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Powered Wheelchair Simulator : Application to People with Multiple Sclerosis

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Abstract

This study presents the first results of the driving analysis on powered wheelchair (PW) of people with multiple sclerosis using a simulator (ViEW). In order to guarantee the security of the patient and his entourage in the use of a PW, it is important to evaluate his driving capacities. The simulator allows to measure driving data in secure environment. They are then analyzed to extract objective parameters for evaluation. After the study of elementary indicators like the run time and the collisions number, the study of the joystick command will allow us to define other time and frequency indices. The goal is to know if the use of the ViEW simulator can help us to identify difficulties or an impossibility of driving a PW in a secure way because of cognitive or driving disorders.

Key words: Simulator; Powered Wheelchair; multiple sclerosis.

1. Introduction

Powered wheelchair (PW) became an essential mobility assistive technology for people with severe motor disabilities. It can however tend to be dangerous for oneself or the others in the event of poor control. Its use involves evaluating the control skills of the person, for example at the time of medical wheelchair prescription or in the case of an evolutionary pathology, with various stages of the evolution of the disease. It also supposes a personalization of the wheelchair: choice of the sensor for human-machine interface and setting of the joystick control parameters.

Driving experiments on real wheelchair can lead to safety issues and it is technically difficult to extract some obvious quantitative parameters such as variations compared to an ideal trajectory. For these reasons, since the beginning of the nineties numbers of studies are related to the design of PW simulators. They allow to test and evaluate simply various situations of control with a PW in full safety [1], [2], [6], [7], [8]. However, they not became of everyday usage in rehabilitation. Initially conceived mainly in 2D, the environments are now developed in 3D thanks to the evolution of the 3D design software and the increase in the computing power of the computers. A visual information feedback towards the person is provided by one or multiple screens [3], or with a Head Mounted Display [5]. To increase the immersion in the virtual environment one can plan the design of a platform to allow a kinesthetic information feedback [3], [4].

Measuring in a simple way various indices of driving performance through acquired data is one of the main simulator interests: achievement duration of a driving task, numbers of control command on the joystick, [7], spectral analysis of these movements [9], mean velocity, average deviation compared to a reference [10] or compared to a trajectory considered as optimal [9], length of a trajectory, number of collisions [11].

Within this general framework of the evaluation in simulation of the performances of PW control, this study relates to people with multiple sclerosis. This disease is evolutionary (succession of phases of aggravation and remission) and is characterized by various clinical pictures. Difficulties to walk are frequent and can require the use of a manual or an electric wheelchair. However the PW control can be disturbed by the weakness or tremor of the limb which control the joystick or by cognitive disorders, in particular difficulty concentrating (sustained attention and divided attention) and difficulty in planning. It then appears important for safety reasons to regularly evaluate the capacities of control of the person with multiple sclerosis. A PW simulator can be, in this context, a good tool for facilitating the achievement of safe and reproducible experiments with quantifiable performances. The objective of this study is then, starting from the realization of imposed courses in simulation, to extract parameters allowing to evaluate the quality of control command of the person.

After a description of the ViEW simulator used in our study, one will present the experimental methodology used and the results obtained with a panel of 21 people with multiple sclerosis.

2. Methodology

2.1 ViEW simulator

The 3D wheelchair simulator ViEW (Virtual Electrical Wheelchair) designed in our laboratory has several aims : 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 [12], [13]. To facilitate the diffusion and the experiments with the simulator in various rehabilitation centers we chose a “software only” development. 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 used in this study is a traditional wheelchair joystick (or a functional equivalent) (Figure 1).

Fig. 1. ViEW simulator

A 3D environment reproducing a part of the CNRF (Neurological Center and of Medical Rehabilitation of Fraiture-in-Condroz, Belgium) where the experiments took place was developed specifically for this study (Figure 2). During the experiments one records the elapsed time since the beginning of simulation, the successive positions of the virtual PW, the actions of command on the joystick, the collisions and the selected range speed.

