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Guiding Wheelchairs by Active Optical Profilometry, for Persons with Multiple Disabilities

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Abstract

This paper presents the progress of a project which purpose is to design, implement and evaluate an assistance device by active optical imaging, to secure the movement of wheelchair users with motion and cognitive disabilities and endow it with an adaptable multimodal interface, based on sensory-motor skills of the disabled person. A combination of embedded sensors can analyze the user's environment to interact directly on the chair in case of path considered as hazardous. In a second step, a multimodal interface will provide a wide range of interaction possibilities, in order to adapt in the most optimal way, to the interaction capabilities of the multiple disabilities people.

Key words

Wheelchair, physical disability, cognitive impairment, CP (Cerebral Palsy), PRM (People with Reduced Mobility), laser, telemetry, flight time, multimodal interface, sensors

1. Introduction

Each year in France, over 1800 children born with cerebral palsy (CP) [1]. This pathology mainly due to brain damage, occurring before birth, causes various disorders on perception, behavior, communication, sensation and may even cause seizures and other musculoskeletal problems [2]. Responsible of delays in the intellectual and motor development of children, newborns with CP, thus, find themselves in a situation of multiple disabilities with respect to their movements and their understanding of the environment surrounding them. Growing up, these children attend different types of specialized centers: Institute for Motor Education (IEM), Medical-Educational Institute (MEI), Center of Functional Rehabilitation (CRF) or Institute of Sensory

Education (ISE), in which they will be accompanied in the learning of their displacement. According to the child's handicap, an adapted mobility solution is proposed. In the vast majority of CP cases the proposed solution is an electric wheelchair, controllable using a manual joystick or an occipital command. This new possibility of movement causes a number of problems related to their condition. Indeed, this population of users often associated motor disorders to cognitive disorders. Their movements and gestures can sometimes be random and non-controlled, in particular in the case of strong emotional charges (coming of a relative, dangerous situation, feeling of fear, incomprehension, ...). This makes the handling of the wheelchair even more dangerous, particularly in situations difficult to grasp (sidewalks descents, stairs, walls, alleys, narrow passages, ...). The objective of our project is to provide a system ensuring a safe movement for the user with multiple disabilities, to facilitate the learning of his motor skills and allow him to acquire more ease in mobility, while providing greater peace of mind for therapists in their supporting tasks. Moreover, the proposed system incorporate a multimodal interface that will adapt the control of the chair to the specificities of each type of disability. Our approach is to equip the chair with sensors to make it able of perceiving all characteristics of its short and medium environment scope. This will anticipate the presence of a static or moving obstacle (wall, person moving around, another wheelchair, ...), to detect the presence of height difference (stairs, walkways, slopes) and intervene automatically on the chair to avoid any dangerous situation for the person.

In a first step, automatic reactions considered, range from a warning sensory signaling the approach of danger, to the total shutdown of the chair through a gradual reduction of its speed.

This article contains four main sections. The section II is devoted to the origins, causes and consequences of motor disorders associated with cognitive impairment. This analysis is supplied with various testimonies from occupational therapists and doctors we have met in different centers for children with multiple disabilities. Section III describes the state of the art of existing systems using sensors to characterize environment. Section IV presents the system we offer and describes specifications that the chair required. It will consider technologies and their integration. Finally, section V takes stock of our current progress. In conclusion, we will discuss future developments the system could benefit.

.2. The cerebral palsy

2.1 Origins

The cognitive and motion impairment, more commonly called Cerebral Palsy is a sensorimotor disorder that affects between 2 and 2.5 children per 1000 births [3]. It has been defined formally by Peter Rosenbaum et al. during a medicine consortium in April 2006 [4]. During this consortium, Cerebral Palsy (CP), has been described as:

"*Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, causing activity limitation, which are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral* *palsy are often accompanied by disturbances of sensation, perception, cognition, communication, and behavior, by epilepsy, and by secondary musculoskeletal problems."*

