Haptic feedback to assist powered wheelchair piloting

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Abstract: The objective of this study is to implement a force feedback joystick on a smart electric wheelchair provided with a set of range sensors. The force feedback is calculated according to the proximity of the obstacles and help the user, without forcing him, to move towards the free direction. The first stage of the project consists in validating the interest of this method of control. In this paper we present our methodology and some first experimental results.

Key words: assistive technology, haptic feedback, human-machine interaction, electric wheelchair.

Résumé : L'objectif de cette étude est d'implémenter un joystick à retour d'effort sur un fauteuil roulant électrique "intelligent" muni de capteurs d'environnement télémétriques. La force de retour est calculée en fonction de la proximité des obstacles et aide l'utilisateur, sans le contraindre, à se diriger vers la direction libre. La première étape du projet consiste à valider l'intérêt de cette méthode de commande. On présente dans cet article la méthodologie employée et quelques premiers résultats expérimentaux.

Mots clés: aides techniques, retour d'effort, interaction humain-machine, fauteuil roulant électrique.

1. Introduction

A recent American study relating to the interview of 200 rehabilitation clinicians showed that for approximately 10% of patients an electric wheelchair is difficult even impossible to use in the everyday life [1]. Moreover, questioned more specifically on the manoeuvres tasks, 40% of patients report difficulties. However, at the end of the eighties, to alleviate the difficulties of these people, some research teams have tried to give to the electric wheelchair a certain “intelligence” [2], [3]. The “intelligence” of the wheelchair may be defined as the capacity to perceive its external environment and to deduce relevant information in the objective of carrying out autonomous or semi-autonomous movements: obstacle avoidance, doors passing, docking, path following, … If several prototypes of smart wheelchairs with high level functionalities are available in the research laboratories, to our knowledge none has reached the commercial stage [4]. In particular, the control of a wheelchair in 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 sophisticated set of 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 motor capacities as well as possible.

When the physical capacities of the user allow it we can mitigate the problem of reliability by controlling the wheelchair in a “shared” mode: the order and the direction of movement are given by the user, the machine, thanks to its environment sensors (ultrasonic rangefinders usually), helps him to avoid the obstacles. The person is thus always free to stop or continue the movement. This type of assisted control presents nevertheless some limitations. In particular certain movements like pushing a slightly opened door become impossible. The psychological drawbacks of the automatic mode do not disappear either: the person loses the control of the movement partly since he divides it with the machine. This can disturb strongly some users, the direction of displacement being not always that proposed via the human-machine interface.

A method to assist the control of the wheelchair while leaving the pilot his whole free will consists in implementing a force feedback on the control joystick depending on the obstacles proximity. We can then speak about an “assisted” control mode: the control of the wheelchair is entirely of the responsibility of the person, the machine, as a movement supervisor, only transmits haptic information to him to enrich the natural visual feedback. In this context the technical and psychological limitations of the automatic and semi-automatic modes do not appear any more. However it remains to be demonstrated that the control performances will be improved to a significant degree compared to a usual piloting of the wheelchair: it’s the objective of this study.

2. Justification

The control of an “intelligent” wheelchair by a person with disability opens research problematics close to those met in teleoperation [2]. In particular the human-machine interaction is an essential factor to optimize. Thus, many studies have related to the transmission of information from the disabled person who, by hypothesis, has very limited motor capacities, towards an assistive technology device (mobility aid, manipulation aid or communication aid). On the other hand the information feedback from the machine towards the human remains, at the present time, insufficiently explored. It concerns essentially visual feedback associated in certain cases with sound information (voice synthesis). The sense of touch (considered in the broad sense of an “haptic” return i.e. including tactile, proprioceptive and kinaesthetic information), if it is naturally requested for people with visual impairment, is only very rarely used for assisted devices intended for people with motor disabilities. Some work in this way was however reported in the literature. In [6] a joystick was specifically conceived to test in an entirely modelled environment an algorithm of “passive” force feedback (the joystick resists to a movement towards an obstacle) and an algorithm of “active” force feedback (the joystick moves the wheelchair away from the obstacles). The “active” algorithm being proven more effective, it was tested on 5 people with disability [7]: for 4 of them the number of collisions in a course test has decreased compared to a piloting without force feedback. In [9] the authors describe an algorithm of the “active” type based on the potentials method modified: to circumvent the difficulty in passing the doors with this method the authors, to calculate the repulsive force, only take into account the obstacles located at +/- 30° in the forward direction of the wheelchair.