Fig. 2. Simulated environment of the CNRF

2.2 Experimental method

The experiments related to a sample of 21 people, 11 men and 10 women, with multiple sclerosis, divided into 2 groups. Group 1 has been made up with people already using a PW for at least 6 months, the group 2 with people having never used a PW. Each one of these groups is divided into 2 sub-groups: the sub-group A consists of patients not suffering from cognitive disorders, the sub-group B of patients suffering from cognitive disorders. The criterion of inclusion in the sub-group B is to have at least 4 shortfall fields in the Tests of Evaluation of Attention (TEA [14]) from 6 items tested: divided attention, flexibility, phasic alertness, eye scanning, negligence, incompatibility, field of vision.

The distribution of the people in the sub-groups is the following one:

Group 1 sub-group A: 6 patients

Group 1 sub-group B: 4 patients

Group 2 sub-group A: 6 patients

Group 2 sub-group B: 5 patients

Each person of each group follows 6 experiment sessions of 45 minutes maximum each, 3 in real PW driving and 3 in simulated PW driving. Each session (with real or virtual PW) starts with 5 minutes of initial familiarization to the control of PW : a “ slalom course” between cones (only for sessions 1 and 3 in reality and virtual) and a “complete course” including a slalom between 7 cones, turn right twice, turn left 3 times, ,4 doorways (90 cm wide and 80 cm wide, width of the PW is 67cm), 2 half-turns on the right and 2 on the left, 4 free half-turns, entering and exiting an elevator by right and left side, driving backwards twice and in straight lines twice too. The initial slalom followed by the 1st turn on the right ("course 1") is identical in reality and in the virtual environment. The following course is made up of the same difficulties in the two environments but the distances to be covered are different. In real driving, the human obstruction and hardware cumbersome are variable according to session contrary to course 1 reserved for the experiments.

Several experimental biases have to be noticed before analyzing the results. The ViEW simulator has only one screen, so the peripheral vision is reduced. This induces a higher number of collisions during virtual driving than in real driving. In addition the people of group 1 (use of a PW for more than 6 months) have good skills in driving real PW. This level of training was not possible to reproduce in virtual driving in the time of the study. Finally Range speed 1 (minimal speed range) was imposed to all patients during real and virtual driving in order to be able to compare the data of all people. This choice a contrario could bias some behaviors of control in particular for the experienced users of PW, used to more important speeds.

3. Results

3.1 Elementary parameters: time and collisions

Two basic parameters were measured during each course to exhibit the overall performance of a person : the overall duration of the course and the number of collisions. These results are presented in Table 1 for course 1 and in Table 2 for the complete course. One computed the average values on the 3 courses achieved by all the people of the same sub-group in real driving and virtual driving. In the sub-group 2B, few people failed to achieve some courses within the time limit. In this case the corresponding performances were not accounted.

TABLE I. AVERAGES OF TIMES AND COLLISIONS NUMBER FOR THE COURSE 1

Sub-groups	Time (real course)	Time (virtual course)	Collisions (real course)	Collisions (virtual course)
1A	38 s	89 s	0.06	3.3
1B	46 s	115 s	0.22	2.4
2A	74 s	68 s	0.33	3.1
2B	84 s	207 s	0.53	7.4

TABLE II. AVERAGES OF TIMES AND COLLISIONS NUMBER FOR THE COMPLETE COURSE

Sub-groups	Time (real course)	Time (virtual course)	Collisions (real course)	Collisions (virtual course)
1A	378 s	926 s	0.3	19
1B	504 s	1099 s	1	35
2A	753 s	890 s	1.8	31
2B	1102 s	1430 s	4.5	51

In real environment, course 1, the average time of the sub-group 1A (experienced drivers with few cognitive disorders) is, with no surprise, the weakest and the sub-group 2B (non-PW users with cognitive disorders) the most important. The sub-group 1B (drivers with cognitive disorders) outperform the sub-group 2A (non-PW users with few cognitive disorders). This same performance hierarchy remains if one considers the parameter of collisions number.

