

# A Review on Electric Wheelchair Innovation to Ease Mobility and As a Rehabilitation Tool for Spinal Cord Impairment Patient

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**Abstract**— Wheelchair is used to assist disability people to do daily activities in order to reduce depending on other to continue their living. Adding some device into it, wheelchair can be not only help in mobilization, it can be rehabilitation device to the user. This review paper focus modifications done onto market available wheelchair. Variety types of sensor used to improve the mobility of electric wheelchair and to make it as a rehabilitation tools at the same time.

**Keywords** – Instrumented wheelchair, spinal cord injury, sensors

## 1. INTRODUCTION

For those who are having impairment for lower and upper extremity, wheelchair is one of their ways to move around. These kind of people, tend to be more depressed comparing those who are healthy and wheelchair provide them mobility to ease their day. On the other hands, their depression can be reduced a little bit by moving around. In United States alone, more than 200,000 use wheelchair as their primary means of mobility[1].

The demand for electric wheelchair increasing since the price been reduced and user switching from manual to powered wheelchair[2]. Especially for patient that suffer in higher level of impairment to ease their daily life[3]. Electric wheelchair can be control by a joystick to move forward, backward, turn left and right. But for some patient with severe motor-disabilities, they can't hold the joystick properly to move around on their wheelchair.

Research to improve electric wheelchair started since 30 years ago to make sure all type of severe motor impairments patient has a wheelchair that can be used by them without bring any harm. Harm can be happened when they miss control the joystick and possibility to hit obstacle and wall. For a cerebral palsy or cognitive impairment, high-level spinal cord injury, and quadriplegia patient, they can't control amount of force to push the joystick and over pushing will caused the wheelchair accelerate instantly.

Control algorithm and control techniques should be developed in order to enhance the riding safety for them. Sensors are needed to detect and measure the object and send the signal to processor to be calculated based on algorithm set before. Control techniques is normally for a pediatrics to teach on how to control their wheelchair to move from point A to point B. Basically the objective to modify available electric wheelchair are to ease the mobility by assist the navigation and as rehabilitation tools. This review paper is discussing about type of sensors installed and how it is work to navigate the movement of electric wheelchair and modification to make it as a rehabilitation tool.

This paper is written to gather as much as possible innovation on electric wheelchair for spinal cord impairment patients. Lots of innovation has been done to cater the wheelchair movement control problem faced by the patients. Normal wheelchair can't be control easily because of they has problem to move their arm and finger especially to control the joystick. Different sensors and different algorithm used by many researcher but their objective is the same, to ease patient to control their wheelchair without hitting other object that can cause injury to them. Additional features added by making it as a rehabilitation tools at the same time to speed up recovery process.

A Review on smart wheelchair component system done by Richard Simpson, Edmund LoPresti[4]. They discussed on hardware, software and performance evaluation on 17 smart wheelchair developed from year 1996 to 2002. Variety type of sensors installed such as sonar, infrared, dead reckoning, ultrasonic, gyroscope vision, line tracker, bump sensor and navigation assistance software are well explained.

Sharmila Ashok wrote a review on innovated wheelchair focus more on hands-free control system from years 1999 to 2013 [5]. Hands-free control wheelchair is not only for disable patient but also for normal people that need to perform other task by their hand while moving around. Wheelchair's control system is based on gesture, electromyography (EMG), electroencephalogram (EEG) and electrooculography (EOG). This paper discuss about the hardware and software installed to control the hands-free wheelchair for each interface. Command to control each wheelchair and performance evaluation are also available in this paper.

This paper gather as much as possible information on innovated electric wheelchair from year 1983 to 2016. Innovation objective is not only focusing on ease the mobility of patient, including also as a rehabilitation tools for spinal cord impairment patient. Combination of sensors to improve the performance of electric wheelchair is needed to reduce possibility of misread the environment, to make rehabilitation exercise more efficient and to increase motivation of patient. Even though in a system that is using more than one sensor must be one sensor will be the dominant that other sensors can't overwrite its signal. The flow of the control process explained in this paper.

Misread the surrounding condition can cause accident to the user during operating electric wheelchair. That's why more than one sensors is needed to make sure surrounding objects are detected by system before the wheelchair is allowed to move even though all of it produce the same output. For example, ultrasonic and infrared is used to measure the distance of the object but both of it installed on the same wheelchair. As a rehabilitation tools, effect of exercise must be 100% successful to targeted area to speed up the recovery process and patient has high motivation to keep on doing it. If not, rehabilitation period will be longer and demotivate the patient.

Flow of the control process explained for some innovated electric wheelchairs that using more than one sensor to operate. But still there are few innovated electric wheelchairs that are using only one sensor. This is where the algorithm is critically that developer needs to look into to make it easy for user to operate it. Especially to researchers who are using muscle contraction detecting sensor such as electromyography (EMG) and electroencephalogram (EEG). Same goes to efficient rehabilitation electric wheelchair can be built by using correct sensors in order targeted area get the benefit out of it and can keep patient's motivation to continue do the exercise.

The objective of innovation on electric wheelchair can be divided into two. First one is to ease the mobility and number two is as a rehabilitation tool for spinal cord impairments patient. Not all electric wheelchair that innovated to ease mobility can provide rehabilitation exercise to the user. But electric wheelchair built for rehabilitation exercise, it can ease mobility of user at the same time. Type of sensors for each objective is the same but how the control system works is different as explained further in this paper.

## 2. TO EASE THE MOBILITY

Modifications are not only done to manual wheelchair, electric wheelchairs are also been focused by researchers to improve its mobility. As shown in Table 2, all are electric wheelchair modifications. Since for electric wheelchair, amount of force needed to move is not problem at all, so the researchers made improvement on navigation system.