More specifically, these conditions generally have for origin the reduction or discontinuation of oxygen supply in parts of the brain. In the majority of cases (75 to 80% according to F.F.A.I.M.C[1]), it is due to antenatal accidents, the prematurity of the child, malformations in its development, cerebral cardiovascular accidents, or infection contracted by the mother. However, there are also cases of cerebral palsy caused by difficult accouchements (mostly because of the wrong position of the umbilical cord, causing circulatory disorders), and even after the birth, as a result of physical trauma caused during accidents of life, infections, stroke, cardiac arrest or seizures [5]. All these causes have for effect a decreasing or a complete stop of irrigation in the brain. It should be noted that advances in obstetric medicine, including intensive care, have significantly increased the survival rates of very preterm (28-32 weeks) and extremely preterm (less than 28 weeks). According to the INSEE[2], over the past five years, the number of deaths related to prematurity fell more than 9.25%. On 100,000 premature births, deaths diminish from 415 in 2010 to 377 in 2014, with a gradual decrease each year. Unfortunately, these survivors are subsequently more often subject to present sequels in their motor and cognitive development. It is estimated that by the age of 5 years, nearly 10% of very preterm children suffer permanent behavioral or motor disorders. We also observed in more than 30% of them an intellectual quotient lower than 85[3].

2.2 Analysis

CP covers a large number of clinical cases and various handicaps degrees. This is why it is necessary to establish a relevant classification system, in order to characterize the population likely to be helped via the development of our system. In this context and in order to better understand the needs of people with such infirmities, we have established collaborations with different specialized centers for multiple disabilities children. We have thus met the staff supervising IEM of Bailly, IES of Champigny sur Marne, CRF of Saint-Fargeau-Ponthierry, the motor reeducation center for small kids (CRMTP) in Antony and build bonds with the entire Ellen Poidatz foundation, which with, we currently work today. These meetings took place in the presence of various occupational therapists, psychomotor and specialist doctors (PMR[4]). These interviews enabled us to gather useful information for the design of our system, we have become aware of the great diversity in the types of disabilities targeted. Apart from motor disabilities, moving a wheelchair requires planning capabilities, organization, coordination, problem solving etc. which are often limited among children in cerebral palsy. He would be illusory to believe that our system may be used by all children with multiple disabilities. Indeed, although all children in the centers, are there in the

[1] Fédération Française des Associations d'Infirmes Moteurs Cérébraux (Http://www.ffaimc.org/)

[2] http: //www.insee.fr/fr/themes/tableau.asp reg_id = 0 & REF_ID = NATnon06228

[3] http://www.futura-sciences.com/magazines/sante/

[4] Physical Medicine and Rehabilitation

purpose of a motor rehabilitation and learning of mobility, only a part of them will be able to use our system, for two reasons:

First, a category of children presents minor cognitive and/or motor impairment, which means after a learning period they will be able to move with a classic displacement assistance device (electric wheelchair, manual, walker, etc.). Another category is too severely disabled in the motion part as in the cognitive one, to be able to use any travel assistance device. It is the case for example, of children with dystonia (involuntary sustained muscle contractions, causing abnormal postures), spasticity (involuntary tension of skeletal muscle, in the opposite direction of desired movement), ataxia (lack of muscle coordination) or tremor, preventing users to properly handle their chair. In this case, the use of a third party to manipulate the chair is unavoidable. The remaining third category is potential users of our system. These are people who already are moving with an electric wheelchair, but that have various attention disorders or movement, making sometimes their navigation perilous. It can also be people of the second category, who will access the electric wheelchair only in the case where this latter would be more secure. Moreover, it is important to highlight the positive impact of an access to mobility for those with multiple disabilities. According to a study in the late 90s [6], clearly demonstrate links between an independent drive and an increase in children intellectual abilities. Indeed, in the majority of cases, the transition to the chair (electric or manual), enables an improvement in the spatial representation of the user and his ability to solve problems. Also independent navigation allow the awakening of the child through the exploration of his environment and the confrontation to life stimulations.

After four meetings with practitioners and after three sessions of children's observation during different activities (learning games, class, recreation, first try of an electric wheelchair, ...), we decided to focus our work initially on securing users' moves. Several tricky situations and sources of danger have been reported by all the teams we have met:

- Crossing gates remains a major challenge for some children, who anticipate path and impinge on one side of the doorway.
- Collisions between chairs or armchair and pedestrian (another child lying on the ground) are frequent and damaging both the health of children and sustainability the equipment.
- The sidewalks, stairs or vertical drop may represent situations of high risk and generate poorly controlled reactions.
- Other examples from everyday life such as approaching the table during meals (with chair having to be inserted below the table) or crossing a narrow corridor are also situations potentially dangerous.