In virtual environment the best time performances are obtained by the sub-group 2A followed by the sub-group 1A. This unexpected hierarchy is due to two aberrant values from people of the sub-group 1A during their first test. It is probably due to a lack of exercise. The cognitive disorders of the people of the group B lead to more important driving times than those of the group A (1A versus 1B and 2A versus 2B). This is not the case for the collisions number of 1A vs 1B for the same reasons referenced above.

For the complete course in real environment the obtained values are only indicative because of variable obstruction of the environment during the drive. However we denote the same global trends as for course 1. In particular a clear differentiation between the sub-groups of people with or without cognitive disorders (1A vs 1B, 2A vs 2B) for the run time and the number of collisions raises up. In virtual environment in the case of the complete course, one notes this differentiation remains. The increase number of collisions is essentially due to the lack of peripheral vision.

3.2 Analyzes of the joystick control

The study of the joystick control will allow us to define quantitative indicators of the driving skills of the users. In this part we deal with the course 1 (see figure 3) and we will use time and frequency indicators based on the data gathered during simulation:

the angle and the amplitude of the the joystick control by computing the standard deviation and the average on all the achieved courses. These two parameters allow to emphasize the variations (oscillations) of the command.

a frequency analysis of angle data to detect different control modes and to differentiate between groups. This type of method was used in [15]. The spectral study of the measured angle quantifies the fluidity of the action of a user on the joystick.

The data collected on the simulator represent more than 400Mo. The analysis was achieved using Matlab.

