Haptic Feedback and Motor Disability : A Preliminary Study

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***Abstract*— The haptic feedback, natural for assistive devices intended for persons with visual disability, has been explored only recently for people with motor disability. The aim of this work is to study its potentialities in this context, and more particularly to assist to the powered wheelchairs control. After a bibliographical study on this question, we propose to model the wheelchair piloting task with an alternative of the classical Fitts law. The goal is to objectively evaluate the interest of a force feedback on the control joystick of an electric wheelchair.**

***Index Terms*— Powered wheelchair, assistive technology, haptic feedback, Fitts law.**

I. Introduction

This work lies within the general scope of assistive technologies for people with disabilities. Within this framework, however functionality is concerned (mobility assistance, manipulation aid, communication aid …), the human-machine interaction seems an essential factor to take into account. Indeed, as for any human-machine system, a dialogue has to be established between the system to control and the user. This dialogue may be made difficult, even impossible, by traditional ways because of motor and/or sensory deficiencies of the disabled person.

Three senses are naturally requested for the information feedback towards the user: vision, hearing and touch. This last one is considered in the broad sense under "haptic" name by including tactile, proprioceptive information (perception of our body, of the position of the members …) and kinesthetic (feeling of the limbs movements). A sensory deficiency may be compensated by the assistive device by calling upon another sense. A mobility aid for blind people will use for example the haptic sense (blind cane) or the auditive sense (telemetric cane which returns a sonic image of the close environment).

The transmission channel from the user towards the assistive device may be also defective because of a motor disability of the person. Then, in some cases, we can use another way than the muscular control by calling upon a voice recognition device. This supposes that the voice of the person is sufficiently understandable. Moreover, this control mode authorizes only discrete orders. It's also possible to strengthen the motor control by haptic information on the level of the human-machine interface : force feedback or tactile information. We propose in this article to study the potentialities of this haptic feedback for assistive technology intended for people with motor disability. We are interested more particularly in the assistance to powered wheelchair driving. Our matter is based on a review of the literature associated with some experiments in simulation.

II. Background

A. Haptic feedback

Many works described in the literature relate to the teleoperation assisted by a haptic feedback. These applications only concern users without disability but, nevertheless, their conclusions are indicative on the potential of the method. Thus, according to Sheridan, the haptic feedback in teleoperation is essential for certain tasks not for others [1]. For a position control in free space for example, and more particularly if the movements are slow, the advantage of the haptic feedback is weak. It is on the other hand essential in handling or assembly tasks. In [2] experiments are carried out in simulation concerning the teleoperation of a mobile base in hostile environment. The authors note a significant reduction in the number of collisions by using a force feedback joystick compared to a traditional one. On the other hand the duration and the length of the paths are only a little modified from one situation to another. A similar experimentation in [3], carried out using a haptic device 3D PHANToM^{TM}, limited to 2D, leads to the same conclusions: the haptic feedback decreases the number of collisions without increasing the duration of navigation significantly. However, measurements of performance are not always sufficient to show the interest of the haptic feedback: in [4], mental workload measurement during a teleoperation of a helicopter leads to the conclusion that certain force feedback functions improve the performance but significantly increase the mental workload.

B. Haptic in rehabilitation engineering

The first applications of haptic in rehabilitation engineering have naturally related to the compensation of the visual disability with in particular the invention of the Braille alphabet at the 19th century. Much more recently appeared softwares associated with force and/or tactile feedback allowing haptic sensations of forms drawn on the screen of a microcomputer. The applications of this principle are very varied: exploration of a geographical chart, of electric circuits, of mathematical curves, of graphic documents on the Web [7], [8]… The force feedback has been also used for assistance to the mobility of persons who cumulate motor and visual disabilities: the Spam prototype (Smart Power Assistant Module) increases the resistance of the pushrims of a manual wheelchair according to the proximity of the obstacles [9]. In the same way, the powered wheelchair describes in [10] returns information from the environment but, this time, by the means of a force feedback joystick.