In another context, the human-computer interaction, some tests with people with disabilities also showed that a force feedback interface could improve the performances obtained in a pointing task [8]. These results are corroborated by a study described in [10] bearing on a group of 10 people with motor disabilities.

Other works described in the literature relate to the teleoperation of a mobile assisted by a force feedback. These applications only concern users without disability but their conclusions are indicative all the same on the potential of the method. Thus in [15] experiments are carried out in simulation concerning the teleoperation of a mobile base in hostile environments. The authors note a significant reduction in the number of collisions by using a force feedback joystick compared to a usual one. The duration and the length of the ways on the other hand are only little modified from one situation to another. A similar experimentation in [16], carried out using a 3D force feedback device PHANToM ™ restricted to 2D, leads to the same conclusions: the force feedback decreases the collisions without increasing the duration of navigation significantly. However performance measurements are not always sufficient to validate the interest of the force feedback: in [17], mental workload evaluation during the teleoperation of an helicopter lead to the conclusion that certain force feedback calculation algorithms improve the performance but significantly increase the mental workload.

3. Methodology

3.1 Experimental environment

The force feedback calculation is carried out, by hypothesis, according to the proximity of the obstacles measured by range sensors. An experimentation in real conditions thus requires to get a wheelchair equipped with a set of environment sensors. We'll use the robot resulting from the VAHM project (French acronym for "Autonomous Vehicle for People with Motor disabilities") initiated in 1989 in the University of Metz. The objective of this project is to facilitate the control of electric wheelchairs by using methods and technologies coming from mobile robotics [3]. Two prototypes of this smart wheelchair are currently available, both equipped with a belt of 16 ultrasonic sensors, with a dead-reckoning system and with a computer implemented to the back of the wheelchair.

In a first stage, to be free from the technical problems inherent to the tests in real situation, the experiments are carried out in simulation: the environment is represented in 2 dimensions, the force feedback joystick (Microsoft Sidewinder ™ Force Feedback Joystick 2) moving a cursor in this environment. Simulation is programmed under Matlab/Simulink ™. It is made up of three main building blocks:

- The "joystick interface" block makes it possible to read the position of the joystick and to apply to him a force adjustable in amplitude and direction.
- The "graphic animation" block translates the joystick position into a robot motion which it displays on a 2D animation (Figure 1). The possible collisions are underlines by a change of colour of the mobile. The dimensions of the mobile and of the environment are selected in order to correspond to realistic situations. It is the same for the speed of the wheelchair which maximum is fixed to 0.5m/s.
- The "force feedback" block reads at regular rate the distances data obtained by the 16 ultrasonic sensors and deduces a force feedback on the joystick.

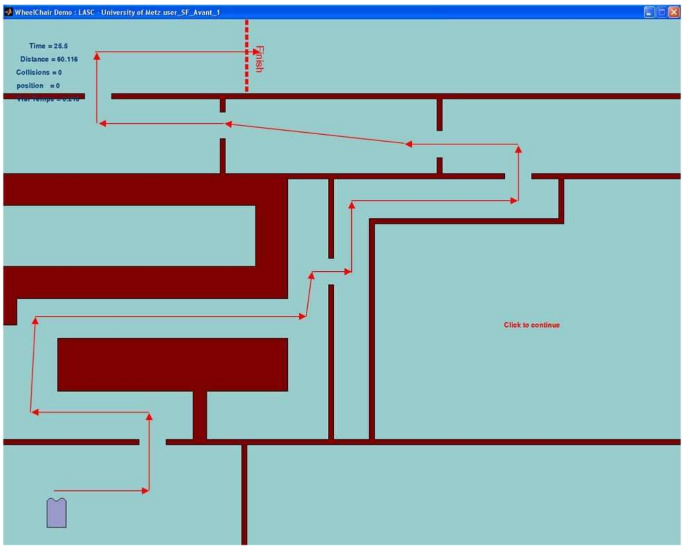

Figure 1. 2D test environment; The task consists in guiding the virtual mobile from the initial position to the final one while endeavouring to minimize the course time and the number of collisions.

3.2 Force feedback calculation

The principle of the force feedback calculation consists in applying a force to the joystick in the most adapted free direction, i.e. the direction which corresponds the "best" to that indicated by the pilot. The main difficulty is to define this direction. It is important to note that this method does not prohibit any movement decided by the person. We only make the motions leading to a collision more difficult.

