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Review of Assistive Devices for Electric Powered Wheelchairs Navigation

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ABSTRACT

The decreasing costs of microprocessor systems and increasing range of "Smart Sensors" have led to a boom in Assistive Device Technology. The annual rate of expenditure for mobility related devices has reached $1 billion dollars in the United States alone. The industries current focus is to develop a wider range of Independent Mobility Controllers to allow, even the most severely disabled person, the ability to control an Electric Powered Wheelchair (EPW). Advances in Autonomous Robot Design have led to corresponding improvements in EPW technology. This paper outlines user interfaces and input device technologies used at present to navigate an EPW.

Keywords: Autonomous, Input Devices, Electric Powered Wheelchairs, Rehabilitative, Assistive Devices, Robot Navigation.

1. INTRODUCTION

Over the years advances in medicine have led to an increase in life expectancy and changed the focus of medical care from acute treatment to long-term rehabilitation of patients. This has generated a greater demand for more advanced wheelchairs, in specific, powered wheelchairs, encouraging developments in Assistive Device Technology (ADT). In 1994 there were over 54 million people with disabilities in the United States alone representing nearly one fifth of the American population. Out of this figure almost 1.8 million required the use of a wheelchair [1].

A clinical survey in 2000 [2] of 200 practicing clinicians in the U.S. showed that a vast amount of their patients rely on joystick, sip-and-puff, chin or head control devices for navigation. However, 40% of these patients found steering and maneuvering tasks difficult or impossible. This paper outlined the requirement for more "independent mobility controllers"; controllers which allow even the most severely immobile person the ability to navigate a powered wheelchair. This enables them to implement day to day tasks without the intervention of carers, hence increasing their autonomy and experience of life. Over the last decade there have been many attempts to design an Autonomous EPW System [3]-[15]. These attempts have benefited from the decreasing cost of microcontrollers and increasing range of readily available smart sensors. The introduction of new ADT's such as Global Positioning Systems (GPS) [16], Electroencephalogram (EEG) [17] and Gesture control systems [18], in the last five years, gives new hope to those users who previously could not use an EPW. At present, many of these new ADT's are in the experimental stages of design. Therefore this review is intended to highlight the currently available ADT's and provide an insight into future designs.

2. DISABILITIES

The three main types of disabilities are Physical, Sensory and Emotional. A disabled person may have one or more of these disabilities but it is mainly physical disabilities which cause motor function impairment and necessitate the need for ADT equipped wheelchairs. A physical disability limits basic physical activities such as walking, climbing stairs, reaching, lifting or carrying. There are several physical disabilities/conditions which require the use of EPW including brain injury, stroke, fractures, amputation, pulmonary disease, neurological disorders, musculoskeletal diseases/injuries and spinal cord injuries.