In the field of assistive technology for people with motor disability the haptic feedback, less natural in this context of application, is a subject of study only recently. Two problems seem to hold the attention of the researchers. The first relates to the access to the computer for people with motor disability having difficulties in using usual pointing devices. Experimentations on people with disability have showed that a force feedback interface could dramatically improve the performances obtained in a pointing task [5]. These results are corroborated by a study described in [6] bearing on a group of 10 people with motor disability. Moreover, the modelling of the coupling between the user and the haptic interface shows that it is thus possible to remove the pathological tremors of certain disabled people [16]. The second problematic, to which our work relates more specifically, relates to the assistance to powered wheelchair driving.

C. Haptic and powered wheelchairs

For many potential users the powered wheelchair control remains indeed difficult, even impossible, because of too severe motor disabilities [11]. A certain number of research teams have endeavoured to remedy to this situation by developing smart wheelchairs [12]. The "intelligence" of the wheelchair may be defined as the capacity to perceive its external environment and to deduce some relevant information in the objective to carry out autonomous or semi-autonomous movements: obstacles avoidance, doors passing, docking, automatic courses, … However the control of a wheelchair in an automatic mode poses two major problems, a technical problem and a psychological one. From the technical point of view, a perfect reliability of an autonomous motion supposes to use a set of sophisticated environment sensors and a heavy data-processing treatment not very compatible with the requirements of such an application as regards cost. From the psychological point of view many potential users on the one hand apprehend to leave the whole control of the movement to the machine, on the other hand wish to use their residual driving capacities as much as possible. A method to remedy to these two disadvantages consists in introducing on the joystick a force feedback, function of the obstacles proximity. We can then speak about an "assisted" control mode: the control of the wheelchair is the whole responsibility of the person, the machine, as a supervisor of the movement, only transmits haptic information to him to enrich the natural visual feedback. In this context the technical and psychological limitations of the automatic mode do not appear any more. However it remains to be shown that the driving performances will be improved to a significant degree compared to a usual piloting of the wheelchair.

Few works of this type are referred in the literature. In [13] a joystick was specifically conceived to test in a whole modelled environment a "passive" force feedback algorithm (the joystick resists to a movement towards an obstacle) and an "active" force feedback algorithm (the joystick moves away the wheelchair from the obstacles). The "active" algorithm being proven more effective, it has been tested on 5 persons with disability [14]: for 4 of them the number of collisions in a course test has decreased compared to a piloting without force feedback. In [15] the authors describe an "active" type algorithm based on the potentials method modified: to circumvent the difficulty in passing the doors with this method, the authors only take into account the obstacles located at +/- 30° in the wheelchair forward direction to calculate the repulsive force.

III. METHODOLOGY

A. Introduction

The objective of our work is to conceive a new control mode for powered wheelchair based on haptic feedback: we apply a force on the joystick function of the obstacles proximity to help the pilot to move towards the free space nearest to the direction which he has selected. This requires to implement range sensors on the mobile base: we'll use for this purpose a smart wheelchair prototype developed within the framework of the VAHM project [12]. Initially we try to validate the interest of the method by experiments in simulation. Comparative tests of virtual wheelchair piloting with and without force feedback were carried out and are described in [20] and [21]. They prove in particular that in certain environment configurations, for passing a door for example, the use of force feedback improves the driving performance. To help to analyze and refine these results we propose to model the control task like a pointing task, using the Fitts' law [18]. A first attempt in this direction was already described in [17] with the objective of comparing two piloting interfaces, an isometric joystick and a traditional joystick. The authors proposed to cut out the driving course of the wheelchair in small segments of 30 cm, the end of each segment constituting the pointing target. We suggest for our part reasoning in a more global way by adopting an alternative of the Fitts' law, the "steering law" [22]. The first validation tests of this law are detailed in what follows.

B. *Fitts Law – Steering Law*

In Human – Computer Interaction (HCI), the Fitts' law [18] is used to model the pointing task on Graphical User Interfaces (GUI). It also models the act of pointing in the real world, using hands or fingers for example. Using Fitts' law, we can predict the time required to move rapidly from a starting position to a final target area.

