A LOW-COST ELECTRIC POWER WHEELCHAIR WITH MANUAL AND VISION-BASED CONTROL SYSTEM

Prof. Abhinav V. Deshpande
Assistant Professor, Department of Electronics & Telecommunication Engineering, Prof. Ram Meghe Institute of Technology & Research, Badnera, Amravati-444701, India

ABSTRACT

This paper presents the design, implementation and experimental platform of a low cost intelligent wheelchair for the motor disabled. The first prototype developed is an electric power wheelchair whose cost is one third of the commercially available ones and is capable of both manual and autonomous operation. The manual operation relies on a joystick and is intended for people that in spite of their disability are well capable of maneuvering the wheelchair. The Autonomous operation relies on a mobile robotics inspired computer vision system to navigate through the corridors, halls, indoors/outdoors, among other structured environments and is intended for the severely impaired, such as the tetraplegics. Besides from being an affordable to everyone device, its current application is museum guidance, based on a location aware interactive storytelling platform, the wheelchair guides the user among the museum’s rooms while providing audio information.

Key words: Autonomous Navigation, Computer Vision, Edge Detection, Power Wheelchair, Mobility Aid, Storytelling


1. INTRODUCTION

According to the World Health Organization (WHO), between the 7 and 10% of the population worldwide suffer from some physical disability. In Latin America, the physically disabled are estimated in 55 million people, which represent the 9% of its total population [1]. This census indicates that the most common disability is motor, followed by blindness, deafness, intellectual and language. All alone, the motor disabled achieve 20 million in Latin America and there is an anticipated continued growth due to increase in ageing, longevity and accident-related injuries (mostly car
and sport accidents). Wheelchairs make up a significant portion of the mobility assistive devices in the use today. Since the 1930’s the design concept of a wheelchair has been the same: a main frame, two large rear wheels and two small front wheels called as casters (Fig. 1). This basic design has been used to develop many of today’s wheelchairs by applying slight design modifications to produce lighter, more durable and more comfortable wheelchairs for people who use them on a daily basis. While the standard wheelchairs are mainly used by those who have the necessary upper-body strength to propel and maneuver it, the electric power wheelchairs (EPW’s) are destined for those who cannot; people with excessive body weight, poor health, weak upper limbs and those long times living with the disability [2]. Unfortunately, conventional EPW’s are not always sufficient to compensate for mobility disabilities: people suffering from physical dexterity and coordination, cerebral spasticity, tetraplegia/paraplegia, tremors, spasms or head trauma cannot use an EPW and are prescribed with a standard wheelchair whose mobility is facilitated by a human attendant or caregiver [2]. In this case, robotic technology might become relevant for providing wheelchairs a certain amount of autonomy. This paper presents the design, implementation and first prototype of a novel EPW that aims to meet two criteria: offer a truly affordable EPW for Latin-American standards and be user-flexible: conventional electric for those capable and autonomous for the severely disabled while, of course, being standard or hand-operated at any time. The system which is proposed in this research paper is based on a commercial standard wheelchair which has been equipped with two low cost high power motors and a mobile robotics inspired vision system for intelligent control and autonomous navigation. The rest of the paper is organized as follows: Section 2 overviews the design, implementation and experimental platform of a low cost EPW. Section 3 presents and discusses its operation modes while Section 4 addresses an on-going application for this prototype: museum guidance. Finally Section 5 concludes summarizing the main concepts and future work perspectives.

Figure 1 Classical Design Concept of a Standard/Hand-Operated Wheelchair for the Motor-Disabled
2. DESIGN AND PROTOTYPE
The prototype chair is shown in Fig. 2. The system is based on the standard aluminum lightweight foldable wheelchair which is commercially available and the cost of the wheelchair is 180 USD. Two high power electrical brushless hub motors are incorporated to each rear wheel. They are powered by two 12 Volt batteries with the help of an electronic drive. The wheelchair is manually steered by a high sensitive joystick. I reach a maximum speed of 10 km/hr and has an autonomy of 2 hours. The laboratory cost is 1000 USD, which represents one third of the most commercially available EPW’s [3]. Furthermore, a Laptop computer and a Color camera are incorporated with the system. The total laboratory cost of the prototype with these systems increases to about 2100 USD, which is still less than the commercial EPW’s. There are two modes of operation which are available with the system: manual or conventional electric mode and autonomous mode, while of course being the standard and hand-operated at all times. The Fig. 3 shows the functional block diagram of the operation of both the modes.