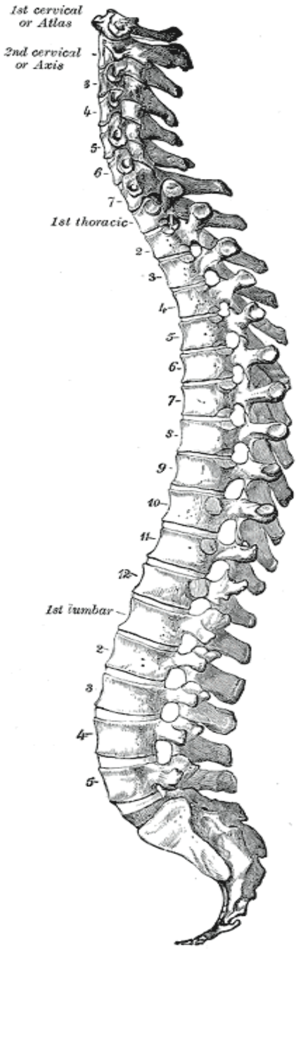

Figure 1 Human Spinal

<table>
<tr><th colspan="9">Complete spinal cord injury branch levels and candidate input devices</th></tr>
<tr><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th><th>C6</th><th>C7</th><th>C8</th><th>T1</th></tr>
<tr><td>Eye tracker</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Eye wink switch</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Brain wave</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Facial movement</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bite switch</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tongue joystick</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tongue switches</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Head switches – limited movement directions</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Head 6DOF position– limited movement directions</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Chin switch</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Speech</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="9">Muscle EMG (available muscles)</td></tr>
<tr><td></td><td></td><td colspan="3">Sip-puff switch (diaphragmatic)</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Chin joystick</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Head mouse</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Mouth stick</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="4">Shoulder switches</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="4">Shoulder 6DOF position</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4">Elbow flexion switch (assisted return)</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="5">Shoulder joint – upper arm switches</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="5">Shoulder joint – upper arm 6DOF position</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="3">Wrist extension switch (assisted return)</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">Mouse</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">Trackball</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">Joystick</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">Glidepoint</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">Touchscreen</td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Wrist switches</td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Spaceball</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Space glove</td></tr>
</table>

Figure 2 Spinal cord injury and candidate input devices [20]

column [19]

The Spinal Cord is the largest nerve in the body and is responsible for carrying motor communication to the muscles. The spinal cord runs through the spinal column and consists of 8 cervical (neck), 12 thoracic (upper back), 5 lumbar (lower back), and 4 sacral (base of the spine) branches (Figure 1). The number of the branch, running from cervical to sacral, and a letter indicating the region are used to denote each nerve branch throughout this paper. Figure 2 depicts a map of the spinal cord injury branches associated with possible candidate ADT's. Spinal cord injury patients require expert analysis from occupational therapists and rehabilitation engineers when deciding which ADT will be most suitable for controlling an EPW.

3. ASSISTIVE DEVICE TECHNOLOGIES

The main components of an Electric Powered Wheelchair can be categorised as Inputs, Control System and Outputs as illustrated in Figure 3 below. Assistive Device Technologies are categorised as inputs to Electric Powered Wheelchairs control systems.

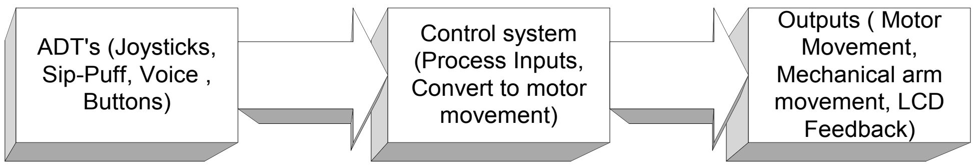

Figure 3 Components of Wheelchair

Figure 4 illustrates the various areas of the human body which can be used to control an EPW. A joystick is the most common control device for an EPW and unless specifically requested is normally supplied with all wheelchairs. The most commonly used joysticks are tongue, chin, finger and hand .The main types of joystick are switched and proportional. The Switched Joysticks act in a unidirectional manner converting electrical contact signals into discrete positioning information. They usually implement four switches giving a total of eight discrete positions, four by activating a single switch and four by combined activation of switches.

Proportional Joysticks get their name from the (proportional) movement of the joystick resulting in a proportional output signal, due to resistive or inductive change, which indicates the position of the joystick. Another type of proportional joystick is the Force Feedback Joystick [22]. Sensors are used to detect obstacles in the wheelchairs path, a force is applied to the joystick lever in opposition to the wheelchairs direction so that the user may avoid the obstacle. Results have shown that these Joysticks enable the user to improve manoeuvrability with fewer collisions in their environment [23].

