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Intelligent Wheelchairs: Filling the Gap between Labs and People

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Abstract. The works on Intelligent Wheelchairs (IW) have been an active research area in Assistive Technologies since its first prototypes in the 1980's. But more than 30 years after that promising start almost none (but a few) of those prototypes reached their final users. This work will try to analyze the problems that maintain those vehicles in the labs, far from the real people. Among the possible reasons for that, two main issues are the availability of suitable sensors (in terms of cost and reliability) and over all the lack of an appropriate standard platform in the market to build up an IW. In this paper we will focus our analysis on the platform problem. Under our point of view, it is mandatory to reduce the cost of any IW proposal by using a common framework from the more basic to the most advanced systems. To reach that goal, our proposal for an Intelligent Wheelchair framework take advantage of using standard Electronics systems and Communication devices (USB, CAN, WiFi) in order to guarantee its compatibility with other electronic subsystems and services around the environment (i.e. location based services) and to be able to follow the continuous upgrade of such subsystems.

Keywords. Intelligent wheelchair, Smart Wheelchair, Assisted Mobility, Distributed Control System, USB Wheelchair.

Introduction

Along the last decades there have been continuous and spectacular advances in several technological fields related with the mobile robotics systems. Better and cheaper sensors, actuators and embedded digital processors along with advanced control strategies have been the main results of such activities. Derived from those advancements, there has been also an active search for innovative applications for this kind of systems, some of them in the area of Assistive Technologies.

Already in the early 1980's some works at Stanford University [1] began to apply Ultrasonic Sensors (US) to an adapted wheelchair. Around the years 1990's, other research teams around the world began their works in developing innovative Mobility Assisting vehicles ([2] [3] and [4]). Those vehicles were similar in its initial conception to any standard mobile robot: a set of motors, wheels, sensors and controllers. Those activities were spreading out throughout the world in the pursuit of the so-called Intelligent Wheelchair (IW).

Nowadays, more than three decades after such initial works, just a few of such research reached their target population: those ones with strong mobility restrictions. During this period of time, new research teams have addressed the same task with more

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or less the same results. Then, how the people with severe handicaps could benefit from those advancements? Let's stop for a while to have a look backwards trying to identify the possible causes of the mismatch between labs research and the real world.

1 A Short Review: Intelligent Wheelchairs (and More) around the World

Keeping track of all the projects related with IWs is a heavy task. Currently there is high number of projects on the field and also there is a lack of a standard set of definitions about this kind of Mobility Assistance systems. In the scientific literature we can find different adjectives referred to such Wheelchairs like: Smart (SW), Intelligent (IW), Advanced (AW), Autonomous (AuW), Robotic (RW), and some other variations. Taking only those basic denominations into account and using Google Scholar as a searching engine, the evolution of scientific publications on those fields from the years 1980's can be recorded. Table 1 reflects such evolution in periods of five years; data from the last period (2010-2014) has been extrapolated assuming a short-term linear growth from the actual data (last column).

Table 1. Number of scientific publications about the listed concept in periods of five years. Source of information: searches on Google Scholar, till May 2013.

Five years period: **Concept**	**from 1980**	**from 1985**	**from 1990**	**from 1995**	**from 2000**	**from 2005**	**forecast 2010**	**actual 2010-13**
Advanced wheelchair	1	3	8	26	24	68	81	57
Autonomous wheelchair	0	2	11	95	189	322	356	249
Intelligent wheelchair	0	3	11	104	182	541	899	629
Robotic wheelchair	0	0	3	72	237	749	901	631
Smart wheelchair	3	4	13	59	80	391	544	381
Totals:	4	12	46	356	712	2.071	2.781	
Relative increment:		200%	283%	**674%**	100%	**191%**	34%	

The data from Table 1 cannot be thought of as a precise tool but it is useful to show the evolution of this field. It is clearly exponential with time, reaching currently about 500 references per year. From Table 1 some other conclusions can be derived:

- There is a huge increment of references in the 1995-1999 period. This effect can be related with the IJCAI'95 Robotics Wheelchair competition [5] that contributed to extend the interest in this field. In fact, the prototypes in that competition are among the most cited in the area [2] [3] [6] [7].
- The growth is lower in the 2000-2004 period but grows again between 2005 and 2009. This growth can be related with the application of new robotic strategies (for instance SLAM) to the IW problem.
- Finally, if the forecast for period 2010-2014 is correct, there are signs of a certain saturation on these topics because a relative growth of only a 34%.

