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Novel Alternative Approaches for Developing Smart Wheelchairs: A Survey

Ashwin.S
Post Graduate Student/Department of EEE
PSG College of Technology, Coimbatore, India

Sandhya Devi.R.S
Assistant Professor/Department of EEE
PSG College of Technology, Coimbatore

***Abstract*— Independent mobility is critical to quality of life for people of all ages and impaired mobility leaves one with both physical and mental frustration. Assistive technologies have been dedicated to providing additional accessibility to individuals who have physical impairments and disabilities. Unfortunately, there are some individuals unable to operate an electric wheelchair due to physical, perceptual, or cognitive deficits. Some elderly and disabled users also have restricted limb movements caused by some diseases such as Parkinson's disease and quadriplegics. The prime objective of the present research was to explore various novel technologies that are incorporated to develop intelligent wheelchairs which can provide mobility assistance to individuals who would otherwise find it difficult or impossible to operate a power wheelchair. The smart wheelchairs discussed throughout this paper serve users with wide range of impairments. Each of them differs from each other in terms of control, safety, comfort, flexibility, weariblity and sophistication. This paper presents a review of the literature on different types of contemporary wheelchairs and prototype being proposed by researchers throughout the world. In addition, research trends and challenges in this field are identified and directions for future research are discussed.**

Index terms -Assistive Technology, electric-powered wheelchairs, independent mobility, Parkinson's disease, quadriplegics, smart wheelchair, wheelchair prototype

I. Introduction

Conventional electric powered wheelchairs which are operated using joystick have several disadvantages. For persons with limited dexterity, or fine control of the fingers, access to mechanical hardware such as buttons and joysticks can be quite difficult and sometimes painful. For individuals with conditions such as Traumatic Brain Injury (TBI), Multiple Sclerosis (MS) or Amyotrophic lateral sclerosis (ALS) voluntary control of limb movement maybe substantially limited or completely absent. There is error and variability in movement produced during joystick. With prolonged use, the joystick and the buttons can become stuck. Extensive use of joysticks can cause repetitive stress injuries and Hand injuries can lead to inflammation, muscle strain or tissue damage.

The "Sip and Puff" wheelchair system requires the user to suck or blow air through tubes in front of the mouth to control the wheelchair functions. These control options are expensive and also interfere directly with the user's ability to communicate while operating the chair. While the needs of many individuals with disabilities can be satisfied with traditional manual or powered wheelchairs, a segment of the disabled community finds it difficult or impossible to use wheelchairs independently. This population includes, but is not limited to, individuals with low vision, visual field reduction, spasticity, tremors, or cognitive deficits.

These individuals often lack independent mobility and rely on a caregiver to push them in a manual wheelchair. As a result, it is necessary that an alternative wheelchair system be developed. Such an alternative is to design 'smart wheelchairs'.

A smart wheelchair is any motorized platform with a chair designed to assist a user with a physical disability, where an artificial control system augments or replaces user control. Its purpose is to reduce or eliminate the user's task of driving a motorized wheelchair. Usually, a smart wheelchair is controlled by a computer, has a suite of sensors and applies techniques in mobile robotics, but this is not necessary. Smart wheelchairs are designed for a variety of user types. Some platforms are designed for users with cognitive impairments, such as dementia, where these typically apply collision-avoidance techniques to ensure that users do not accidentally select a drive command that results in a collision. Other platforms focus on users living with severe motor disabilities, such as cerebral palsy, or with quadriplegia, and the role of the smart wheelchair is to interpret small muscular activations as high-level commands and execute them.

Thus, smart wheelchairs play an important role in helping the handicapped and the elderly people to live more independently at home and have a low cost on their healthcare. By equipping a wheelchair with an intelligent controller, the control of the wheelchair is shared by the user and the controller. Various wheelchair prototype systems have been developed which are controlled by hand gestures, head movements, eye tracking and voice controlled wheelchairs. Few other wheelchairs are controlled by various biometric signals like EEG(Electroencephalography), EMG(electromyography signals), ECG(Electrocardiography),TDS(tongue drive systems) etc. To classify these signals accurately, researchers have proposed various techniques based on neural networks and fuzzy theory.