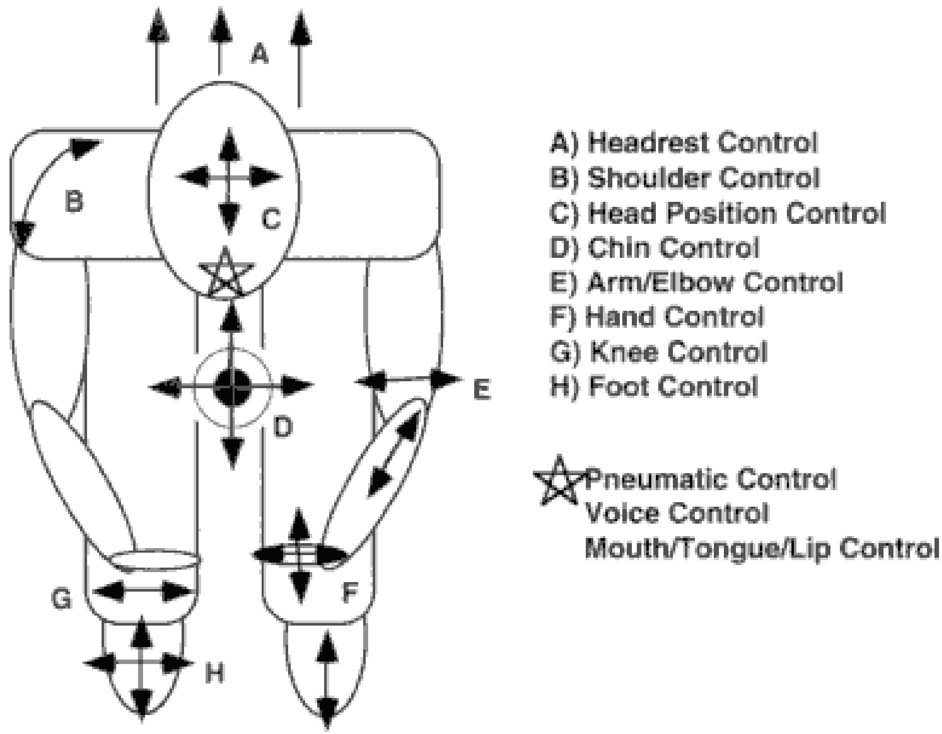

Figure 4 Possible anatomic sites on the body which can be used to control an EPW [21], © DEMOS Publishing.

Arthritis is one of the major reasons for wheelchair use in elderly patients [24]. Constant use of Switched/ Proportional Joysticks and repeated wrist movements can be very painful for an arthritic patient, and may prove difficult for elderly patients. Isometric Joysticks [25] use Force Sensing Resistors (FSR) to sense the force of the joystick in any given direction. Isometric Joysticks do not utilise spherical or orthogonal pivots on the base of the stick so there is minimal movement of the wrist and upper body. This has the advantage of reducing muscle movement normally encountered with the operation of Proportional Joysticks while also reducing motion triggered reflexes, such as spasticity. Many of the switched, proportional and isometric joysticks are implemented digitally which allows seamless integration with digital controller systems often used in EPW's. This improves immunity to interference from phones, citizen band (CB) radio and even electric motors of the wheelchair.

For motor function impairments that limit upper and lower body movement, a combination of devices are used. Headwands (Figure 5) usually consist of a pointer or extension device that is mounted to a head piece and extends from the centre of the forehead angling downwards In a similarly fashion, a stick which is controlled by the mouth is used and is known as a Mouthstick. Headsticks and Mouthsticks are usually used in direct selection of an object such as a key on a keyboard or a symbol/word on a board. They are primarily for use by persons with good head control.

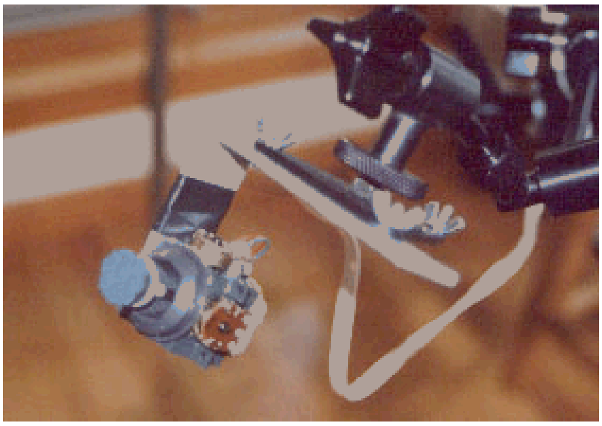

Figure 5 Headstick (Left) [26].

They are useful when it comes to everyday tasks like turning on a light or typing a message but they are not so useful for controlling an EPW's directional movement, because while the user is concentrating on position of the stick they are distracted from the path in front of them leading to increased collisions. Therefore Headsticks/Mouthsticks are primarily used as an accessibility device for seating position and computer input.

Chinsticks (Figure 6) can be used to directly control the navigation of a wheelchair, they consist of a small joystick mounted on a mechanical arm under the users chin. Sip/Puff devices (Figure 7) are widely used for controlling EPW's. A Sip/Puff switch is head mounted (Figure 8) and used to actuate a two-position switch by a simple sip or puff (pulling and pushing of air through a tube). It consists of a head frame with a switch box and replaceable plastic mouth tube attached. Sips and puffs are converted to switch closures inside the Switch Box.