A first series of experiments reported in [18] have allowed to validate the experimental system. The force feedback calculation was based on the "potentials method": each obstacle detected by an ultrasonic sensor emits a repulsive force inversely proportional to its distance to the wheelchair; the force feedback applied to the joystick is the vectorial sum of all these forces. The results obtained by this method are not very convincing, in particular in very constrained environments (doors passages). This had already been noted in the literature in the context of the shared control of an electric wheelchair [14].

We propose in this paper to calculate the force feedback by two algorithms described in [5] and [14], the VFH algorithm (Vector Field Histogram) and the MVFH algorithm (Modified Vector Field Histogram). They indeed were initially conceived to mitigate the deficiencies of the potentials method and were tested successfully on several prototypes of smart wheelchairs [5], [20]. The principle of the VFH algorithm is as follows:

- We build an occupation grid around the wheelchair, a cell being incremented with each measurement of the presence of an obstacle and being regularly decremented along the time (factor of lapse of memory).
- We deduce a polar histogram (Figure 2) representing the density of obstacles around the wheelchair (the significant values represent close or large-sized obstacles).
- We choose as force feedback direction the free direction nearest to the one indicated by the pilot via the joystick.

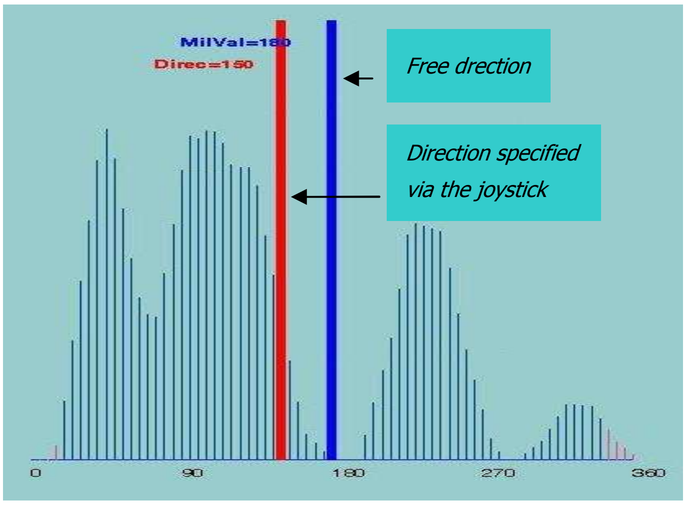

Figure 2. Polar histogram (VFH algorithm): we represent in ordinates the obstacles density in each angular arc of 5 degrees around the robot.

This algorithm was defined initially to carry out a shared control of the wheelchair: the forward direction is then that indicated above as being the force feedback direction. The authors have noted certain difficulties for passing doors of standard size (0,76m for a wheelchair of width 0,63m) and also that, with this method, significant changes in the direction selected by the pilot may not generate any variation of direction of the mobile [19]. Thus they proposed a modified algorithm, the MVFH algorithm, which, during the calculation of the movement direction, minimizes the sum of the histogram and of a parabolic function centred on the direction desired by the person (Fig.3). This one can thus carry out little local deviations of the trajectory. In particular, the door passing manoeuvres are improved by this way.

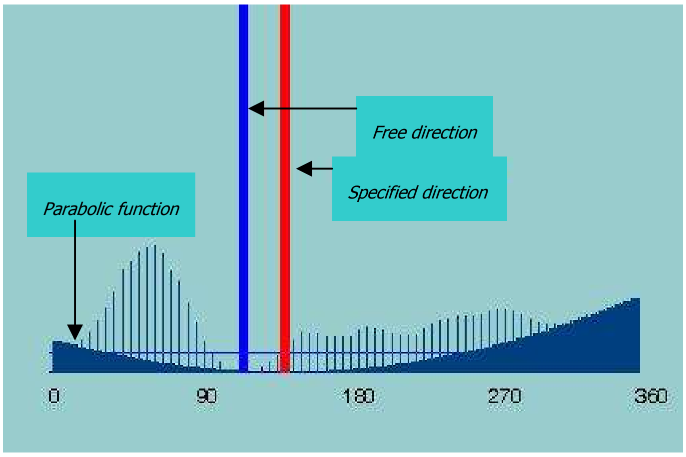

Figure 3. Polar histogram (MVFH algorithm); the polar histogram resulting from the VFH method is weighted by a parabolic function

The application context of our study not being the same one (a force feedback is applied but we don't impose any motion to the wheelchair) we are going to test in what follows two algorithms, the VFH and the MVFH, to confirm or invalidate the results obtained above.