The paper is organized as follows. Section 2 describes the various solutions for eye movement based wheelchairs. Section 3 elucidates the head movement based wheelchairs followed by voice controlled wheelchairs in Section 4. Hand gesture recognition implementations for wheelchair control are discussed in Section 5. Section 6 deals with how biological signals and recent technologies like EEG, EMG and TDS are used to control wheelchair. Section 7 illustrates a comparative study of standard commercial wheelchairs that are available as a base model. Finally Section 8 furnishes the conclusion of the survey.

I. EYE MOVEMENT BASED WHEELCHAIR

For those who cannot even move their head, there is guidance alternative: to guide the wheelchair using the position of the eye into its orbit.

Ville Rantanen et al [1] developed a hardware prototype system to aid disabled people with limited mobility over their hands. It is a functional, multimodal prototype system combining head-mounted, video-based gaze tracking, and capacitive facial movement detection. Eye and head orientations tracking algorithms to map gaze direction to on-screen coordinates were combined together with the one to detect movements from the measured capacitance signal. The point and click experiments conducted using this hardware proved to be very accurate. However, the system undergoes certain performance issues only with pupil detection algorithm as the used algorithm is not up to date. The system could be further developed by updating the hardware. Powerful transmitters can be used to avoid distortions in the videos.

Two novel solutions [2] are proposed by Zhiwei Zhu and Qiang Ji to allow natural head movement and minimize the calibration procedure of existing eye gaze trackers to only one time for a new individual. First, 3-D gaze direction is determined and by intersecting it with the object the gaze point on an object in the scene can be obtained. Second, gaze point on an object is estimated from a gaze mapping function implicitly. A dynamic computational head compensation model is developed to automatically update the gaze mapping function whenever the head moves. Two main advantages of this system are that eye gaze can be estimated under natural head movements with minimum calibration and also the proposed method improves the usability of eye gaze tracking technology.

An eye model based on electrooculography signal is put forward by Rafael Barea et al [3]. The system consists of a standard electric wheelchair with an on-board computer, sensors and a graphic user interface run by the computer. In addition to this, this eye-control method can be applied to handle graphical interfaces, where the eye is used as a mouse computer. The main advantage of this EOG based wheelchair is its modularity which makes the system appropriate for specific user's needs. Also it has got an appropriate set of different driving modes according to user's capacities and the structure of the environment. A future improvement would be to design new systems which allow disabled to handle a computer by means an eye-operated mouse based on electrooculography, and on videooculography using a Web cam to reduce costs, because today the use of graphical interfaces has been propelled.

Kohei Arai and Ronny Mardiyanto developed a wheelchair prototype [4] specially controlled by eye gaze which is analyzed by image processing. It consists of a single infrared camera mounted on the user's glasses, netbook PC, a microcontroller, and a modified Yamaha JWII wheelchair.

The user's image is acquired by this camera and subjected to Adaboost Classifier eye detection, adaptive threshold and finally pupil detection determines the gaze. This current system provides robust against vibration, illumination change, and user movement. Another benefit is safety because when system fails to analyze the user gaze or when the user changes the gaze direction, wheelchair will stop immediately.

III. HEAD MOVEMENT BASED WHEELCHAIR

Few solutions for head movement tracking are:

- By using tilt sensors to detect head movements.
- Using accelerometer
- Visual recognition of head gestures
- A built in head control unit on the wheelchair [5]
- Lips detection to detect head movement in turn [6]
- Camera-based motion tracking of an infrared LED array which is impregnated in a head cap to be worn by the user [7].

Henrik Vie Christensen and Juan Carlos Garcia presented a new human-machine interface which determines the position of the head by use of infra red sensors attached behind the head of the user, with no parts attached to the head of the user [8]. This system is more satisfactory than above head cap based tracking as the user need not wear any extra accessory.

In 1998, E. D. Coyle et al implemented a non-contact head-movement electric wheelchair control device [9] using ultrasonic sensors. An ultrasonic transmit transducer emits inaudible sound waves which propagate through the air until they strike an object. An attenuated portion of the transmitted signal is then returned and picked up by an adjacent receive transducer. By application of Pulse Mode transmission the time taken for a "burst" of pulses to travel from transmitter to receiver is determined, providing a measure of distance travelled.

