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Robotics at the service of wheelchair mobility for people with disabilities: story of a clinical-scientific partnership

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Abstract

The mobility of people with motor disabilities combined with sensory or cognitive disabilities, sometimes leads to safety issues that make independent travel impossible. In this context, teams based in Rennes in the west of France have been working together for several years to design two devices: - an power wheelchair simulator to promote learning to drive in an immersive virtual environment - a driving assistance module that can be added to an power wheelchair to pass and avoid obstacles. This transdisciplinary work was made possible by the geographical and human proximity of the scientific, technical and clinical teams in order to best meet the needs of the end users who were integrated into this co-design approach. This article describes the evolution of this work and future prospects.

power wheelchair, driving assistance, driving simulators, neurological impairments,

1 Introduction

Most of people with disabilities need help to move but also to use mobility technical aid. These aids can be assistive, such as canes or walkers, or can even supplement the action such as when using wheelchair. In this context, a Power Wheelchair (PWC) may be the only solution to enable people with severe limitations to perform long and safe trips, allowing them to be more mobile and independent. The benefits of using a wheelchair with this population have already been demonstrated: an improved mobility and participation, a reduced caregiver burden, and a reduced likelihood of referral to long-term care facilities. However, while only 10% of wheelchair users have powered models, 25% of accidents are related to their use. In addition, because of cognitive or behavioral disorders or because of a motor deficiency that is too disabling (uncontrolled movements, non-functional spasticity, etc.), it is not always possible to be eligible to use a wheelchair. This is related to the risk of facing a difficult situation or being a danger for the surrounding people, despite regular training in a rehabilitation center with occupational therapists. In 2006, 100,000 accidents involving wheelchair users were recorded in the United States. Edwards [EM10] reports a 21% annual accident rate among wheelchair users in Australia in 2010. 54.7% of subjects in Chen's Taiwan study [CJW⁺11] (2011) reported having at least one crash in the past three years. The risk of accidents involving a collision is thus one of the main problems reported, and is strongly linked in particular to environmental factors (obstacles, quality of the road) and human factors (difficulties related to the disability, or the behavior of others). This has major consequences for health and social participation.

Yet the importance of improving quality of life, users' autonomy, and social inclusion has been highlighted by Helal [HSMA08] and Edwards [EM10]. In this context, encouraging learning and driving in safety, scientists of INSA Rennes and clinicians of the rehabilitation center Pôle St Héliier in Rennes combine their skills in order to improve mobility for people with disabilities since 2011 [RFL18] [MPL⁺20]. They developed 2 assistive technologies: a smart power wheelchair and a virtual reality simulator to learn driving. These devices were created and tested following a users-centered approach through this partnership [VGD⁺19] [LFB⁺20]. This trans disciplinary approach required human and geographical proximity. All teams are based in Rennes in Brittany in France and know well each other. Collaborative work required the adoption of a common clinical and technical language

while respecting each other's expertise and listening to wheelchair users to formulate their needs in terms of technical specifics. Cross-theses were carried out: a roboticist in a thesis immersed in the rehab center, a physician in the computer laboratory. cross-theses were carried out: a roboticist in a thesis immersed in the rehabilitation centre, a doctor in the computer laboratory. This paper combines the results of 10 years and opens the next perspectives of development.

2 Virtual simulator to promote learning to drive

This PWC simulator is composed of three connected parts: the platform moving at four degrees of freedom (pitch, roll, yaw, and heave) composed with a Quickie salsa M2 seat, a joystick to drive the wheelchair in the virtual environment and one interface. The driving simulator was developed by computer science researchers from the INSA Rennes. These circuits were modelled in 3D using Unity game engine to create three test scenarios in virtual reality (VR). Vestibular feedbacks were generated by a mechanical platform for entertainment and simulation D-BOX - Gen II Actuators 1.5. The interface can be VR HMD (HTC Vive Pro) ?? or immersive room [DBN+17] [VDP+21] ??.