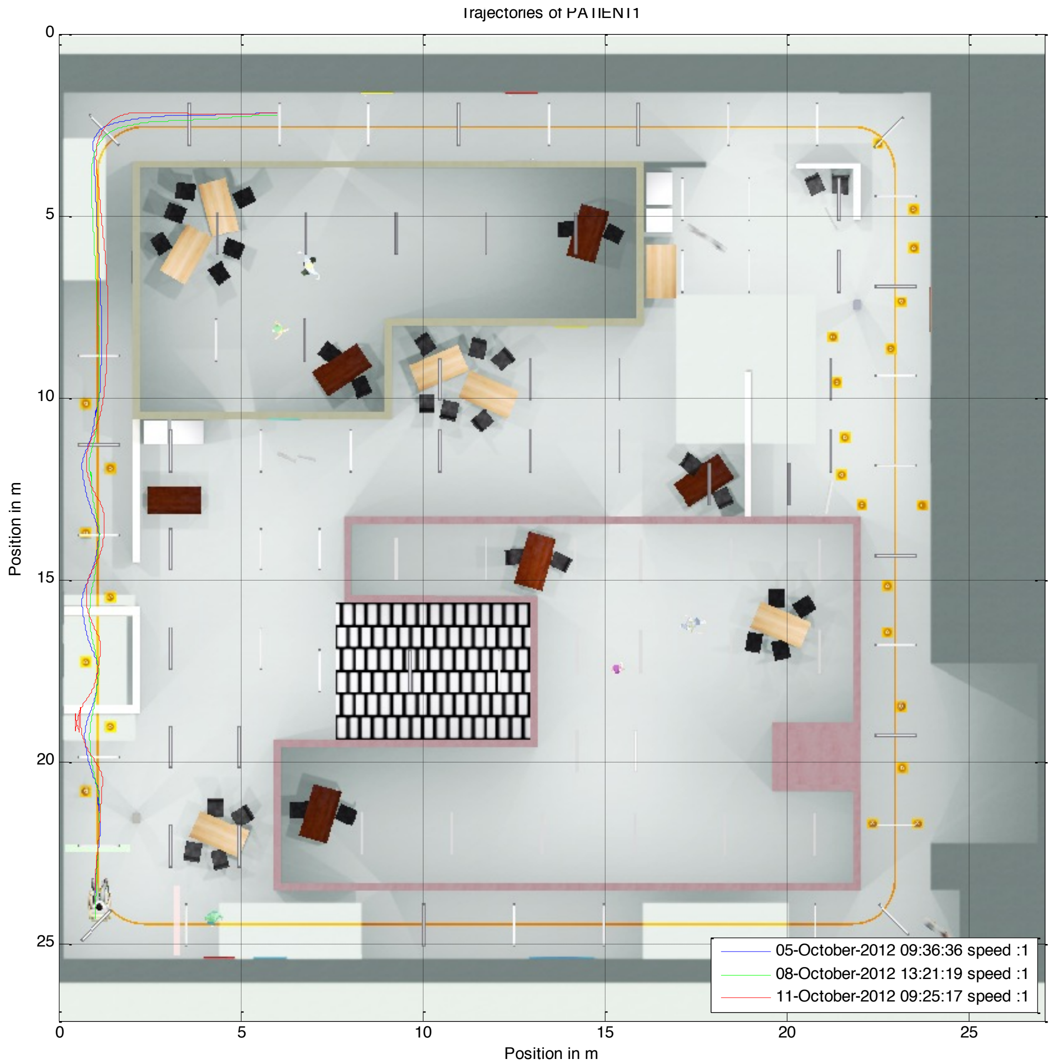
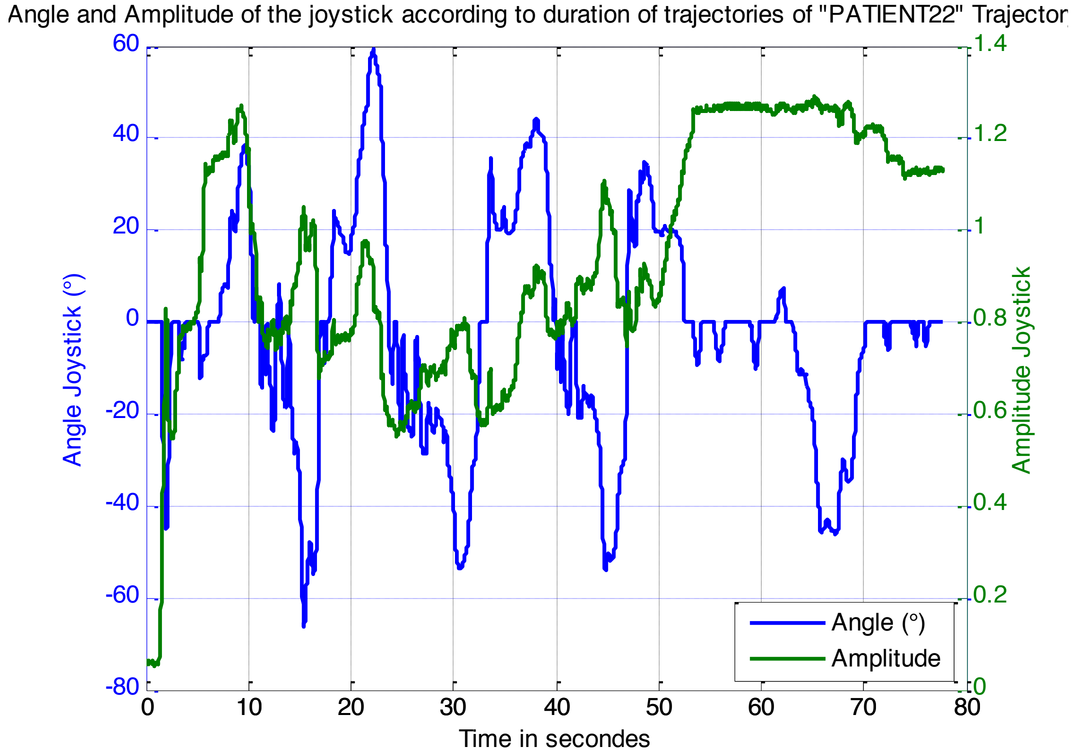


Fig. 3. Course 1 of patient 1

3.2.1 Amplitude and standard deviation

The data of angle and amplitude imposed on the joystick can be represented in a temporal way as described in figure 4.