Figure 7 A Sip/Puff system [28].

Figure 8 Head Mounted Sip/Puff device [29]

A serious of sips can determine the direction the operator wants the chair to travel while the puff confirms the choice. They are commonly used in conjunction with a Liquid Crystal Display (LCD) so that the user can navigate using a computerized menu system and obtain feedback. This maybe the only device which is operated without movement of the upper and lower limbs but again it has its pitfalls as the user must have strong respitory control.

Switches are also used to control directional movement of EPW's. The control scheme is similar to that of the Switched Joystick and is nearly always used with a Switch Box Controller (Figure 9). Nearly every limb on the body can be used to activate a switch (see Figure 4). There are different types of switches namely non-contact, contact, hit, and target. Non contact switches work by detecting movement; accelerometers and mercury switches are used extensively for detection of limb movement. Contact switches work by touching, pressing or squeezing the switch and can be capacitive, inductive or resistive. Hit switches are usually the type which need to be depressed to work, are possibility mounted on a spring and are butted or smacked to operate and have a higher tolerability for the force placed on them. Most contact switches are target switches were the user has to reach out and touch the switch.

Pressure type switches are also used to determine pressure in certain areas of the patient's seating to determine directional movement of EPW. There are several examples of two way switches/transducers used as partial control in EPW and they are usually placed according to the anatomic site which the patient has most precise control over.

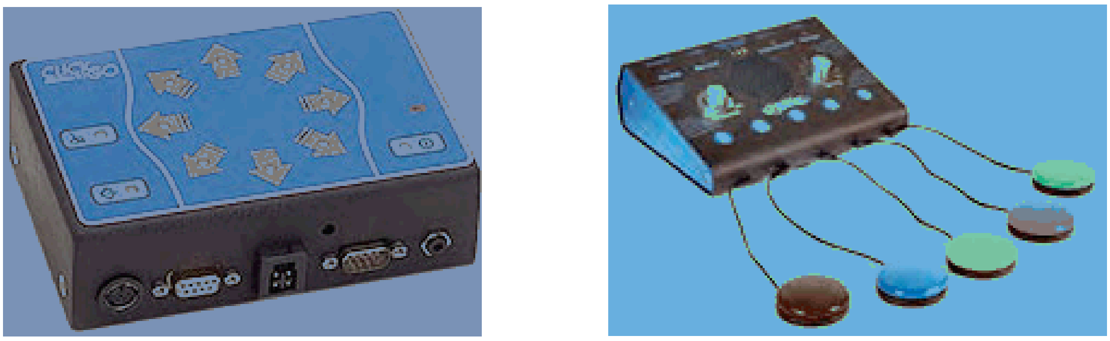

Figure 9 Switch Box Controllers for EPW Navigation [30]

For example, if the operator has stronger control over an anatomic site like the foot then switches can be mounted around the foot to control movement of the chair. The foot can also be used to control a pedal similar to a pedal on a bicycle or an accelerator in a car. This can be used to control speed or direction. Accelerometers have successfully been used on C5/C6-Level quadriplegic patients, on the elbow, as an access device on wheelchairs [31]. The shoulder has been used as a control device since the early seventies, by using dual-axis transducers researchers have successfully tested the use of shoulder movement as a control device in C4 and C5 Level patients [32]. The head can be used in several ways as a control device. With C5/C6 patients switches or Ultrasonics [33], mounted in the headrest can be used to track left and right head movement. While a joystick attached to the headrest detects forwards and reverse movement. Head tilt on a two dimensional axis can be monitored using accelerometers to control direction. There are also examples of wrist, blink and bite switches commercially available on the market.

Electropalatography [34] [35] is an instrumental technique for determining tongue/palate contact during speech. The technique utilizes an artificial palate with electrodes embedded in its tongue-facing surface. Each palate is made to fit the subject and normally requires a simple dental impression and subsequent fitting. The electrodes on the palate are connected to an electronics unit, which collects contact data from the palate and passes it on to a computer. The computer displays the contact patterns, either in real time, or off-line for analysis. This same technique was being used to control wheelchairs from as early as the nineties. The user can adapt any number of electrodes on the palette to control the direction and speed of the wheelchair. This type of interface is advantageous over others as the tongue does not suffer from fatigue like other limbs and can be controlled very accurately.