As a conclusion, we may think that there is already a lot of accumulated expertise in this field, covering the entire world: U.S.A. [1] [6], Europe [4], Asia [8] [9], South America [10] [11], and more. We will not make here an extended review but there is an excellent compilation and analysis of the works up to 2004 in [12].

2 The Long and Winding Road to Market

The first work referenced here was the driving aid to quadriplegic users designed by David L. Jaffe in Stanford [1]. Despite the interest of this system as HMI to a robotic wheelchair [13] it is not commercially available. This has been also the case for other advanced HMIs, like Eagle-Eyes [14], which is available now as a communication tool but it was also tested for commanding wheelchairs on Wheelesley in the 1990's [2].

Going to 2005, in the review work from Simpson [12] he mentioned up to five commercially available Smart Wheelchairs (SW) or kits coming from four different companies. In 2011, only two of them [15] were still available:

- The "Smart Wheelchair" [16] [17], from Smile Rehab Ltd. (Scotland, UK) [18], available for children with cognitive disabilities,
- TAO-7, available from Applied AI Systems [19], but only for research.

How could we get IWs then? This is now the key issue [20]. Because the lack of commercially available IW, the transfer of all our accumulated expertise to people is blocked [21].

2.1 Looking for the IW Platform. First Problem: Industry.

To fill up the gap between labs and people we do need the active collaboration of the industry. Realistic productions plans are needed [15] in order to balance costs and demands in a very scarce market of potential users: those ones with strong mobility restrictions. The Fig. 1 summarizes the basic problem: too high costs for too little production, that is what we call "the inverted pyramids" question.

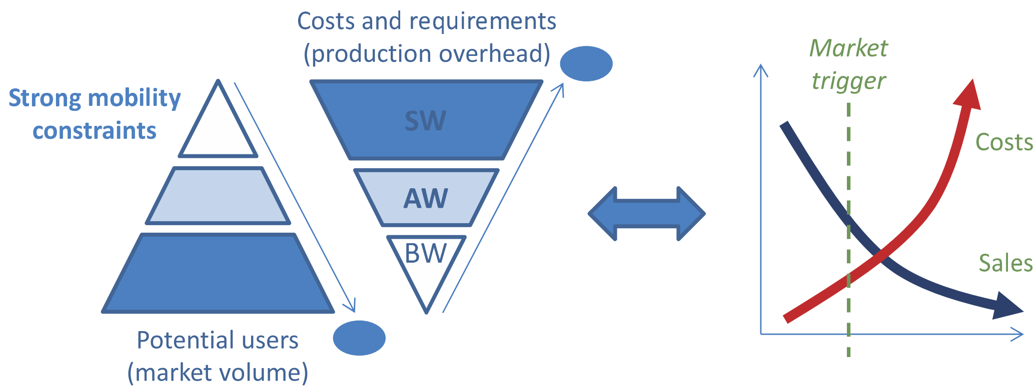

Fig. 1. The "inverted pyramids" question on Smart Wheelchairs (SW), related with a typical profile of market behavior. BW, AW and SW stand for Basic, Advanced and Smart Wheelchairs respectively.

To better understand Fig. 1 we have to assume that a Smart Wheelchair is not really a simple robotic platform: it must carry a person, the user, with comfort, safety and at a reasonable and affordable cost. Other important considerations are:

- If the user has a full control of his hands and other sensory abilities, this user will need only a Basic Wheelchair (BW), powered or not. That stands for the majority of potential users (base of the user's pyramid), so the cost of a BW is reduced also because the sales previsions can be high.

- There is also a big group of users that have got a reduced mobility on hands but can still maneuver a powered wheelchair with some electronics assistance (sensors and appropriate HMIs). The cost of such sensors has been lowering with time because big scale productions, for instance in the automotive industry. That stands for what we call Advanced Wheelchairs (AW).
- The smallest group of users, by far, is the one of those with strong mobility or sensory restrictions. They will need the best robotic sensors, the best processors and the best algorithms altogether with highly instructed personal for adaptation and maintenance of each SW to each user. So the SW costs are extremely high, which is represented by the upper base for the costs pyramid.