According to Fitts' law, the average time required to achieve a pointing task is function of (i) the distance to the target and of (ii) the size of the target. The most common form of the Fitts' law is the Shannon formulation for a movement along a single dimension, given by:

$$MT = a + b.\log_2\left(\frac{A}{W} + 1\right) \tag{1}$$

Where:

- *MT* is the average time taken to complete the movement,
- *a* and *b* are empirical constants, depending on the task at hand,
- *A* is the distance from the starting point to the center of the target,
- *W* is the width of the target, measured along the axis of motion.

From equation (1), we can see a speed/accuracy tradeoff in pointing tasks, which implies that small and/or further away targets are more difficult to acquire (and thus, will require more time) than large and/or close ones.

The term $\log_2(A/W + 1)$ is called the Index of Difficulty (ID) and is expressed in *bits*. It describes the difficulty to achieve the task: the greater ID, the more difficult the task. Notice the linear relationship between the movement time and ID:

$$MT = a + b.ID \tag{2}$$

An Index of Performance (IP) or Bandwidth can also be computed from equation (2): IP = 1/b. It is measured in *bit/s*. This measure can be thought of as the human rate of information processing.

Fitts' law is used to model one type of movement and is only valid for the elementary task of hitting a target over certain distance. In HCI, this corresponds to the very frequent task of pointing the various elements of a computer GUI.

However, computer input devices (such as the mouse) are used not only for pointing to targets, but also for producing trajectories in drawing, writing and in numerous other tasks requiring to move the cursor along a specified trajectory. For these tasks, Fitts' law does not make it possible to predict correctly the movement time. Thus, it is not a good model for this type of behaviour.

J. Accot and S. Zhai realized of this limitation in their work, so they brought to the Fitts law some improvements so that it can be used to describe movements implying the follow-up of a trajectory. Thus, they introduced the *Steering Law* [22] which has the same form as the Fitts law but, in this case, ID is given by:

$$ID_C = \int_C \frac{ds}{W(s)} \tag{3}$$

Where:

- *ds* is the curvilinear coordinate associated to the trajectory *C*,
- *W(s)* is the width of the trajectory at point *s*.

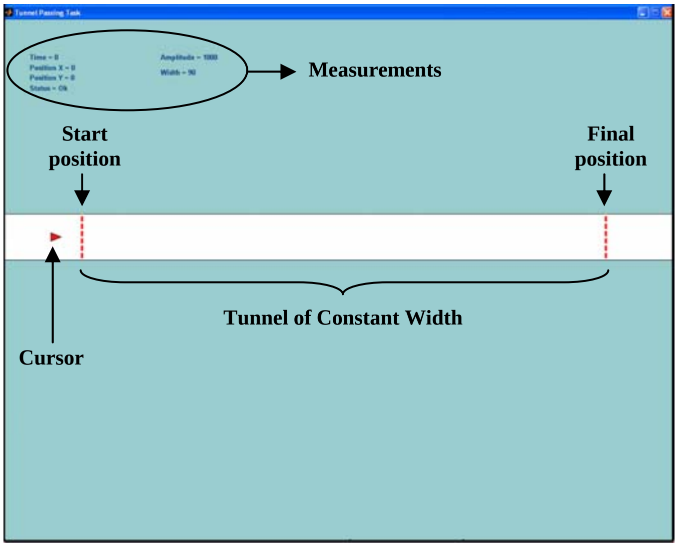
In the particular case where the trajectory *C* is a straight tunnel of constant width *W* and length *A*, equation (3) yields:

$$ID_C = ID = \frac{A}{W} \tag{4}$$

C. *Experimental procedure*

In the experimental part, we studied the effect of the force feedback on different corridor passing tasks. We're seeking here for the validation of the Steering law in the context of driving a simulated electric wheelchair and also for comparing control performances with and without force feedback. The strength of the obtained model is indicated by the correlation coefficient between ID and MT. Comparison parameters are the error rate (collisions number/ total experiments number) and the index of performance IP.