Speech control [36] is another useful way of controlling automation of EPW's. Speech systems are usually used with higher level spinal injury patients C1 – C4. The EPW's is configured with a built in speech recognition system which recognizes a small vocabulary of words used to control directional movement e.g. forward, back , left, right etc [37][38]. Some more advanced systems use speech recognition to recognize all spoken words so that the user may use it for navigation and communication through computer systems e.g. email, documents [39]. Another method is to use Electropalatography to determine tongue movements on spoken words, such as directions, and process the movements with a pattern recognition system so that the system will recognize the pattern and implement the directional movement.

Facial expression (Gesture) tracking systems [40] are a relatively new way of controlling EPW. The chair is mounted with a camera and computer system. The camera monitors the patients face and hands for gestures, it uses the face to recognize the patient, and locate the patient hands so not to mix them up with other patient's hands. Other examples include, face and gaze tracking systems [18], which monitors the position of the head and the area around the eye to see if the patient is staring in a certain direction. The chair will then go in that direction after confirmation from the user by nod or shake of the head. An advantage of this system is that the chair can monitor their surroundings and by using a nod of the head the chair can automatically be called to the patient's side. Electrooculography [41] is a novel method which uses electrodes placed around the eye to detect the position of the eyeball in its ocular cavity giving the user the ability to control the chair by eyeball movement. Fiber-optic [42] technology has also been used for monitoring the movement of the patients cheek, a headset around the ears which monitors the movement of the patients cheek checking for a wink like movement, this can simulate the left of right clicking of a mouse or be used for directional control.

4. FUTURE TECHNOLOGY

There have been several new advances in access device technology although the trend is in designing of autonomous system which requires little patient input. Researchers have had significant results in using Electroencephalogram (EEG) [43] to control wheelchair direction. This involves monitoring of the brains electrical signals and a neural network to learn patterns resulting from moving of a joystick. This is an area which shows great potential as to be able to control a chair by thought would reduce all levels of muscle fatigue and could be used widely across all levels of spinal injury patients. But as yet this is still in the experimental stage.

Capacitive and Magnetic technologies are being realised at the University of Limerick, Ireland, as possible replacements for the two dimensional switched and proportional joysticks. They require little movement from the user and act similar to that of a touch pad system on a laptop. They are inexpensive methods of tracking limb movement for use in control of EPW Navigation. They require low power consumption and can readily be adapted to any analogue or digital controller systems.

There has been significant work on integrated controllers for EPW which has led to a new ISO standard being adopted (ISO/TC-173/SC-1/WG-7). The Multiple Master Multiple Slave (M3S) [44] initiative is a European Union (EU) effort to develop a standard interface between the various assistive devices so as to make all devices plug and play and give the user increased independence and control over the configuration of the EPW.

5. CONCLUSION

As electronic devices continue to drop in price the use of Switched/Proportional Joysticks will decline with the trend lending towards Isometric Joystick Systems. Since the inclusion of micro-controller hardware, the capabilities of EPW have increased rapidly, extending the range of assistive devices on the market today. New technology has made it possible for users to fine tune the assistive devices used to control their EPW's without the need for carer intervention. Future developments will see inclusion of remote monitoring of EPW systems through onboard modems, reducing servicing time for the manufacturer and patient. Furthermore the advances in rehabilitive technology will give more flexible control over Electric Powered Wheelchair Systems.

6. REFERENCES

1. McNeil J.M., Americans with Disabilities: 1994-1995, *Data From the Survey of Income and Program Participation,* P70-61.
2. M. W. E. L. Linda Fehr, Phd;Steve B.Skaar,Phd, "Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey," Journal of Rehabilitation Research and Development, vol. 37, pp. 353 - 360, 2000
3. R. C. Simpson and S. P. Levine, "Automatic adaptation in the NavChair Assistive Wheelchair Navigation System," *IEEE Transactions on Rehabilitation Engineering*, vol. 7, pp. 452-463, 1999.
4. M. I. Bresler, "- The Tamara system for control of mobility, communication, and Enviorment.," pp. 121-123, 1992.
5. R. Madarasz, L. Heiny, R. Cromp, and N. Mazur, "- The design of an autonomous vehicle for the disabled," vol. - 2, pp. 117 -126, 1986