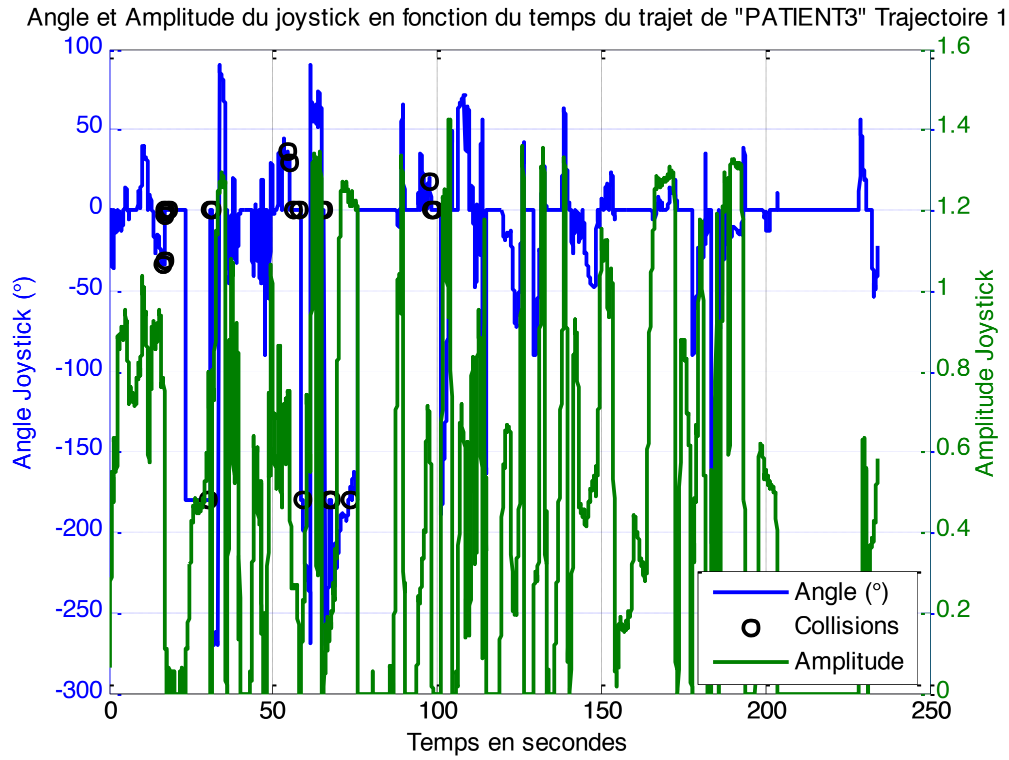


Fig. 4 : Angle and amplitude of the joystick for the course 1 of patients 22 (1A Group) and 3 (2B Group)

These two figures show clearly, for the same course, very different actions on the joystick. This is partly due to the effect of the collisions, but for patient 3, on the second part of the course which does not count a collision, the control mode remains identical.

In order to synthesize the data of the all 22 patients, we computed averages on all the trajectories of each user, then on each user group too for the following parameters: average and standard deviation of the amplitude, average and standard deviation of the angle. All results are given in figure 5 for the amplitude of the joystick and in figure 6 for the angle.