Handlings were carried out using the Microsoft SideWinder™ Force Feedback Joystick 2.



Tunnel Passing Task

Time = 0
Position X = 0
Position Y = 0
Status = Ok

Amplitude = 1000
Width = 90

Fig. 1. Corridor Passing Task
A=1000, 750, 500, 250 (pixels); W = 90, 80, 70, 60 (pixels)

In experiment 1, a GUI was realized to check the validity of the Steering law for a corridor passing task where cursor movements are controlled by the force feedback joystick (figure 1).

In experiments 2 and 3, the GUIs represent corridors similar to some indoor environments where a mobile robot can navigate. The represented corridors have various forms and may include doorway passages (figures 2 and 3).

In each task, the operator must steer the cursor from one corridor's end to the other one. The contacts with corridor's borders or doorway passages are considered as errors (a collision for a mobile robot). A stopwatch starts when the cursor crosses the corridor's left end (starting position) and stops when it arrives at the right end (final position). In the case of error, simulation is stopped and the result is rejected. These GUIs and the joystick control were achieved using Matlab®/ Simulink® and the joystick model developed in [20].

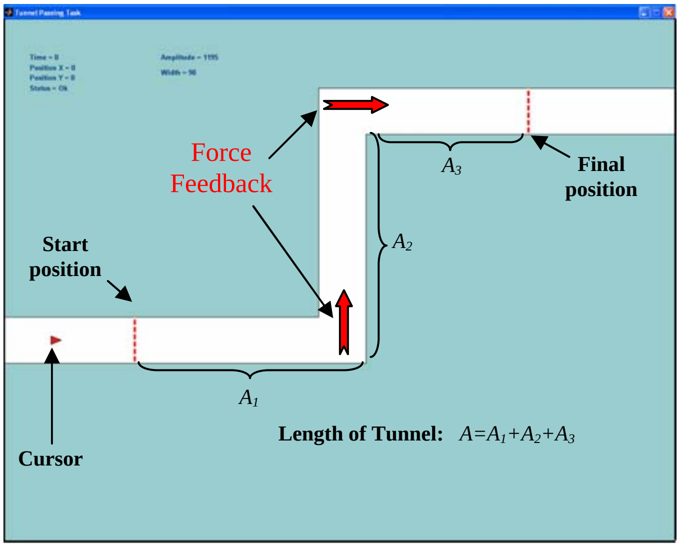

Time = 0
Position X = 0
Position Y = 0
Status = Ok
Amplitude = 1195
Width = 90

Fig. 2. Three Segments Corridor Passing Task
A=1295, 1045, 795, 545 (pixels); W=90, 80, 70 (pixels)

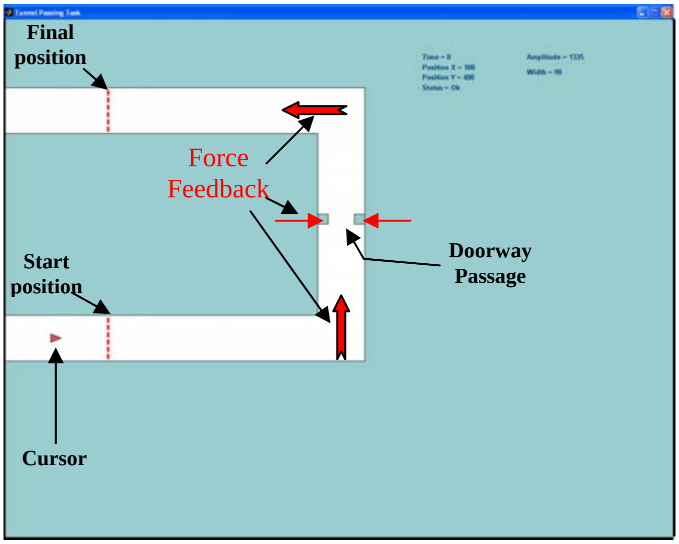

Time = 0
Position X = 100
Position Y = 400
Status = Ok
Amplitude = 1335
Width = 90

Fig. 3. Corridor with Doorway Passing Task
A=1335, 1105, 905, 735 (pixels); W=90, 80, 70 (pixels)

To determine the Steering law parameters, several tests were carried out while varying the ID. For each value of ID, many tests are completed to find out an average movement time and finally, the parameters *a* and *b* are computed by linear regression.