3. Existing systems

At the dawn of the 2000s, awareness of general interest of secure travels for persons with multiple disabilities, caused a rise in the design of "smart" chairs [7]. The tools used are all intended to locate the chair in the space, and its relation to its surroundings. The study of existing work allows to identify six types of sensors used:

• Ultrasound: based on the measurement of time between transmission and reflection of ultrasonic waves, to calculate the distance between the chair and the obstacle [8].

• Infrared: use the measurement of the difference between amplitudes of infrared emitted waves and their reflection, to estimate the distance to the obstacle. [9]

• Laser: by triangulation, it calculates the distance traveled by the laser, exploiting the angle with which it is reflected to the transmitter [10].

• Image processing: seeks to replicate human sight to locate the wheelchair in the middle of his environment [11].

• Rotary encoders: measures the number of rotations wheels to estimate the distance traveled by the chair from a starting point. [12]

• Bumpers: electronic bumpers placed at the periphery of the chair; they trigger an immediate stop to the chair when they are under pressure [13].

Whatever type of sensor used, each present advantages and disadvantages. The ultrasonic sonar (largely democratic by the NavChair [14]) enable relatively fast and accurate detection of obstacles. Their weaknesses are observable with the presence of a significant impact angle from the transmitter to the obstacle. Indeed, the wave is not sufficiently reflected towards the receiver, a non-detection of the obstructing object is possible. In the case of relatively confined environments (indoor navigation), the multitude of nearby obstacles, can cause false alerts, due to indirect rebounds of the ultrasonic waves on the different surfaces. Several solutions have been proposed to solve this problem, such as EERUF method [15], exploiting synchronization between acquisition times of the different ultrasonic sensors, to distinguish direct reflected waves from parasitic rebounds. Infrared sensors are equivalent to ultrasound sonar but use light. The properties related to the electromagnetic nature of light, allow to skirt problems related to angle of incidence with obstacles. In addition, loss of information due to the infrared component of sun and the reflectivity of the obstacles, often highlighted in some articles [16] can now be relatively compensated [10]. The only real imperfection persisting, relates to transparent or translucent barriers, such as glass or Plexiglas. This is why, gradually, systems having both infrared and ultrasound detectors have emerged [17] because combination of both allows almost perfect coverage of the environment. Accurate due to its highly directional nature, laser telemetry enables reliable positioning of the obstacle through sweeping movements. [18] Here we can find the same inherent flaws as in infrared sensors. Used in several prototype of augmented chairs [19] image processing is based on preliminary knowledge of the environment in which the wheelchair moves. In the case of an unknown environment or potentially subject to changes (urban transport), it becomes irrelevant. Regarding encoders, they are present in the majority of developed systems and are essential for evaluating position, speed and acceleration of the chair. Meanwhile, bumpers are used to stop the machine in case of extreme necessity.

4. System description

4.1 Genesis

This project is the initiative of Aziz Zogaghi, who, during the development of electronic cane for blind people [20] was confronted to a number of visually impaired users also having motor disabilities. Therefore, unable to use the cane in a conventional manner, a set of sensors disposed on each side of their wheelchair has been proposed. Then a basic vibrators interface allowed to report the presence of obstacles on the path of the chair. After great results, enhancing users' displacements, there was an awareness about the usefulness and the need to develop more extended devices for people with a motor disability associated with cognitive impairment.

4.2 Specifications

Reflection around a new augmented wheelchair, allowed us to identify two main axis of work. The first is about the environmental detection and characterization surrounding the chair via a sensor set. The second deals with the communication of information to the user and the possible takeover of our system on the chair (slowdown, braking). There is therefore a component directed towards the development of sensors for analyzing the environment, and another more focused on the interaction between the user and his chair. Figure 1 (a) illustrates the case where the chair detects the presence near a staircase. Thus, the user is warned of its approach to a dangerous area by signals sensory (sound, vibration, ...) adapted to its type of disability. In the case where it persists in its path towards the steps, the system will reduce its speed gradually until the complete stoppage of the chair. If the route is urban and imply sidewalks, as in Figure 1 (b), it is necessary that the chair is able to recognize edges to guide the user along its path. In this situation, there is no question of stopping the chair to approach the curb, but maintain direction of the chair in such a way along the edge, without risk of tipping.

