to the Figure 2. The control algorithm calculates the appropriate commands for the right and the left wheel motors in order to drive the wheelchair in the desired speed and direction. The human operator observes the present position of the wheelchair P_a and modifies the applied force F_h such that the present position P_a approaches the desired one P_d.

The objective of this study is to find the "optimal" feedback force which helps the wheelchair users with severe disabilities guiding their wheelchair in unknown environments. This feedback force must be a function of the environment structure and the human operator behavior. However, in this preliminary study, only the environment factor will be taken into consideration.

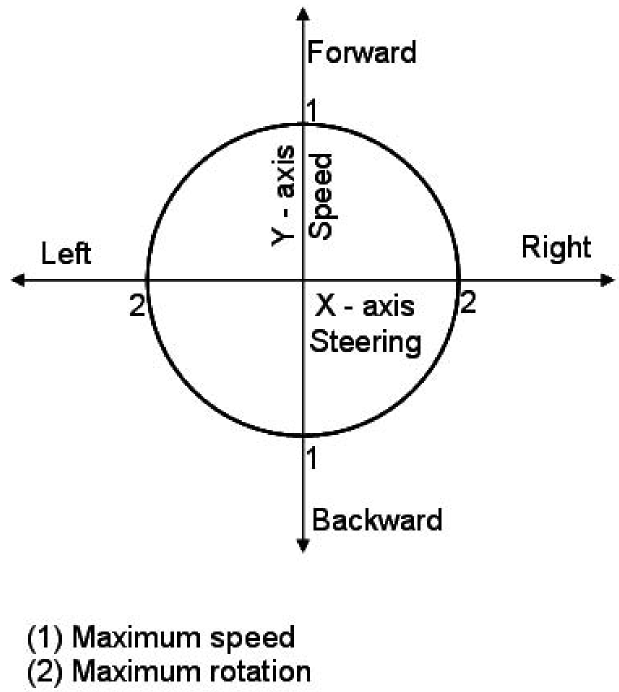

Figure 2: Joystick axis interpretation

Two approaches can be used for the force feedback: active and passive forces approaches. In active force approach, force controller applies forces to the driver by adding energy to the human-wheelchair system. This might be done using servomotors to generate feedback forces. The magnitude of the forces could be directly regulated by the control algorithm. On the other hand, in passive force approach, force controller applies forces to the driver by removing energy from human-wheelchair system. This might be done using energy dissipation elements such as a friction brake or a magnetic particle brake which apply resistance to the driver motion. In this paper the active feedback force is considered, where a spring force is created for each axis of the joystick. The stress of the spring is controlled by the force feedback algorithm and it will be detailed in the next subsection.

2.2 Force feedback algorithm

The goal of the force feedback algorithm is to calculate the magnitude and the direction of the feedback force. To this end, sixteen displacement sensors were used to detect the environment as shown in Figure 3.

Each sensor provides the direct distance from itself to the nearest obstacle. The sensors range is limited to the interval $[0, 2]$ meters so if an obstacle is far from the sensor more than two meters, the distance is considered infinite. Moreover, if the distance is less than or equals to 0.1m, it is considered

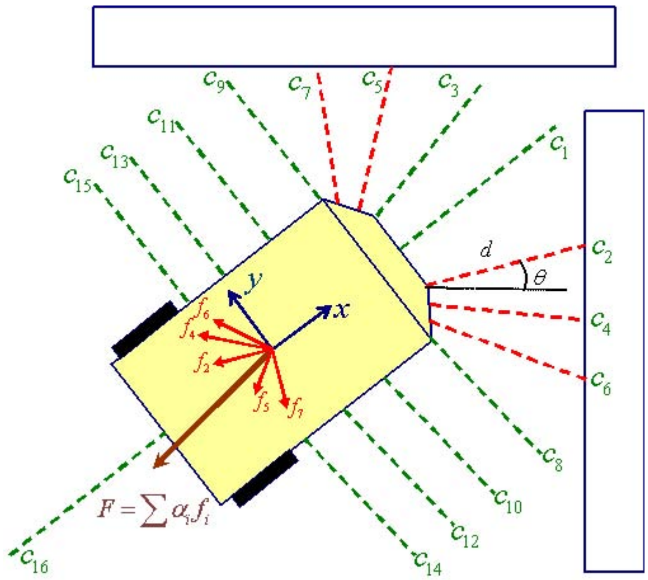

Figure 3: The wheelchair and its distance sensors

0.1m. Based on these measurements, the feedback force is calculated as follows:

$$F = \sum_{i=1}^{16} \alpha_i f_i \qquad (1)$$

where α_i is a constant weight, and f_i is the feedback force corresponding to the i^{th} sensor and is given by:

$$f_i = \frac{1}{d_i} e^{j(\pi+\theta_i)} \qquad (2)$$

d_i and θ_i are the magnitude and the angle of the vector between the i^{th} sensor and the nearest detected obstacle respectively.

It should be noted that other force feedback laws will be considered in future works. The constant weights α_i can be replaced, for example, by a linear or nonlinear function.

3 Computer simulation system

The simulation runs on a PC using MATLAB®/Simulink® from The Mathworks Company. The simulation block diagram is shown in Figure 4. It consists of three main blocks: the joystick interface block, the animation block and the force feedback block.

1. The joystick interface block: it contains a dll file[1] which was created using Mathworks Simulink® s-function technology [1] and Microsoft® DirectX™ technology [7]. It allows reading XY-position of the joystick and applying a spring force with desired magnitude and direction.

[1] A first version of this dll file can be downloaded from http://www.mathworks.com/matlabcentral/fileexchange/loadFile.do?objectId=4629&objectType=file

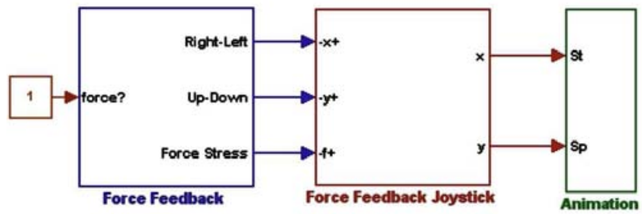

Figure 4: Simulation block diagram

2. The animation block: it contains an M-file which takes the XY-position of the joystick and interprets them as a desired speed and steering according to Figure 2. Then it updates the position and the direction of the wheelchair on the screen if there is no collision with an obstacle (see Figure 5 and Figure 6).

3. The force feedback block: it contains an M-file which reads the sixteen displacement sensors data and calculates the appropriate feedback force according to (1)-(2). The force feedback algorithm is activated if the block input is one, otherwise it will not be activated.

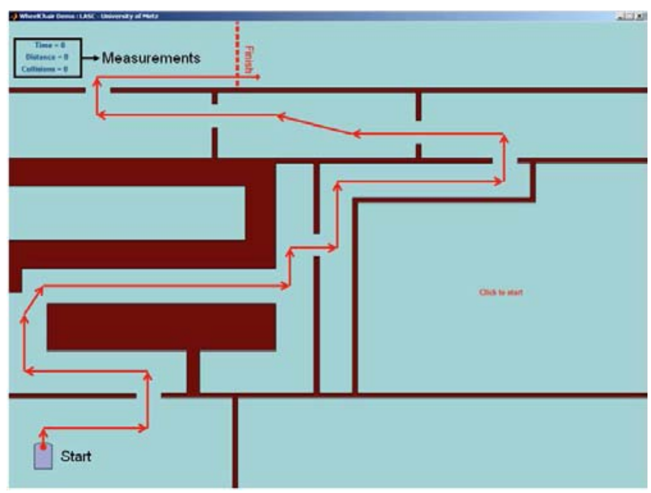

Figure 5: Graphical user interface (GUI) and the test course

The simulation logic used in this work is shown in Figure 6. It starts by displaying the GUI on the screen (see Figure 5). Then it reads the XY-position of the joystick and interprets them as a desired speed and steering (see Figure 2). The next wheelchair position and direction are calculated according to the desired speed and steering and the possibility of a collision with an obstacle is detected for the new position. The new wheelchair position is updated if there is no collision, otherwise the wheelchair color is only changed. At the same time, the feedback force is calculated and applied on the joystick according to the force feedback algorithm detailed in

Section 2. The simulation stops when the wheelchair reaches the final position.