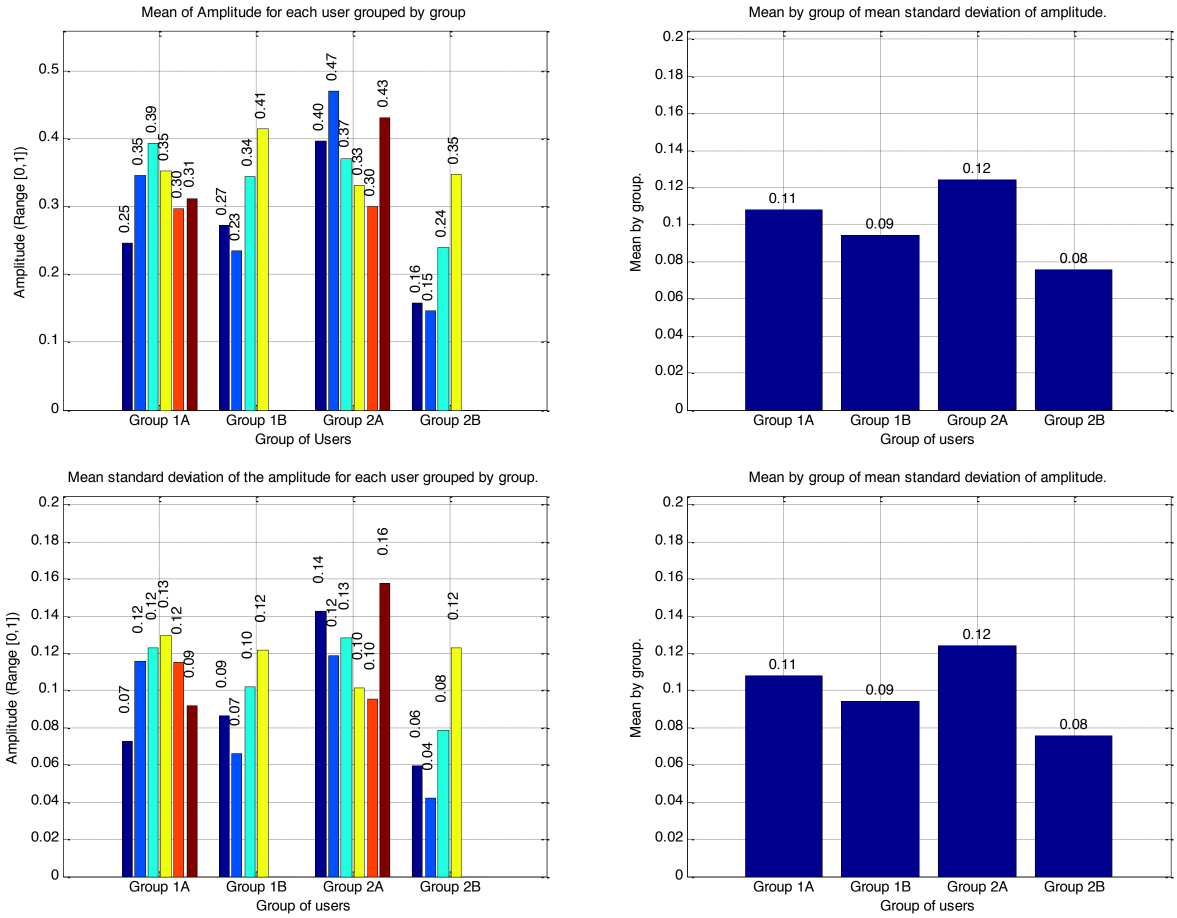


Fig. 5 : Average and standard deviation of the amplitude of the joystick on all users courses