In 2010, Zhang-fang Hu Lin Li et al proposed a novel intelligent wheelchair control approach based on lip movement detection [6]. The traditional Adaboost algorithm is used for this. The location of the lips is compared with a fixed rectangular window, the head gesture commands are determined as shown in Figure 1 (including head up, head down, turn left, turn right) and the intelligent wheelchair movement such as turn left turn right, forward, backward are determined correspondingly.

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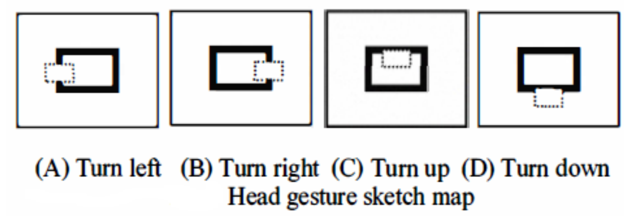

Figure 1. Lip detection using Adaboost algorithm.

IV. VOICE CONTROLLED WHEELCHAIRS

G. Pacnik et al built a Voice Operated Intelligent wheelchair (VOIC) [10], intelligent voice based wheelchair lab prototype. There are two main modules namely the sensors data acquisition module and the wheelchair steering module. Voice recognition used in this system involves input signal sampling, word isolation, LPC cepstral analysis, coefficient dimension reduction and trajectory recognition using fixed point approach with neural networks. The pros of this wheelchair are reduced complexity due to use of LPC cepstral analysis and coefficient dimension reduction and also good quality voice recognition. The con is that it does not differentiate a normal conversation from a command. Hence, the future scope of enhancing this system is to improve the feature extractor, recognizer to classify the everyday conversations from the given commands. Another possible upgrade is to perform face recognition using camera, sensors and different neural nets.

Muhammad Tahir Qadri and Syed Ashfaque Ahmed implemented a voice activated wheelchair through speech processing using Texas Instruments TMS320C6711 DSP Starter Kit (DSK) [11].The DSK generates analog signals corresponding to three main parameters measure from voice signal. Energy, zero crossing and standard deviation are the parameters determined from the voice signal by DSK. Matlab's Real-Time Workshop (RTW) was used to compile, load, and execute graphically designed SIMULINK models on an actual DSP plat-form.

A speaker adaptable language independent isolated word recognition system (IWRS) was developed by H.R. Singh et al [12]. A microcomputer receives the singles from IWRS and controls the function of chair accordingly. The voice signals were subjected to various techniques like signal processing for extraction of acoustic parameters, removal of redundant information, intensity and time normalization, and pattern matching etc. for their best performance and later implemented on a hard wired microcontroller based system for achieving real time/ near real time operations. Special importance has been given to the design of motor driver module to save energy. In addition to this, the combination of linear time warping (LTW) and dynamic time warping (DTW) have been employed to minimize the computational time. For utmost security and safety of the vehicle and the user, the proximity sensing has been provided. This adds intelligence to the vehicle so that it gives advance warning on sensing an obstacle in the path.

V. HAND GESTURE RECOGNITION TECHNIQUES TO CONTROL WHEELCHAIRS

Jianjie Zhang et al illustrate in their paper [13] a hand gesture recognition which detects single-hand gestures efficiently in an intricate environment. Gestures are captured using a camera in room lighting. An adaptive complexion model based on mean intensity has been developed to detect skin-like pixels.

Using eroding operation, skin-like region of maximal area are extracted from the binary image. This is followed by gesture normalization through interpolation and then recognition algorithm. This algorithm combines the implementation of voting theory and relief algorithm. Relief algorithm is used to select which pixels to vote for each category. The proposed technique is effective and robust for gesture recognition. In future, this method can be applied to mobile robots as well as to control movement of wheelchairs. Online retraining can also be done.