6. K. B. Stanton, P. R. Sherman, M. L. Rohwedder, C. P. Fleskes, D. R. Gray, D. T. Minh, C. Espinoza, D. Mayui, M. Ishaque, and M. A. Perkowski, "- PSUBOT-a voice-controlled wheelchair for the handicapped," vol. -, pp. 669 - 672 vol.2, 1990.
7. G. Pires, N. Honorio, C. Lopes, U. Nunes, and A. T. Almeida, "- Autonomous wheelchair for disabled people," , pp.797 - 801 vol.3, 1997
8. P. Beattie, "- SENARIO: SENsor Aided intelligent wheelchaiR navigatIOn," vol. -, pp. 2/1-2/4, 1995.
9. T. Gomi and K. Ide, "- The development of an intelligent wheelchair," vol. -, pp.70 - 75, 1996.
10. N. I. Katevas, N. M. Sgouros, S. G. Tzafestas, G. Papakonstantinou, P. Beattie, J. M. Bishop, P. Tsanakas, and D. Koutsouris, "- The autonomous mobile robot SENARIO: a sensor aided intelligent," vol. - 4, pp. 60 - 70, 1997.
11. G. Pires, R. Araujo, U. Nunes, and A. T. de Almeida, "- RobChair-a powered wheelchair using a behaviour-based navigation," , pp. 536 - 541, 1998.
12. S. P. Levine, D. A. Bell, L. A. Jaros, R. C. Simpson, Y. Koren, and J. Borenstein, "- The NavChair Assistive Wheelchair Navigation System," vol. - 7, pp. 443 - 451, 1999.
13. A. Roberts, W. Pruehsner, and J. D. Enderle, "- Vocal, motorized, and environmentally controlled chair", pp. 33 - 34, 1999.
14. S. Vicente Diaz, C. Amaya Rodriguez, F. Diaz Del Rio, A. Civit Balcells, and D. Cagigas Muniz, "- TetraNauta: an intelligent wheelchair for users with very severe mobility restrictions," vol. - 2, pp.778 - 783, 2002.
15. G. Bourhis and P. Pino, "- Mobile robotics and mobility assistance for people with motor," vol. - 4, pp. 7 - 12, 1996.
16. M. Imamura, R. Tomitaka, Y. Miyazaki, K. Kobayashi, and K. Watanabe, "- Outdoor waypoint navigation for an intelligent wheelchair using differential GPS and INS," vol. - 3, pp.2193 - 2196, 2004.
17. K. Tanaka, K. Matsunaga, and H. O. Wang, "Electroencephalogram-Based Control of an Electric Wheelchair," Robotics, IEEE Transactions on [see also Robotics and Automation, IEEE Transactions on], vol. 21, pp. 762-766, 2005.
18. Y. Matsumotot, T. Ino, and T. Ogsawara, "- Development of intelligent wheelchair system with face and gaze based interface", pp.262 - 267, 2001
19. Image of Human spinal Column from wikimedia, http://upload.wikimedia.org/wikipedia/commons/8/83/Gray_111_-_Vertebral_column.png
20. Bates, R., Computer Input Device Selection Methodology for Users with High-Level Spinal Cord Injuries - Proceedings of the 1st Cambridge Workshop on Universal Access and Assistive Technology (CWUAAT), Trinity Hall, University of Cambridge 25th-27th March 2002”
21. R. A. Cooper, "-Wheelchair Selection and Configuration," pp. 121 -126, 1998.
22. A. Fattouh, M. Sahnoun, and G. Bourhis, "- Force feedback joystick control of a powered wheelchair: preliminary study", pp. 2640 - 2645, vol.3, 2004.
23. eJames L. Protho, M. S., B. S. Edmund F. LoPresti, et al. (2000). "An Evaluation of an Obstacle Avoidance Force Feedback Joystick." The Proceedings of the Annual RESNAConference, Orlando, FL: 447-449.
24. Pickles B., Topping A., “Community Care for Canadian Seniors: An Exercise in Educational Planning”, Disability and Rehabilitation, vol. – 3, pp. 181-189, 1994.
25. R. A. Cooper, D. M. Spaeth, D. K. Jones, M. L. Boninger, S. G. Fitzgerald, and S. Guo, "Comparison of virtual and real electric powered wheelchair driving using a position sensing joystick and an isometric joystick" Medical Engineering & Physics, vol. - 24, pp. 703 - 708, 2002.
26. HeadStick image from AT Soloutions, http://www.atsolutions.org/images/headwand_small.jpg
27. Chinstick image from Pulsar, http://www.pulsar.org/2k/images/widgits/chinstick1.jpg
28. Sip/puff control system image from M.I.M.E. Senior Design Clinic Spring 2002, http://www.mime.eng.utoledo.edu/
design_clinic/design_ Expo/ Spring02Pages/2002-01-08/sip_puff2.html
29. Image of Head mounted Sip/puff device from Origin Instruments Corporation, 2002-2004, http://www.orin.com/
dealer_press_page/sip-puf_head.jpg.
30. Images of Switchbox controllers from Click2Go, http://www.click2go.ie
31. P. E. Crago, W. D. Memberg, M. K. Usey, M. W. Keith, R. F. Kirsch, G. J. Chapman, M. A. Katorgi, and E. J. Perreault, "An elbow extension neuroprosthesis for individuals with tetraplegia," Rehabilitation Engineering, IEEE Transactions on [see also IEEE Trans. on Neural Systems and Rehabilitation], vol. 6, pp. 1- 6, 1998.