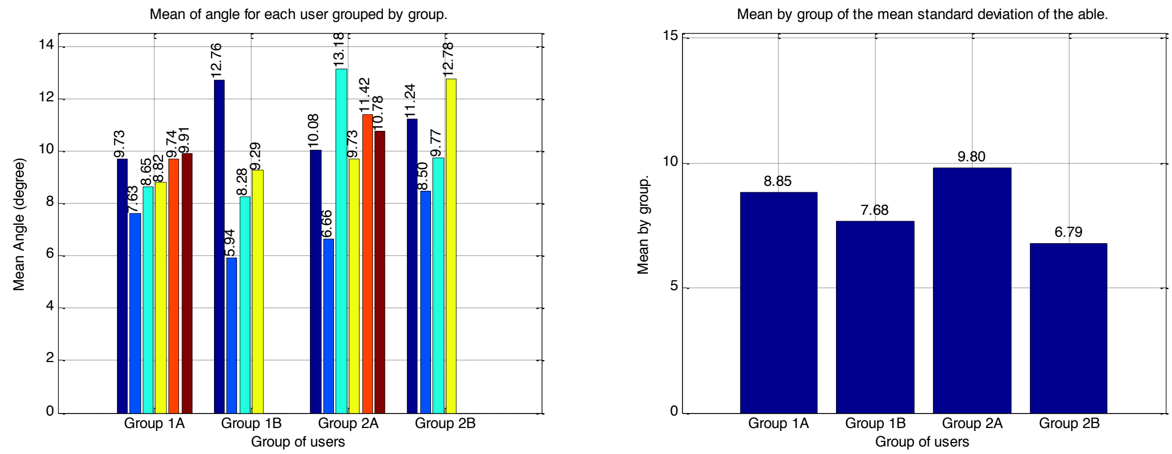


Fig. 6 : Standard deviation of the angle of the joystick on all users courses

The first remarkable thing is the strong interindividual disparity in the user groups. We however try to detect a trend by computing averages by group on each parameter. As the amplitude imposed on the joystick is concerned, one can notice a very small difference between the 1A group (patient without cognitive disorders) and 1B (patient with cognitive disorders).

This difference is more pronounced on group 2: it seems that the patients with cognitive disorders achieve smaller amplitudes on the joystick than sub-group A (without disorders). As standard deviation is concerned, it seems that the patients of the groups B operate on the joystick weaker displacements around the average value (which is weaker too) than the patients of groups A. This causes lower speed of driving and longer run times.

The figures on angle averages show similar results for all groups. Indeed, for an identical course, the average angle of the joystick is almost identical. For the standard deviation of the angle, the conclusions are a repetition of those made for the amplitude. The patients of the groups B tend to achieve minor direction changes around the average position than those of group A.

3.2.2 Spectral analysis of the angle

The transformation in the frequency domain of our data leads to a problem: we have a non-regular sampling of the data. When the frame rate decreases (in the case of a 3D scene with a lot of objects), acquisitions are not regular any more. It is not possible any more to use the standard Fourier transform. To address this issue, one can achieve a spectral analysis of data sampled not uniformly thanks to the method of Lomb and his Matlab implementation FastLomb [16, 17].

Figure 7 shows, as an example, the frequency spectrum of course 1 of patients 22 (1A group) and 3 (2B group). One can notice many differences between these two curves. For the user from group 1A, the curve is smoothed and presents only some frequency peaks, a main one in low frequency and three smaller ones in the higher frequencies. The spectrum of the user from the group 2B has a maximum in low frequency but also many peaks of high amplitudes in the higher frequencies.

In order to sum up these results, we compute an integral on the periodogram as follows :

$$I_{freq\_max} = \int_0^{freq\_max} P_N(f)df$$

The frequency $freq\_max$ was empirically chosen to 0.04 Hz. This allows to highlight a control mode of the joystick. An important energy in this low frequencies range shows that the user does not achieve fast direction change on the joystick.

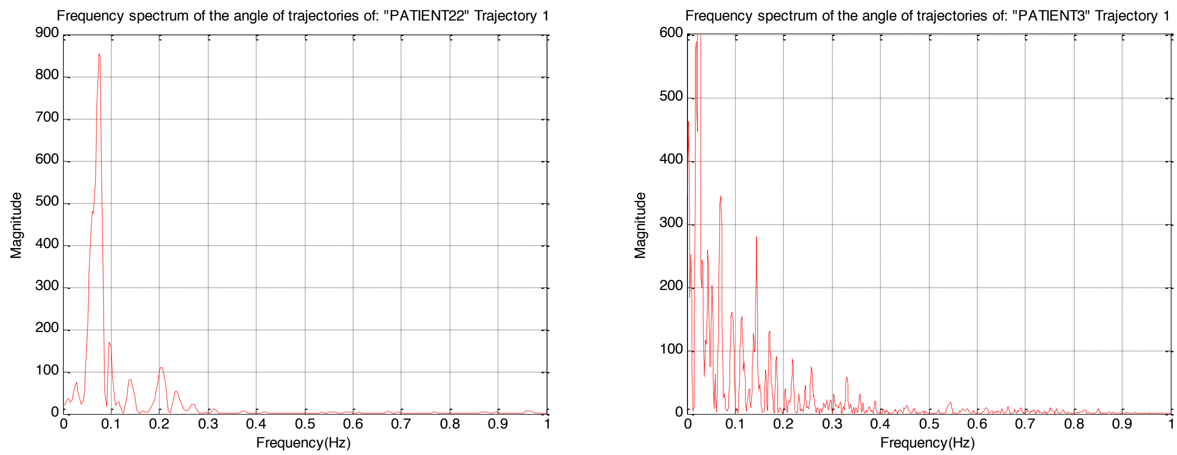


Fig. 7 : Frequency spectrum on the range [0Hz-1Hz] of courses 1 of patients 22 (1A group) and 3 (2B Group)