G.R.S. Murthy and R.S. Jadon suggested a technique to classify hand gestures using neural networks. A model based on pattern recognition techniques using supervised feed-forward neural net training and back propagation algorithm for classifying hand gestures into ten categories [14]. A web camera is used to capture the video of hand movements. The algorithm is as follows:

Steps :

- Capture only the background comprising of one frame as static image
- Extract frames from video and using absolute difference find resultant image containing only hand of user.
- Convert RGB to grayscale and then to binary image and filter the noise.
- Calculate extreme coordinates of the hand and the line vector with only edges from arm to the tip of fingers.
- Input these images to a neural network with 750 neurons in input layer, 7 neurons in hidden layer and 5 neurons in output layer for training.
- Once training is over, we have to build the map of the weights and found the weighted average of the relevant area in which the fingers exists. Consequently, we can implement this technique to develop a wheelchair based on hand gestures in the future.

A novel intelligent wheelchair control system based on Hand Gesture Recognition (HGR) was devised by Yi Zhang, Jiao Zhang and Yuan Luo [15]. Haar-like features and Adaboost algorithm for hand gesture recognition are used in this machine vision based system. Haar-like features depict the ratio between the dark and bright areas within a kernel. as a result, they are reasonably robust to noise and lighting changes. Since, the eye region on human face is darker than the cheek region; one Haar-like feature can efficiently catch that characteristic. Using this one Haar-like feature only a weak hand gesture classifier was trained. After getting the weak hands classifiers, the Adaboost learning algorithm is employed to adaptively select the best features in each step.

Many weak classifiers are combined in cascade to form a strong classifier. This results in highly accurate classifier and achieves real-time performance. The block diagram of this hand gesture based wheelchair is shown in Figure 2.

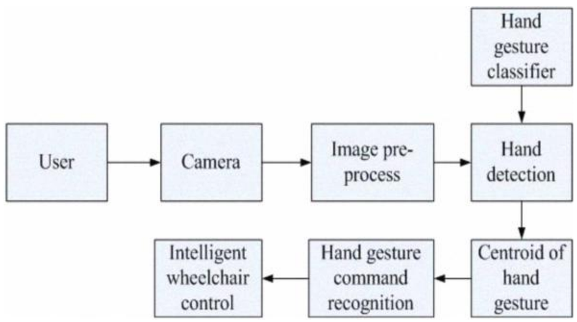

Figure 2. Block Diagram of HGR based wheelchair.

Chun Zhu and Weihua Sheng designed a neural network system for gesture spotting and a hidden Markov model for context based recognition [16]. They have proved that this method is accurate through their results.

Xu Zhang et al presented a framework for hand gesture recognition based on combined inputs from three-axis accelerometers (ACC) and EMG sensors [17]. A decision tree and multistream hidden Markov models were employed as decision-level fusion to achieve this. The combination of EMG and ACC measurements can boost the functionality and reliability of gesture-based interface. Future enhancement can be to extend this scheme to gesture-based mobile interfaces. In addition, tiny, wireless, and flexible sensors that are better suited for universal users in real applications can be designed.

VI. EEG, EMG AND TDS STIMULATED WHEELCHAIRS

Brain–computer interface (BCI) has received significant attention in the recent years. The BCI is a system that obtains and analyzes neural signals from the brain with the objective of creating a direct high-bandwidth communication channel between the brain and the computer. BCI's translate in real time the electrical activity of the brain in commands to control machines and devices.

They are envisaged to have huge prospective for a wide ranging areas of research and applications such as brain signal acquisition and processing, bioengineering, and understanding the underlying neuroscience etc. Brain–machine interfaces also offer fascinating challenges like controlling wheelchairs directly by brain.

Kazuo Tanaka et al put together a study of EEG based control of an electric wheelchair [18]. In this research, a recursive training algorithm was developed to categorize the recognition patterns from EEG signals. To remove the artifacts from the EMG signals, band pass filter is used. Then the recursive algorithm is applied.

This algorithm is briefly discussed below.

i. Set number of iterations = 1
ii. Record EEG through the 100 trials for each of the left thinking and right thinking. Divide the recorded data into generating data and checking data.
iii. Generate left thinking and right thinking pattern vectors.
iv. Calculate the Euclidean distances for both thinking from checking data and determine the recognition rates [%].
v. Assume Emax = 70 % and compare both recognition rates with this value.
vi. This step increments the number of iterations if it has not reached maximum value, else go to step 7.
vii. Trained patterns and recognition rates obtained are the final result.