32. J. J. Sarver, B. T. Smith, R. Seliktar, M. J. Mulcahey, and R. R. Betz, "A study of shoulder motions as a control source for adolescents with C4 level SCI," Rehabilitation Engineering, IEEE Transactions on [see also IEEE Trans. on Neural Systems and Rehabilitation], vol. 7, pp. 27-34, 1999.
33. D. L. Jaffe, "An ultrasonic head position interface for wheelchair control," Journal of Medical Systems, vol. 6, pp. 337-342, 1982.
34. Wolfgang Nutt, Christian Arlanch, S. Nigg, and G. Staufert, "Tongue-mouse for quadriplegics," J. Micromech. Microeng, vol. 8, pp. 155-157, 1998.
35. M. E. Tyler, D. Kim, and D. J. Beebe, "Development of a Tongue-Operated Switch Array as an Alternative Input Device", International Journal of Human-Computer Interaction, vol. 18, p. 19, 2005.
36. K. B. Stanton, P. R. Sherman, M. L. Rohwedder, C. P. Fleskes, D. R. Gray, D. T. Minh, C. Espinoza, D. Mayui, M. Ishaque, and M. A. Perkowski, "- PSUBOT-a voice-controlled wheelchair for the handicapped,", pp. 669 - 672 , vol.2, 1990.
37. K. Komiya, K. Morita, K. Kagekawa, and K. Kurosu, "- Guidance of a wheelchair by voice," vol. - 1, pp. 102 - 107, 2000.
38. R. C. Simpson and S. P. Levine, "- Adaptive shared control of a smart wheelchair operated by voice control,", pp. 622 – 626, 1997.
39. H. R. Singh, A. Mobin, S. Kumar, S. Chauhan, and S. S. Agrawal, "- Design and development of voice/joystick operated microcontroller," vol. - 2, pp. 1573 - 1576, 1999.
40. Y. Kuno, T. Murashima, N. Shimada, and Y. Shirai, "- Interactive gesture interface for intelligent wheelchairs," vol. - 2, pp. 789 - 792, 2000.
41. R. Barea, L. Boquete, M. Mazo, and E. Lopez, "System for assisted mobility using eye movements based on electrooculography," Neural Systems and Rehabilitation Engineering, IEEE Transactions on [see also IEEE Trans. on Rehabilitation Engineering], vol. 10, pp. 209-218, 2002.
42. R. Marsden, "100% Hands-free Computer Access- Madentec's 2000 Series," California State University, Northridge Center on Disabilities' 20th Annual International Technology and Persons with Disabilities Conference, 2000.
43. H. Lakany, "- Steering a wheelchair by thought," The IEE International Workshop on Intelligent Environments, pp. 199 - 202, 2005.
44. S. Linnman, "- M3S: the local network for electric wheelchairs and rehabilitation," vol. - 4, pp. 188 - 192, 1996.