This model, as is, will not work: the cost is the highest when the potential market is the lowest. This is not affordable for any actual AT company unless:

- There were a massive injection of money from public instances, or
- The current cost of a customized Smart Wheelchair is lowered.

2.2 Second Problem: Suitable Sensors

This is another key issue about IWs. Sensors must be used in order to recognize the environment. But also they are essentials as safety devices by detecting obstacles and dangerous situations. From the beginning of IW research [22], safety issues were very important because the hard consequences derived from accidents like falling through stairs or curbs. The lack of sensors with enough reliability under a broad range of environments and situations kept the IW world mainly indoors.

This situation is about to change with the use of modern 3D sensors, able to deal with the outdoors challenge [23]. But this question will need more space than the one available here, so we will keep the focus on platforms: without them there will be no IW to put the sensors on.

3 Intelligent Wheelchair (IW) Architecture

Let's use the term Intelligent Wheelchair (IW) to identify a modular solution that could build Basic, Advanced and Smart Wheelchairs (BW, AW and SW) just using the same platform, modules and structure for all of them. This idea is shown in Fig. 2.

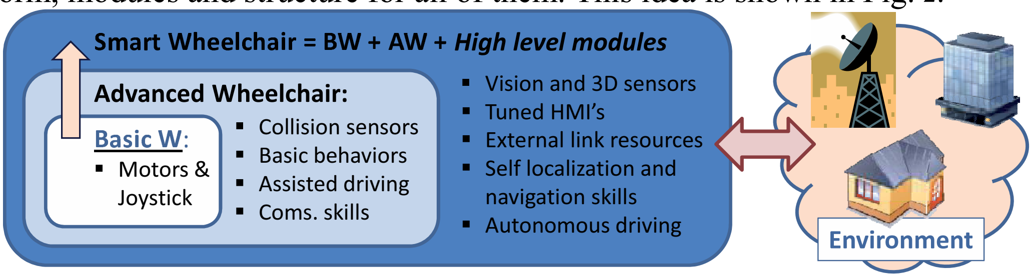

Fig. 2. The Intelligent Wheelchair model: from Basic to Smart Wheelchair by upgrading.

In this model, SW would benefit from a common framework and the reduced cost of a big scale production of fully compatible BWs. In between, some middle range behaviors, like Assisted Driving modes, could be implemented on a BW with a simple software upgrading. Further improvements can be installed also on top of that structure allowing a gradual evolution from a BW to the specific SW needed by any specific user.

Another key issue in that layered structure concept is using standard and high volume products as far as possible. That can be done almost in every point of this IW; for instance about the sensory system we could have:

- Basic Behavior Sensors: using low cost US modules and Vision sensors coming from the automotive and multimedia industry.
- Advanced Behavior Sensors: using up-to-date range sensors coming from the entertainment industry, for instance the new 3D Kinect sensors.
- Finally don' forgetting that the best sensor and controller ever is the user.

3.1 Intelligent Wheelchair: Our Proposal for a Common Framework

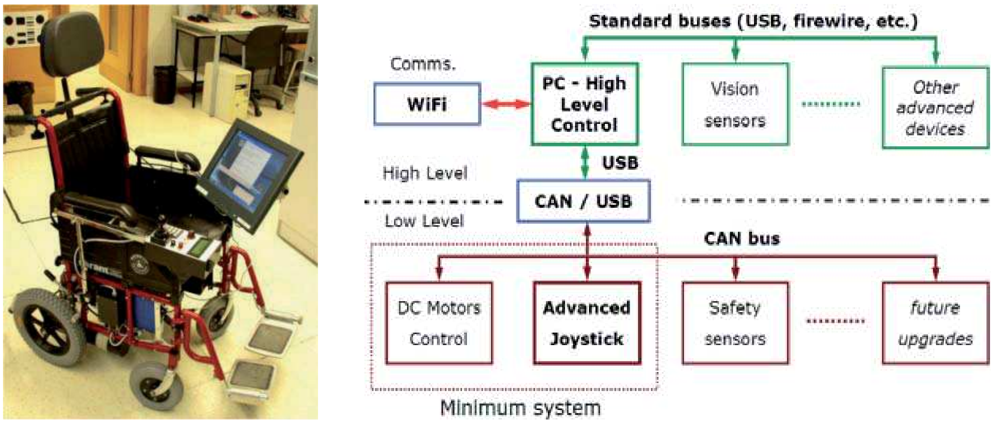

Fig. 3. General view and hardware architecture of the prototype of Intelligent Wheelchair.