The average recognition rate is about 80%. This shows the viability of EEG-based control for an electric wheelchair. Further research can be undertaken to improve this rate.

A new control method for power-assisted wheelchair based on the surface myoelectric signal [19] was designed by Yuusuke Oonishi et al. The human-machine interface uses an electromyogram (EMG) sensor for input interface. But the magnitude of this sensor output varies from one person to another depending on the fatigue of the muscle and the conditions of the skin the sensor is located on. Hence a disturbance observer is introduced to detect the exerted human force and to find out how much torque should be supplied by motors to help the user. Furthermore, the EMG signal is combined with the estimated force to provide more safe and comfortable assistance. A non invasive dry surface electrode is used in the above method. As shown in Figure 3, EMG is measured by the surface electrode on the skin and this type of EMG is called surface electromyogram (sEMG). It is apt for measuring entire muscle activation since it is a temporal and spatial summation of the action potential of the muscle fiber under the surface electrode. Two phases are defined namely: Grasping phase is the range of about 0.5 s before and after propelling the handrims while propelling phase is the range during which the driver propels the handrims and wheel velocity is increasing.

The EMG signal processing used in the above research is as follows:

i. The weak signal is amplified by the differential amplifier and is digitized using sampling rate of 1 kHz through a 12-bit A/D converter.
ii. The sEMG signals are digitally high-pass filtered
iii. Next, the signals are full-wave rectified.
iv. The signals are smoothed by taking a moving average per 50 points to reduce the impulse noise.

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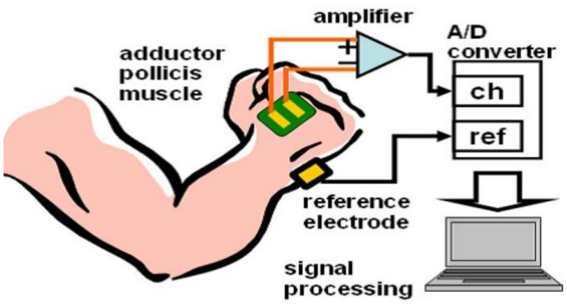
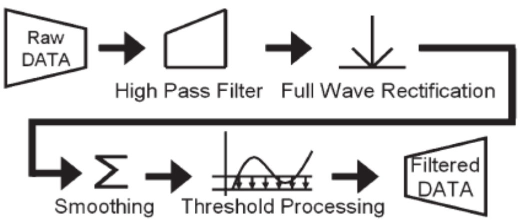
v. Finally, subthreshold signals are cut to zero so that the steady noise is eliminated

Figure 4 shows the steps involved in EMG signal processing.

Figure 3. Measurement of EMG signals.
Figure 4. Processing of EMG signals

The grasping phase alleviates the driver's burden when he or she starts to propel the handrims and the propelling phase reduces the caregiver's burden. More exhaustive analysis of the control system such as the tradeoff between assistance performance and weak robustness should be researched in future work.





I˜naki Iturrate et al have put forth a new noninvasive brain actuated wheelchair that relies on a P300 neurophysiological protocol and automated navigation [20]. When in function, the user faces a screen displaying a real-time virtual reconstruction of the scenario, which is created by a laser scanner. As the user focuses on the location of the space to reach, a visual stimulation procedure educes the neurological phenomenon, and the target area is detected by signal processing. This location is then fed to the autonomous navigation system which drives the wheelchair to the preferred place and also avoids collisions with the obstacles detected by the laser scanner.

<u>Advantages:</u>

- It is a safe and autonomous navigation system.
- Accuracy of above 94% was achieved.
- The maneuverability in com`plex scenarios using the state-of-the-art technology in robotics is possible.
- The system has immense adaptation, high robustness and low variability.