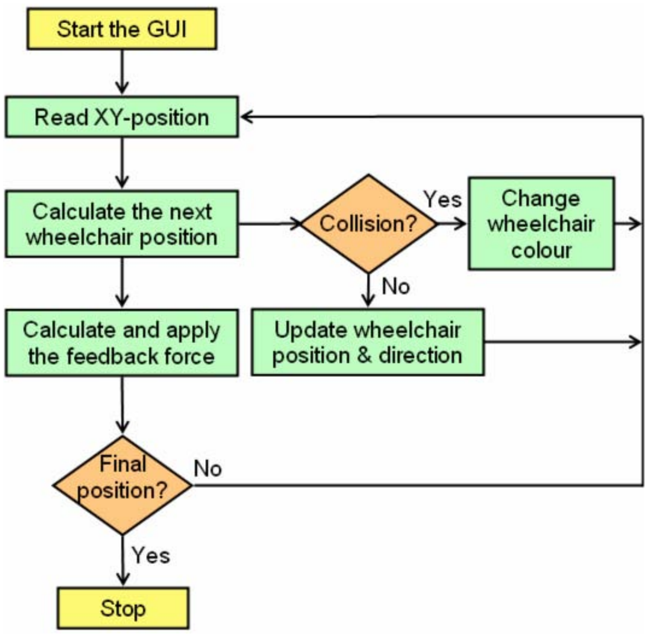

Figure 6: Simulation logic

It should be noted that the algorithm also displays on the GUI the simulation duration, the travelled distance and the number of collisions which will be used to evaluate the driver performance.

Notice that the algorithm detects any possible executing errors and displays an appropriate error message at each step. For example, in the step of reading the XY-position of the joystick, the algorithm detects firstly the presence of a force feedback joystick and displays an error message if there is no force feedback joystick attached to the computer.

4 Application and results

A set of tests has been performed using the computer simulation system described in the previous section. The objective of these tests is to qualify the effect of using a force feedback joystick in driving a wheelchair.

Test subjects used the force feedback joystick to guide a wheelchair through a virtual environment (see Figure 7) with and without the force feedback algorithm activated.

The subjects were all persons without disability. Their performance using the force feedback joystick are measured using the following factors:

1- The time needed to complete a run though the course,
2- The travelled distance and
3- The number of collisions with the obstacles.

The test was carried out on seven subjects. It starts with a training period, where each subject does the test several times with and without force feedback activation. Then six tests are registered for each subject, three without force feedback activation and three with force feedback activation. Finally the mean of registered measurements is calculated and took in consideration to analyze the users performance (see Tables 1 and 2).

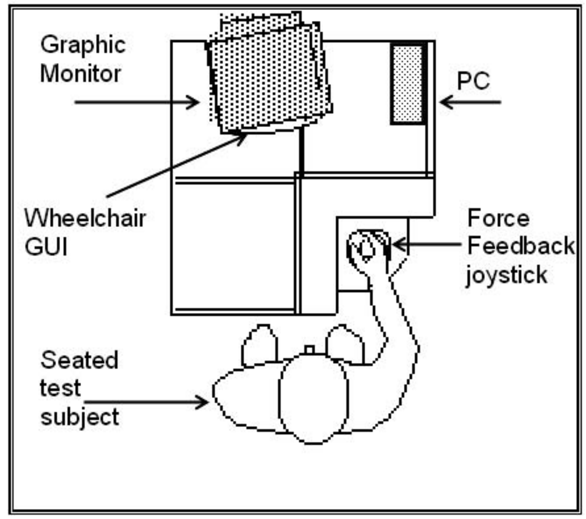

Figure 7: User test configuration

Table 1: Test results without feedback force

	Time [sec]	Distance [m]	Collision
User 1	197.6	54.5	1.7
User 2	161.4	53.9	6.7
User 3	188.7	56.6	6
User 4	203	54.9	0.7
User 5	161.5	53.1	12
User 6	162.1	54.1	6.5
User 7	246.7	54.3	1.7

Table 2: Test results with feedback force

	Time [sec]	Distance [m]	Collision
User 1	193.4	53.8	1
User 2	159.7	52.2	4.3
User 3	183.3	58.7	2
User 4	218.4	53.7	1.7
User 5	189.7	54.2	10.7
User 6	159.7	52.3	5
User 7	298.2	53.7	3.7

The results show that there are fewer collisions when the force feedback algorithm is activated. In the other hand, the distance and time parameters in Tables 1 and 2 don't show significant differences between the two driving modes.