3. MODES OF OPERATION

3.1. Manual Operation
A joystick is the primary control interface between a person with motor disability and an EPW [4]. It provides the control signals which are proportional to the force exerted on the stick to direct the wheelchair in direction and speed. The use usually drives the wheelchair by using a two-axis joystick while the direction changes with the right-left movement. In this mode, the microcontroller receives the analog signals from the joystick and translates them to digital signals with the help of an internal ADC. When moving the joystick straightforward, the microcontroller sends the digital signal to the electronics drive in order to have the same speed on both the motor’s increasing speed according to the joystick’s front or back movement. If the joystick is moved forward but not in a straight direction, then the wheelchair will turn left or right depending on the side the joystick was moved to. By moving the joystick in a straight-right or left, but not in a forward or in a reverse direction, causes the wheelchair to spin around its own axis. Contrary to most EPW’s, where the user has to adapt the force which is exerted on the joystick, the system allows to optimize the joystick’s sensitivity in order to accommodate each user. That is the intended direction from the user can be maintained but the magnitude (i.e speed and direction) can be readjusted according to the user’s capabilities. Both the parameters can be set with the help of a software interface by the user or the clinicians in order to accommodate different cases. The optimization of the joystick’s sensitivity is based on the principle that each user suppresses erratic hand movements and extracts the intended motion from the joystick [5]. This allows a means of allowing people who are unable to independently drive an EPW to do so, while enhancing the efficiency and safety as well.
3.2. Autonomous Operation Mode
In this mode, an EPW uses a vision system in order to navigate autonomously along corridors, halls and a wide variety of indoor/outdoor environments. A color camera obtains the images and transmits them to an on-board laptop computer. The PC takes the best decision which is based on image processing algorithms and sends the corresponding signals to the electronic drive. This system is based on a previous research in on-board vision systems by using a mobile robot IVWAN [6]. As in IVWAN, the EPW vision system is based on a color camera from Panasonic providing 120x160 pixel images. The image processing is performed by using Lab view while the decisions are taken by a JAVA implemented algorithm.
4. VISION CAPABILITIES

One of the most popular applications for vision-based autonomous mobile robots is line following. This application requires the vehicle to follow solid and dashed lines along a path while avoiding obstacles, overcoming terrain changes and attempting to maximize speed. The challenge is to implement a reliable algorithm that works under variable and unpredictable conditions of luminosity, shadows etc. As in mobile robots, this application can be transferred to the vehicles for the motor-disabled. The image was obtained by a RGB to HIS transformation, then a 60 degree rotation in the HS plane so that yellow becomes closer to red and then a transformation back to RGB. To enhance the bright colors blue in the image, a RGB to gray level transformation was performed by using R+G+3B instead of the typical[(R+G+B)/3]. Next a threshold was applied to better identify the bright colors. In order to minimize the number of objects in the image and obtain those of bigger mass density, isolated vicinities of 3x3 were removed as well as holes of 3x3 were filled. At this stage, the image is acceptable and the Hough Transform is reliable. Line following is very useful in the pre-established navigation environments but it results totally impractical for unknown or new environments where a line to follow simply does not exist.

Another possibility for autonomous navigation is corridor or path detection. This application requires the vehicle to detect both the edges of corridors or paths, calculate the available space and navigate between them at all lines. Again, under variable and unpredictable conditions of luminosity and shadows.

5. DECISION MAKING

For both line following and corridor/path edge detection, the resulting image is next processed by a JAVA implemented decision algorithm. This step is necessary because the previous image processing stage might find or generate a number of lines as a result of the conditions of luminosity and shadows. Based on the set of lines found, this JAVA algorithm takes the best decision by removing the unnecessary lines and leaving only the useful ones. For an example, consider a set of 4 lines (L1-L4) which are found in the image processing stage. A Gaussian distribution function is used to assign importance to the set of lines according to their angle. That is, it is more
probable to expect a line at $\theta=0$ degrees (i.e. parallel to the wheelchair) than it is at other angles. The lines at $\theta \geq 70$ degrees that appear suddenly along the path are to be neglected. At each camera refresh time, the line to follow is determined by the simple average function Eqn. (1)

$$L = \frac{\sum_{i=1}^{n} L_i \cdot P(\theta_i)}{\sum_{j=1}^{n} P(\theta_j)}$$

Eqn. (1)

Eqn. (1) can be decomposed into coordinates $x$ and $y$ to determine the next movement of the wheelchair.

6. MUSEUM GUIDANCE FOR SEVERELY MOTOR-IMPAIRED VISITORS

In collaboration with Museo Descubre [7] in Aguascalientes, Mexico, we are currently working towards making of the museum which is available for the severely motor-impaired. The main idea is to use the vision capabilities of the wheelchair in order to navigate autonomously within the museum while transporting a severely motor-impaired visitor. For this purpose, the corridor/path edge detection function was chosen, so that there would be no need to paint a line that disturbs the museum’s aesthetics. Two systems were incorporated to the EPW: (1) A couple of loudspeakers for providing information on paintings, sculptures and exhibits in the form of recorded speech and (2) A broadband wireless system that transmits the state of the wheelchair to a server station.

Concerning the audio explanation system, a set of voice speeches was recorded in the on-board laptop computer. When the EPW approaches a pre-determined point along the visit, both communicate by RFID technology and, upon identification of the point, the EPW plays the corresponding speech. This system is a part of an ambitious location-aware interactive storytelling platform which is given in details in subsections A and B. Concerning the monitoring system, it is important to know the location and state of the EPW at any time. For safety of the visitor, a remote operator should be able to take real time direct action over the wheelchair. With this aim, an active surveillance platform was implemented. By using the broadband wireless system, the EPW transmits in real time four parameters to the server station:

1. The image which is obtained with the camera.
2. The speed of the motors.
3. The location of the wheelchair in the museum and
4. The state of the battery.