<u>Future scope:</u>

- The integration of a BCI-based system with online error-detection can be implemented.
- The substitution of the virtual reconstruction displayed on the graphical interface by an augmented reality with real-time video in devices to launch brain teleoperation of a robot

A very recent study by Dandan Huang [21] presented an efficient and practical prototype of a continuous EEG-based BCI for virtual wheelchair control of subjects. The wheelchair could be operated to turn left or right, to go straight or stop, with all the basic motion functions that a real wheelchair has. The prominent induced power decrease (ERD) and power increase (ERS) associated with imagined natural movements allowed the reliable discrimination of movement intentions.

<u>Advantages</u>:

- Improved control accuracy and increased the degrees of freedom of the wheelchair control system.
- Ease of use for the potential user while keeping a reliable sense of control, with good control speed.
- User friendly design

<u>Future Scope:</u>

In the future research, asynchronous wheelchair control based on the current system can be developed to further increase control speed while maintaining reasonable control accuracy.

In 2012, Jeonghee Kim et al proposed a wheelchair in which developed a TDS–iPhone–PWC (powered wheelchair) interface[21] as part of a wireless and wearable assistive technology to allow individuals with severe disabilities drive PWCs using a headset and a magnetic tongue barbell, while receiving visual feedback on their smartphones.

V. Comparative Study of Commercial Wheelchairs

Apart from the above wheelchairs, there are few standard wheelchairs used around the world to assist people with disabilities. These have been developed in the past few years. Table 1 has been tabulated after review of several research works and it presents the existing commercial wheelchairs. The ideas and technologies proposed in previous sections can be implemented on these wheelchairs.

Table 1. Comparative study of commercial wheelchairs

Wheelchair Name	Description	Author /Year
NavChair Assistive Wheelchair Navigation System	Employs a DOS-based computer system, ultrasonic sensors, and an interface module interposed between the joystick and power module of the wheelchair.	Simon P. Levine et al , 1999
Hephaestus Smart Wheelchair System	Collections of components with an add-on unit that can be attached or removed from existing wheelchairs	Richard C. Simpson , 2002
SENARIO	Provides shared-control navigation obstacle avoidance and autonomous navigation based on internal map. Uses neural networks for localization, and distributed control architecture	Katevas NI et al , 1997
INRO	An autonomous navigation wheelchair	Schilling K et al , 1998
SIAMO	HMI is independent from the rest of the wheelchair system and can be changed without modifying the architecture.	Henrik Vie Christensen a and Juan Carlos Garcia, 2003
iWheelChair	Adopts advanced DSP technology and data acquisition and processing of joystick and ultrasonic sensors.	Tao Lu, Kui Yuan, Haibing Zhu, Huosheng Hu, 2005

VI. CONCLUSION

The paper describes a short survey on contemporary approaches to control electric powered wheelchairs and development of smart wheelchairs and their associated technologies. Although several wheelchair technologies were discussed in this paper, one can see that there exists a large selection of approaches in choosing the type of wheelchair depending upon the disabilities and impairments of the end user. Each of these systems differs in various aspects like accuracy, safety, user-friendliness, robustness, flexibility, computational complexity and weariblity. Thus researchers can decide on which wheelchair control system alternative to choose, depending on the type target user, available resources and the field which is chosen.

Future scope and direction of research for each of the discussed wheelchair systems is also described. The technologies discussed so far can be applied to the standard commercial wheelchairs as add-on units to enhance these wheelchairs. In future, we plan to evaluate these wheelchairs based on the satisfaction index of users

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Authors Profile

S.Ashwin received the **B.E.** degree in electronics and communication engineering from the PSG College of Technology, Coimbatore, Anna University, Chennai, India, in 2008. He is currently doing **M.E.** in electrical and electronics engineering (Embedded and Real-Time Systems) in PSG College of Technology, Coimbatore, India. His research interest includes embedded systems, image processing, communication networks and assistive technology.

R.S.Sandhya Devi received the **B.E.** degree in electronics and communication engineering from the Avinashilingam University for Women, Coimbatore, India, in 2007. She received **M.E.** in electrical and electronics engineering (Embedded System Technologies) from Anna University, India. She is currently working as Assistant Professor in PSG College of Technology, Coimbatore. Her research interest includes embedded systems, real-time operating systems, embedded networks and assistive technology.