4. Results and discussion

The results which follow concern a panel of 6 experimenters without disability. Each of them, after a training phase, guide 3 times the virtual wheelchair in the test environment of Figure 1 using the joystick according to various experimental conditions: without force feedback ("without FF"), with force feedback calculated by the VFH algorithm and with force feedback calculated by the MVFH algorithm. Moreover each one of these three options is realized with two kinematics configurations for the virtual wheelchair: the driving wheels may be backward or forward, which constitutes an usual option of the electric wheelchairs. In each case we record three parameters significant of the operator performance in the guidance task: the duration of the task, the distance covered and the number of collisions. Of course these parameters are not independent.

First of all, from the observation of the experiments and from the results below we can deduce some qualitative considerations concerning the parameters “Distance” and “Time”. The differences in distances covered, the environment being identical for all the tests, are primarily due to the operations carried out to go out of blocking situations. Thus this parameter is strongly correlated with the number of collisions and does not seem a significant comparison element between the navigation methods. The variations of courses durations seem also difficult to exploit. Indeed they are related to the pilot’s behaviour: if he accelerates the wheelchair, he decreases the duration of the course but he increases the collision risks, collisions which, if they occur, increase the course duration. Additional experiments will be necessary to evaluate the relevance of this time criterion to compare the methods of wheelchair control. However we can henceforth note that generally this parameter of time is smaller with the force feedback than without this one.

On the other hand the number of collisions appears directly related to the control mode. For 5 experimenters among 6 the use of the force feedback clearly decreases this factor. This corroborates the results reported in the literature. Quantitatively, the MVFH algorithm does not seem to bring of significant improvement compared to the VFH. We observe however an appreciably better behaviour of the MVFH in the passages of doors compared to the VFH and conversely in the corridors (the trajectory is less stable).

The results of the 4^{th} experimenter are more atypical: the force feedback decreases considerably its performances considering the number of collisions. This is probably due to the fact that he’s an usual player of video games and, consequently, he’s particularly skilful to use the traditional joystick to guide a mobile. This observation does not call into question the utility of this study since it is intended to people which have difficulties in the electric wheelchair control using a traditional joystick.

Table 1 presents the results for the two basic kinematics configurations for an electric wheelchair: rear and front driving wheels. The strategy of navigation is very different according to the configuration but this fact doesn't influence the remarks made above. This will have undoubtedly to be confirmed on more specific tests in very constrained environments.

Lastly, to try to evaluate the comfort of navigation, it is planned for the continuation of our experiments to associate the usual performance criteria an estimation of the person mental workload. A method containing questionnaires, the NASA-TLX method ("Task Load Index") [13], might be used for this purpose.

Operators	Joystick	Collisions (RWD)	Distance(m) (RWD)	Time (s) (RWD)	Collisions (FWD)	Distance(m) (FWD)	Time (s) (FWD)
1	Without FF	15	620	122	12	647	133
	VFH	10	584	111	7	607	115
	MVFH	3	588	107	8	628	124
2	Without FF	11	638	161	16	609	157
	VFH	9	604	168	8	658	131
	MVFH	11	637	181	9	643	125
3	Without FF	29	695	160	39	727	205
	VFH	15	593	121	25	662	158
	MVFH	10	597	111	18	679	157
4	Without FF	1	583	119	1	628	144
	VFH	7	581	112	1	606	113
	MVFH	4	588	108	7	613	115
5	Without FF	15	586	123	13	678	180
	VFH	11	585	128	9	629	144
	MVFH	3	588	121	22	669	152
6	Without FF	20	587	108	15	639	123
	VFH	9	578	101	3	612	111
	MVFH	7	600	109	6	618	109

Table 1. Experimental results for a rear-wheel drive wheelchair (RWD) and a front-wheel drive wheelchair (FWD) (the values indicated are averages on 3 tests)

5. Conclusion

The project above described aims at conceiving a new control mode of electric wheelchair. It is intended for people for whom control by a traditional joystick (or any other adapted sensor) is difficult or impossible because of too severe motor disabilities. It is initially a question of validating the interest of a force feedback to assist the wheelchair control. The first tests reported in this paper have been related to a panel of people without disability in order to elaborate the experimental apparatus and the algorithms. This system being a simulator, it will make it possible to carry out experiments with people with severe motor disabilities without the constraints of safety and reliability which the tests in real conditions imply. If the interest of the “assisted” control mode is validated by the experiments in simulation, the final stage of the project will consist in transposing this system on the smart wheelchair VAHM.

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