Experiments 2 and 3 were run without and with force feedback to study its effect on movement quality and on the validity of the Steering law. First, the force feedback is disabled. Then, it is activated to guide the cursor towards the directions shown by the red arrows on figures 2 and 3. This force feedback helps the user to take the right direction of motion when he passes from one segment of the corridor to the next one. Moreover, another force feedback forces the cursor to remain within the corridor's borders and not to hit the doorway passage in figure 3.

IV. RESULTS

The results of experiment 1 are illustrated on figure 4. In this case, we obtained $a=0.13231$ and $b=0.39181$, with a correlation of $r=0.99386$. Correlations above 0.900 are considered very high for any experiment involving measurements on human subjects. A high r suggests that the model provides a good description of observed behaviour.

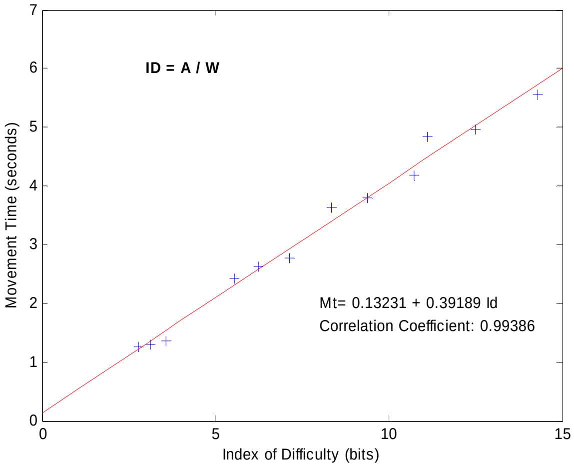


Fig. 4. Scatter-plot of the MD-ID relationship for the corridor Passing Task.

Results of experiment 2, with and without force feedback, are shown by figure 5. The obtained models are approximately identical in both cases. Notice that the correlation is slightly lower in the case of force feedback. Nevertheless, the correlation remains sufficiently high to be a sign that the model well analyzes the task.

We note that in this experiment, the error rate was significantly decreased by the activation of the force feedback, passing from 10.83% to 7.5%. In addition, we compute the IP which passes from 2.36 *bits/s* to 2.52 *bits/s* by activating the force feedback. These two data (error rate and IP) show that the Steering task becomes more powerful with force feedback.

For the doorway passing task in experiment 3, the results are given by figure 6. The models obtained are approximately the same in both cases. The error rate is slightly lower in the force feedback steering task. Note that most of errors occurred at the doorway passage proximities. One future prospect may be the study of cursor trajectories to identify areas where force feedback assistance would be necessary.

The IP in this experiment passes from 2.16 *bits/s* to 2.35 *bits/s* by adding the force feedback. This still indicates a better control performance with force feedback.

The results presented in this paper indicate that the force feedback joystick improves performances in some steering tasks. It has been used for driving the smart wheelchair VAHM in simulation. The obtained results were acceptable [20]. In future work, we'll try to integrate the VAHM dynamics in the simulation to confirm the validity of the Steering law for various indoor environments. This law should be also validated in the real driving task. This supposes that the user has a direct vision of the goal point or that he knows sufficiently the evolution environment in order to be able to carry out a "mental" pointing task.