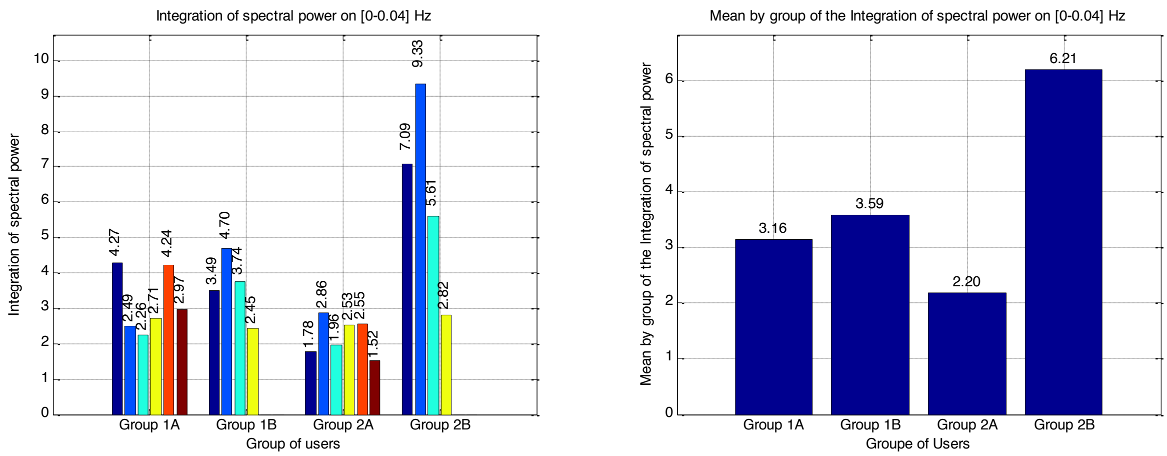


Fig. 8 : Integral of the angle spectral power of the joystick on the range [0Hz-0.4Hz] for all courses 1 of all users

This value can be used like an indicator of driving without jerk. Higher figure 8 presents the integration of the spectral power between 0 and 0.04Hz on all courses of each user. Lower figure 8 presents these same data but sum up by users group.

On this frequency range, the interindividual disparities are always present in each group. The indicator allows to differentiate very clearly the sub-group 2B from the others ones.

Discussion

The main question to which this study seeks to answer is to know if the use of the ViEW simulator allows to identify in an objective way, the difficulties or an impossibility of driving a PW in a secure way because of cognitive disorders. We can note that an analysis of the driving strategies is completely possible in simulation. Thus an easily observable behavior, the half-turn, proved to be similar, whatever the group, during real and virtual driving.

In addition, quantitative information were extracted from these experiments. According to the results presented, it would seem that, in addition to the elementary parameters like run time and number of collisions, the standard deviations on the amplitude and the angle of the joystick command are usable to differentiate the groups A and B.

It can be noted that the collisions generate parasitic behaviors from the user and thus biases time and frequency analyzes. However collisions remain a very good indicator of the level of control. One could restart the whole study by including only the courses without collisions.

As the spectral analysis is concerned, the choice of the frequency range achieved empirically. Patients with cognitive disorders concentrate a greater power in this range than the patients of groups A. Their main movements seem to be slower.

Conclusion

The objective of this article was to present our first results on the analysis of driving a PW in the case of people with multiple sclerosis. We can conclude that we can evaluate quantitatively the capacities of controlling a PW using a simple software simulator. Various parameters were proposed for this purpose. They will have to be validated by other series of experiments.

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