photograph of the power wheelchair



simulator in the Immersia platform : view of a street in the Rennes center
photograph of the power wheelchair simulator with virtual reality helmet

A first randomised controlled trial validated the comparison between driving in the virtual reality simulator and in real life on a racetrack among regular electric wheelchair users. The number of collisions and travel time were similar on 31 PWC users [FLP+22]. A second trial compared 4 different virtual reality interfaces : 2 immersive one (platform moving with VR helmet or in an immersive room) and 2 non immersive (platform moving with computer screen or PWC with computer screen). The main criterion was the number of collision during 3 courses in an indoor traffic situation modelled in 3D. Number of collisions, time of completion, cognitive load, sense of presence and cybersickness were assessed. 25 participants who were expert drivers with neurological disorders were included in the study ???. Participants had a better performance and a higher sense of presence using a HMD (head mounted device) or an immersive room than using only screen, thus highlighting the benefits of a high level of immersion. The cognitive load was not affected by the visual condition.

Variable	CAVE n=23	screen n=24	HMD n=22	simscreen n=92	Overall	Krusk (p
[h!] Collisions	10.33 (9.23)	25.81 (18.14)	13.45 (15.07)	24.43 (18.50)	18.45 (16.81)	< 0
Time (sec)	290.50 (110.42)	335.04 (119.75)	272.14 (98.19)	364.29 (130.96)	315.16 (118.94)	0.0
Missing values	3	2	3	4	12	

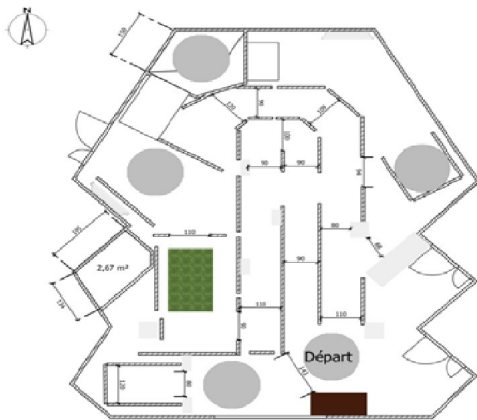
Comparison of number of collisions and driving time in the four conditions. Format: mean(SD) with SD= standard error. $*\leq 0.05$, $**\leq 0.01$, $***\leq 0.001$, cave = immersive room, HMD= head mounted device, screen = no simulator and feedback on screen, simscreen = simulator and feedback on screen.

The next step is to use the simulator in a learning study with patients who are not yet PWC drivers in a populated environment with virtual pedestrians having realistic social behaviors, especially during crossings. To do this, two biomechanical studies were carried out, one in the laboratory and the other in the museums of the city of Rennes in order to model these locomotor behaviors.

3 Smart powered wheelchair to avoid obstacles in everyday life

We proposed a perceptive shared control system that progressively corrects the trajectory as a user manually drives the wheelchair, by means of a sensor-based shared control law capable of smoothly avoiding obstacles. This control law is based on a low complex optimization framework validated through simulations and extensive clinical trials. The provided model uses distance information. Therefore, for low-cost considerations, we use ultrasonic sensors to measure the distances around the wheelchair. The solution therefore provides an efficient assistive tool that does not alter the perceived quality of experience, while ensuring drivers security [DNPB16] [MDT+22].

In a first study[LFD+21], we showed that in 23 patients (11 women, 12 men, mean age of 48 y.o.) there was a statistically significant reduction in the number of collisions on the most complex circuit ?? : 61 per cent experienced collisions without assistance versus 39 with assistance.