Fig. 3 shows the basic prototype of Intelligent Wheelchair designed in our research group [10]. It summarizes the experiences derived from our former SIAMO project [4] [12], improving the standardization of it in a layered and distributed architecture.

The hardware architecture has a conventional robotic structure in two layers (high and low processing levels) formed by functional nodes interconnected by standard serial data links (USB, CAN, etc.). The use of standard modules and buses fulfil the standardization requirements. At the same time, this structure fulfils our IW proposal shown in Fig. 2. The BW can be constructed using just the motors and joystick (the minimum system). The AW and the SW levels can be done by adding the proper software and/or hardware modules.

Another advantage is that the BW could have a standard USB port available (the CAN/USB interface). So, any BW could behave like a standard peripheral to upper level controllers that links to the basic machine (the BW) through data and control messages. That helps to get lower development and exploitation costs by reducing both programming time and additional hardware requirements.

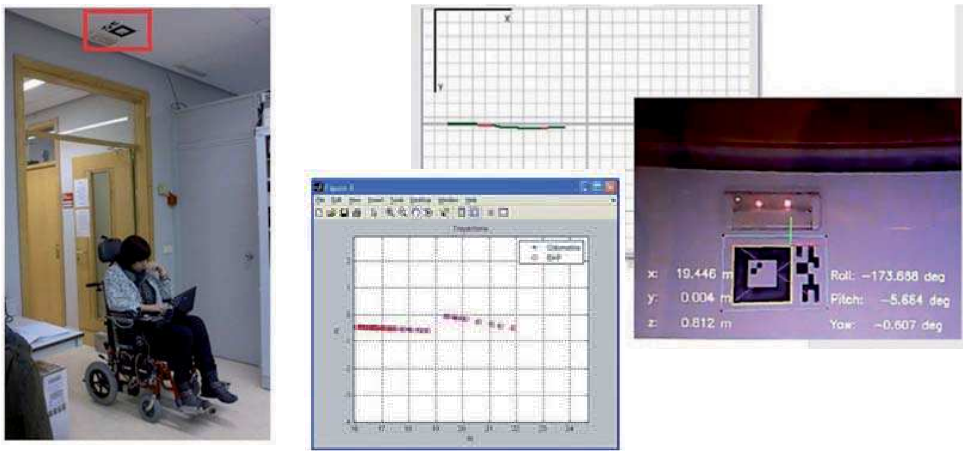

Fig. 4. The IW in an actual navigation test. An artificial landmark helps to correct odometry shifts.

Because the standardization in the interface with the IW, the connection of any external standard processor (like a laptop computer), running any kind of control algorithm is quite easy to do via the USB interface. The Fig. 4 shows one of these runs: a navigation algorithm, based on a Kalman Filter fusion strategy, has been installed in the laptop; the wheelchair uses motor encoders as odometry sensors, so there will be a position drift that must be corrected. The correction is done using a cost-effective absolute positioning system based on artificial landmarks placed on the ceiling; the vision sensor is a web-cam connected in a USB port of the control laptop.

The use of standard links simplifies the development of new control applications. As an example, Fig. 5 shows our IW being commanded with a Smartphone.

Fig. 5. Controlling the IW with a Smartphone, using the Bluetooth interface.

Present works on this IW prototype are devoted to take advantage of the inertial sensors available in modern personal processors like tablet-PCs. We are using the accelerometers, compasses, built-in cameras and, in general, any kind of built-in sensor to improve IW performances and usability altogether with the aforementioned reduction in cost and development time.

4 Conclusions

Throughout this paper we have seen that the works on Smart Wheelchairs have reached a high level of maturity after more than 30 years of research. Despite that, the industry has not shown enough interest in this field, so those advancements in research labs cannot reach to potential final users: those with strong mobility restrictions.

Apart from other considerations, like Safety issues and regulations, the first step is to reach the market. It is needed a standardization effort together (industry and labs) in order to have Smart-able wheelchairs available. The authors think that the proposal made in this paper, a layered and modular IW based on standard modules and interfaces, will help a lot in filling this gap between Labs and Users because the reduction of costs in every production phase (development, construction and maintenance). The advantages for research labs will be also related with the reduction of efforts while tuning a current powered wheelchair to the needs of any specific task.

Acknowledgements

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