Locally at the server station (5) the image is processed as in the wheelchair,(6) the control signals sent to the motors are reconstructed and displayed as well as (7) the path followed by the EPW. On the other hand, the operator is able to remotely (8) set the maximum speed of the motors and (9) stop the EPW.

Even though the EPW had successfully passed a number of laboratories on-site experiments, there is still the need to include a collision avoidance system. It is true that people in the museum move away when the EPW approaches but this cannot be taken for granted. Moreover, the collision with the forgotten objects on the floor such as bags is probable. Two approaches are currently being evaluated: sonar sensing and vision-based obstacle detection. Even though the second one would allow keeping the prototype low cost, it is certainly more challenging.
7. LOCATION-AWARE INTERACTIVE STORYTELLING

7.1. Technology for Location Aware Systems
There has been recent interest in developing location aware applications. There are several projects which are carried out to accomplish this Endeavour [8][9]. The technology which is used for these so-called “location-based” applications can be described as follows: Outdoor and Indoor applications. The technology which is widely used for outdoor applications is GPS whereas the technology which is used for indoor applications are active and passive RFID, WiFi triangulation and infrared communication.

7.2. Interactive storytelling
Telling stories is a quintessential activity for human since the dawn of humanity. There are manifestations of that in the prehistoric art in caverns in Spain and France. In the first half of the twentieth century studies on the structure of a story were carried out. One of the most prominent is that of Vladimir Propp [10]. He studied the morphology of the Russian folk tale. This work is relevant for interactive storytelling, as it divides the story in components. These components can thus be exchanged, but still have the end product of a story with a beginning, a development and an ending.

7.3. Virtual Guides
Since the 90’s, there has been an interest in developing virtual guides on mobile devices. One of the early works is the Cyberguide [11]. It used the GPS to locate the user outdoors and infrared to locate the user indoors. The idea behind this project was to develop a tour guide with a memory of the places he visited. The device used was an Apple Newton. Although the project was visionary, the technology which was available at that time made the project cumbersome and not affordable for handicapped people. Another project in which the guide tells the story from its own perspective was being developed for cultural heritage applications [12] in which the guide tells the story from the conquistadors and the conquered. This project was developed for a desktop.

7.4. Storytelling through an EPW
The work which is presented in this section is being carried out to provide location aware storytelling in a museum for the severely handicapped with the help of an EPW. There are three kinds of users for the storytelling components which are presented therein. The first is the content provider, who uses a tool to provide the content for the stories. This tool is available to the open public. The content uploaded is moderated by a second kind of user, whose role is to moderate the content. The third kind of user is the EPW user that interacts with the location aware virtual guide. The guide tells an interactive story depending on the location and depending on the profile of the user. That is, if the user is child, a young adult or an old age pensioner the stories are assembled to appeal him. A previous location aware project was developed for mobile devices that used the passive RFID technology to locate the user within a site. This project, which is used for this component, is connected through servlets (developed in JAVA J2EE) that provide an abstraction (and connection means) to the content that is stored in a MySQL database. The client application was developed in JAVA J2ME which is connected to the servlets through the EDGE/3GSM communication protocol.
8. CONCLUSION
In this research paper, we presented the design, implementation and the experimental platform of a low cost intelligent EPW for the motor-disabled which aims to meet the two criteria: To be user-flexible and affordable. The first prototype developed can be operated in the standard and manual modes for those capable and in autonomous navigation mode for the severely impaired. Its cost is about one third of commercially available EPW’s and with industrial mass production, a much lower price can definitely expected. Both the manual and autonomous modes are presented and discussed. In particular, the autonomous operation relies on a mobile robotics inspired computer vision system to navigate through the corridors, halls, shopping malls and airports among other indoor/outdoor structured environments. In this paper, the image processing and decision making approach is described in two cases: Line following and Edge Detection in corridors or paths. This prototype is currently been adapted for museum guidance of severely impaired visitors together with a location aware interactive storytelling and an active monitoring remote platform.

9. ACKNOWLEDGMENTS
This research work was undertaken as a part of Technical Education Quality Improvement Program (TEQIP-2) which was sponsored by Maharashtra Human Resource Development (MHRD) for creating awareness among the students and citizens of the country about the recent trends which are taking place in the world of Automation and Robotics in order to implement a new approach in the field of Smart Machines which will be useful for the patients who are suffering from motor disorders like tetraplegia or paraplegia, cerebral palsy and other nervous system disorders. The research work aimed at developing a novel device called as Electric Power Wheelchair which is operated on electric power with the help of manual and vision based control system and which can be purchased at low cost so that the poor and needy people will get the benefits of this EPW. I am especially thankful to all of the staff members, colleagues and Head of the Department of Electronics & Telecommunication Engineering, Prof. Ram Meghe Institute of Technology & Research, Badnera, Amravati-444701 for their fruitful efforts and valuable guidance for the successful carry out of this research work.

REFERENCES

A Low-Cost Electric Power Wheelchair with Manual and Vision-Based Control System