Representation of the power wheelchair test circuit during clinical trials. It was defined to condense the maximum number of difficulties of daily life on the basis of a questionnaire carried out beforehand with occupational therapists

The second trial dealt with users with driving difficulties. For the most complex circuit incorporating the maximum number of risky situations, 100 of the users experienced collisions and the assistance significantly reduced their number from 7.30 (8.90) to 1.33 (1.40) ($p=0.0007$). The effect size was significant for routes 2 and 3 ($r= 0.714$ and $r=0.827$). There was no significant difference between the two conditions on course duration. The use of the assistance module did not affect the time taken to complete the route for people with driving difficulties. The use of the assistance module did not affect the time taken to complete the route for people with driving difficulties. The mental load was similar on the NASA Task load.

The main objective of the next clinical trial will be to evaluate the benefit of using a PWC equipped with the assistance module on the confidence in driving for elderly people in institution, during the period of use of the module and at the end. Confidence will be measured by the confidence subscore of the WST-Q questionnaire. We will highlight the interest of a robotic driving assistance module on driving skill in terms of ability and performance of tasks performed measured by the WST-Q score and its subscores, the amount of travel evidenced by the distance traveled in the smart wheelchair compared

to the personal PWC, measured by sensors embedded, the mental load related, user satisfaction with the system and the acceptability of this tool by the participants.

4 Discussion

The summary of this work during about 10 years shows that it is possible and even necessary to have a multidisciplinary approach to technological innovations especially in technical mobility aids. The user-centred approach that was employed involved academic researchers, clinicians, and power wheelchair users in specifying their needs. It was made possible by the joint existence of a Living Lab within the rehabilitation center and a university chair dedicated to disability in the same city. Starting from the needs of the users, both patients and the professionals who accompany them, this work summarises 2 of the 3 axes that had been defined: the design of a driving simulator for learning and a driving assistance module. The project also included training in new online technical aids so that professionals know how to prescribe such innovative technical aids.

It should be noted that few studies of the various wheelchair or smart chair driving simulators have managed to include so many people with disabilities. concerning smart wheelchairs, Sharma et al. [SSLS12] evaluated an anti-collision assistance system for PWC in 19 healthy people blinded by a blindfold on a standardized circuit. Boucher [BAK+13] compared the driving performance of 17 participants, 8 of them were healthy participants. Studies involving only users involve much smaller numbers: 4 children suffering from cerebral palsy for McGarry et al.[MMG12], 7 people with visual disturbances for Sharma and 5 elderly people with moderate cognitive impairment for How [HWM13]. It is the same for simulators. Arlati [ACF+20] can be found at 62 articles concerning 29 different simulators but with few participants in clinical trials. For example Archambault et al. tested the MiWE on 12 expert PWC users with min 2 years of driving [TA16], or 17 new users [ABR+17]. The VieW simulator were tested on 12 children or young adults with cerebral palsy [MBC+20]. Mahajan tested on 10 participants [MDCD13]. So there are various simulators in the literature but rather few in the clinical trials and very few in every day clinical practises.

It is that why, from the beginning of this trans disciplinary assistive technologies work, we defined a ambitious specifications in terms of technology and needs, but at low cost. this had an impact on the technological choices (choice of sensors on the smart wheelchair for example). Nevertheless, the regulatory process to bring such medical devices to market and thus to use by the patients who need them is long and costly. This slows down the process of making them available to end-users and makes the process rather expensive for enterprises. As a result, few manufacturers are willing to start marketing such mobility aids, in a market that is still considered a niche market, even though demographics and the ageing of the population are creating ever greater needs. Today, both the simulator and the smart wheelchair have not found a manufacturer to market them, despite the user centered approach, the technological barriers that have been lifted and the clinical studies conducted to validate them.

5 Conclusion

The geographical and human proximity of the clinical teams of rehabilitation and scientific teams of robotics and data processing allowed the conception of 2 devices having for objective the improvement of the safety during the driving in wheelchair. This work, which started from a need of users with disabilities, has taken up scientific challenges and has been the subject of joint theses and publications. The approach is now that of industrialization to bring these innovative technologies to the market.

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