As an example, we show in Figure 8 the travelled courses of User 2 for the two cases: with and without feedback force. It is clear from this figure that the wheelchair trajectory is more smooth when the force feedback algorithm is activated.

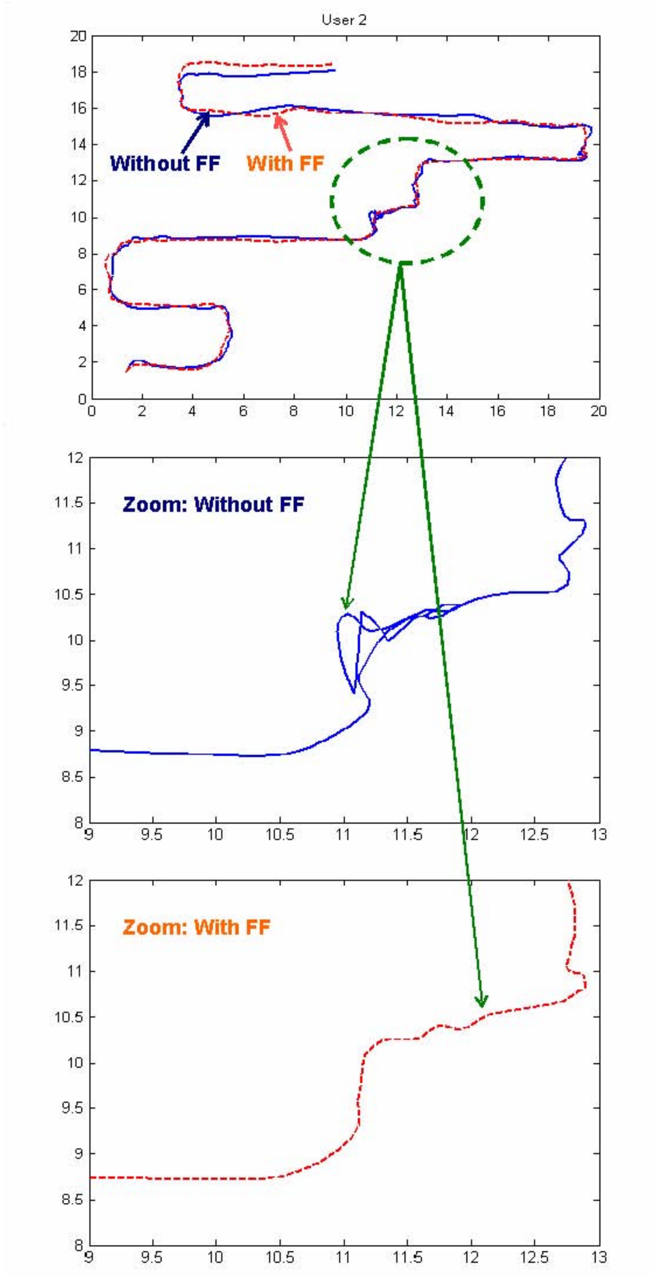

Figure 8: Travelled courses of User 2 with and without force feedback algorithm activation

It should be noted that the evaluation factors used in this work are not independent. For example, the time needed to travel the course depends on the number of collisions. That is, if there are more collisions, user needs more time to accomplish his course. Other independent evaluation factors have to be used in future works.

From a qualitative point of view, all users agree that when the force feedback algorithm is activated, the wheelchair guidance is easier in corridor displacement. In addition, certain persons find also that the force feedback help the door crossing manoeuvre. However, the driver has to initiate first a good trajectory for the wheelchair when approaching a door then the force feedback algorithm will guide the drive to cross the door. It should be noted that our aim in this study is to realize a driving aid not an autonomous wheelchair.

5 Conclusions

In this paper, an evaluation of a force feedback joystick for a powered wheelchair has been performed. The preliminary results on persons without disabilities showed that there are some advantages on using a force feedback joystick. Other force feedback strategies will be considered in future works especially for door crossing. Moreover, the approved strategies will applied practically on our powered Push^{TM} wheelchair and will be tested on users without and with disabilities.

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