Figure 1 (a) Stairs detection; (b) Sidewalk detection

4.3 Realizations

To start and in order to achieve a first prototype, we have chosen to voluntarily limit our specifications, to target a system quickly functional then to make it evolve over time. The first step was to establish a set of front sensors capable of understanding the three space dimensions facing the chair, to determine a potential encounter with an obstacle, in which case the chair is stopped (in a first phase) immediately. Control the gradual slowdown will be done in a second phase. To detect obstacles in front of the chair, we currently use a 3-dimensional imaging system [21]. We carry continuously, acquisition of three vectors of the space, such as a photograph (2D), to which are supplemented by information relating to the depth of the objects composing it. So we can receive data not only on the location of obstacles, but also on the distance that separates them from the chair. This method and 3D imaging devices that we develop are essential in our case, for stairs detection, vertical drop or sidewalks. The active stereovision (Kinect type) in structured light does not work in direct sunlight. We rely therefore on sensors we developed for the blind [22] operating both in sunlight and night. Figure 2 shows an example of this type result approach provides during 3D image acquisition an urban environment.

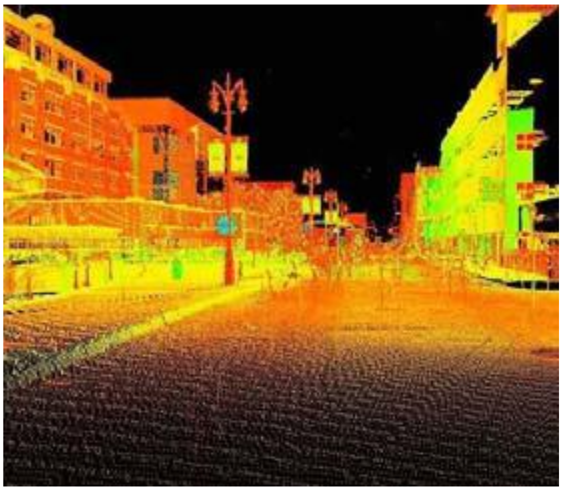

Figure 2 3D Laser scanner[5]

As shown in Figure 2, it is possible to distinguish the arrangement of objects in space, but also measure their distances from the chair, here rendered visible using different colors between nearby and distant objects. Our system therefore emits a collimated light flux in various directions and collect the backscattered flux, with which it is then possible to construct an image similar to the one presented above. In a second step, it will be necessary to extend this front detection system, in all directions (rear, lateral sides, height ...) in order to have a perception almost complete of the wheelchair environment, and to leave no "dead zone" around. Finally, many technical constraints must be taken into account. For example, one important aspect that needs to characterize our system is its adaptability to any type of chair. Indeed from a mechanical point of view, electric wheelchairs vary greatly from one model to another and even within the same brand. This is why our prototype must be assembled and disassembled easily on any medium. Our choice was currently on an attachment under the control joystick. In addition, in order to preserve the assurance and guarantee of the chair, we cannot modify the mechanical structure of one of some way (for example by drilling holes to fix our sensors) or even to supply energy directly on the electric battery of the

[5] From http://hds.leica-geosystems.com/en/Skills-Resources-in-Laser-Scanning_30832.htm

chair. Our system must be autonomous in energy terms, this which urges us to be vigilant on current consumption of our detectors.

Conclusion

In this article, we presented our wheelchair project with a system of 3D acquisition capable to detect and anticipate obstacles to secure movement of people with multiple disabilities. Through our collaboration with Ellen Poidatz foundation, it was possible to conduct several meetings within the IEM of Saint-Fargeau-Ponthierry. First, we were invited there as single observers, to help us better understand the complexity of some children to travel with electric wheelchairs and compare information collected with those we had traces from the different teams in other centers previously visited. Then we were able to freely explore some infrastructure in place within the institute, located some difficult issues and to question the effectiveness of our system to detect obstacles (stairs, vertical drop, doors, hallways, tables, ...). The ability of the chair to manage the front space in real situation will soon be evaluated, long working of calibration and optimization of our imager will be needed. Several trials in collaboration with specialized shelters are planned. The next steps of this work concern system optimization and robustness improvement. It will be about setting up an experimental protocol, in which some children will have the opportunity to test early versions of the chair. Thanks to the observation of their reaction and degree of ownership of the device, we hope to evolve our system until we get to a viable prototype, which meets the expectations of users and medical teams from different centers.

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