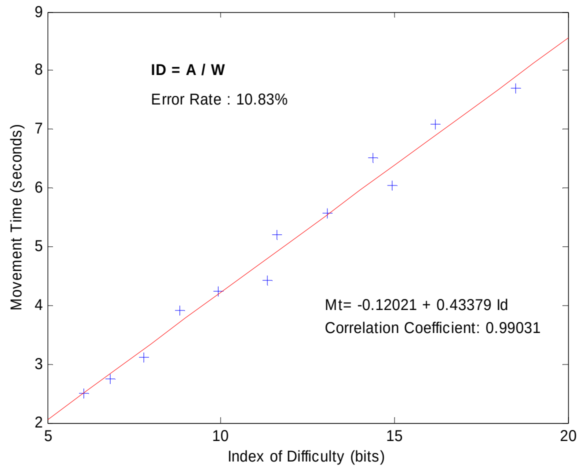


Fig. 5.a. Results of the three segments corridor passing task without force feedback

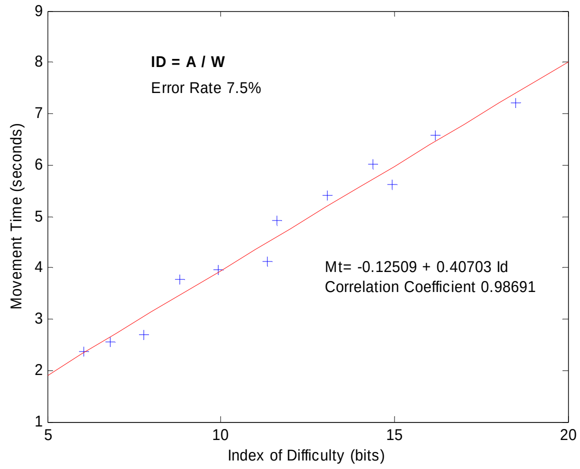


Fig. 5.b. Results of the three segments corridor passing task with force feedback

V. CONCLUSION

We have approached in this article the problematic of the haptic feedback in the control of assistive technology for people with motor disability, and more particularly in the control of powered wheelchairs. An alternative of the Fitts' law, the "steering law" has been applied to evaluate the interest of a force feedback on the joystick to control a powered wheelchair. It should make it possible to compare objectively the performances of the pilot-vehicle system with or without force feedback considering the environment configuration. In this perspective, the first results described in this article are promising.

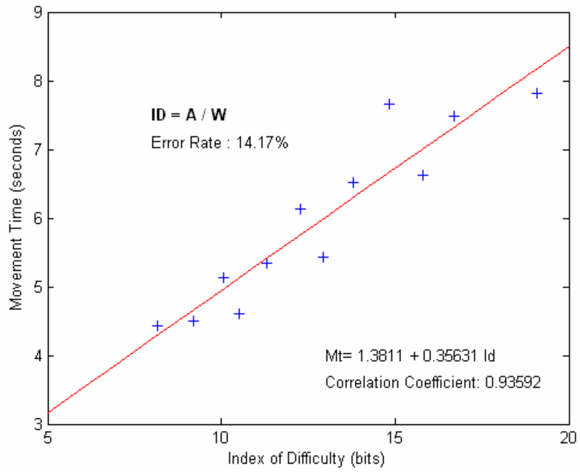


Fig. 6.a. Results of the Doorway Passing Task without force feedback

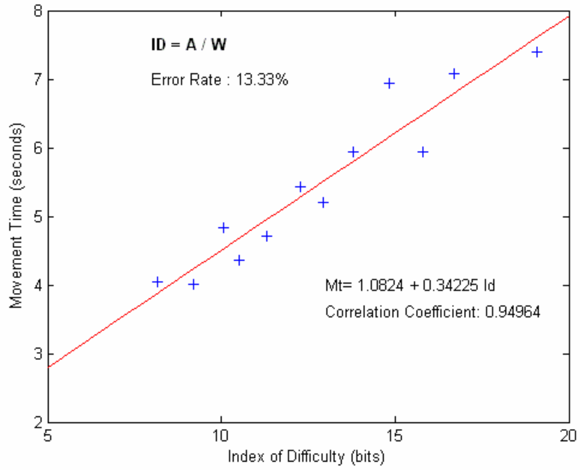


Fig. 6.b. Results of the Doorway Passing Task with force feedback

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