In 1999, NavChair a Assistive Wheelchair Navigation System been developed to reduce the cognitive and physical requirements of operating a power wheelchair for people with wide ranging impairments that limit their access to powered mobility[6]. During this time, Navchair is equipped with ultrasonic sensor, and DOS-based computer to avoid obstacles, door passage, and move along the wall. In 2002, NavChair's feature upgraded by adding voice control as viable control alternative[7]. Voice control itself is impossible to do small adjustment in wheelchair's velocity because of voice's limited bandwidth. Combination between voice control and sonar sensors make the NavChair able to detect for misinterpreted commands for a better navigation assistance. NavChair' navigation assistance helps in small adjustments in speed and direction necessary to overcome obstacles.

Pediatrics electric wheelchair is also one of research area focused by researchers. Almost all the research are using electric wheelchair because of the size and propelling it is a cognitively challenging task of manual wheelchair that not suit to pediatric. Miguel Sarabia and Yiannis Demiris integrated a Nao to a electric wheelchair in order to lowering the cognitive requirements needed for controlling the movement[8].

Nao is a humanoid robot developed since 2004 and can be programmed based on what type of work planned for the robot. In this research, Nao is used to improvethemobility of pediatric wheelchair by detecting obstacles, and informing the user not hit the objects. For the result, children are enjoying driving their wheelchair with companion of Nao and at the same time they can do exercise to improve their condition. As shown is Table 1, researches done on electric wheelchair. As shown in Table 1, innovations done on electric wheelchair.

Table 1: Innovations on automatic wheelchair for spinal cord impairment person

No	References	Modifications	No of Hand Driven	Year Published
1	[9]	Electric wheelchair	One	1983
2	[10]	Sonar, infrared, bumper	One	1990
3	[11]	Infrared, ultrasonic	One	1993
4	Tin Man[12]	Sonar, infrared, bump	One	1995
5	[13]	Camera	One	1996
6	[14]	Algorithm positioning	One	1997
8	Senario[15]	Microphone, ultrasonic	One	1997
7	[16]	Sonar	One	1997
9	Wheelesley[17]	Ultrasonic, infrared, hall effect	One	1998
10	Navchair[6, 7]	Ultrasonic,mic	Zero	1999
11	[18]	Ultrasonic	One	2000
12	Maid[19]	Ultrasound, sonar, infrared	One	2001
13	SIAMO[20]	Vision, ultrasonic, infrared	One	2001
14	WATSON[21]	Camera	One	2001
15	[22]	Positioning	Both	2002
16	[23]	Camera, ultrasonic	One	2003
17	[24]	Emg, ccd camera, sonar, mic	Zero	2003
18	Smartchair [25]	Camera	One	2003
19	CWA[26-28]	Barcode scanner, PA pr	Both	2008
21	[29]	Line follower, robot	One	2010
23	[30]	Infrared ,sonar	One	2011
22	[31]	Microphone	One	2011
24	[32]	Webcam, Kinect, infrared,	One	2012
26	[8]	Robot NAO	One	2013
25	[33]	Infrared, mic	Zero	2013
27	IRC[34]	Robot arm, camera	One	2014
28	[35]	electrooculogram	Zero	2014
29	[36]	Tilt sensor	One	2015
30	[37]	EMG	One	2015
31	[38]	EMG , camera	One	2015
32	[39]	Camera, wireless control	One	2016
32	[40]	Camera	One	2016
33	[41]	Ultrasonic, fuzzy	One	2016
34	[42]	Accelerometer, Infrared, ultrasonic	One	2016
35	[43]	Electroencephalogram EEG	One	2016
36	[44]	Accelerometer	One	2016
37	[45]	Ultrasonic	One	2016
42	[46]	Size of joystick	One	2016
38	[47]	Tele-conference, pressure sensor	One	2016
39	[48]	Ultrasonic, microphone	One	2016
40	[49]	Infrared , microphone	One	2016
41	[50]	Infrared , microphone , accelerometer,	One	2016
43	[51]	electroencephalographic (EEG)	One	2016
44	[52]	Laser range	One	2016
45	[53]	EMG, solar	One	2016
46	[54]	Infrared	One	2016

47	[55]	EMG	One	2016
48	[56]	accelerometer	One	2016
51	[57]	EMG	One	2016
52	[58]	EMG ,accelerometer, gyroscope	One	2016
53	[59]	EMG	One	2016
54	[60]	Infrared, kinect	One	2016
55	HanGes[61]	Infrared	One	2016
56	[62]	EEG, laser scanner	One	2016
57	[63]	EEG	One	2016

### 3. TYPE OF SENSORS INSTALLED

#### A. Signal

Wheelchairs have been developed in a aggressively for the past years. Most of the innovation on wheelchair are by improving the mobility and riding security at the same time by adding more features such as avoiding obstacles. But, not all features are not equal in importance and interest to all patient for upper limb. So, lot of different sensors are equipped to find the best solution. Sensors are used send signal before any action taken by the actuator to move around.

#### B. Sound wave detector sensor

There are 2 type of sound wave detecting sensor available in the market to detect any object in some certain range. Sonar and ultrasonic sensor widely used to improve mobility of electric wheelchair. Sonar (Sound Navigation And Ranging) used by submarine to communicate or detect any obstacles in front of it to move without hitting any objects. In 1997, this technique has been implemented into electric wheelchair by A. Bühlmeier, M. Rossmann, K. Goser, . Manteuffel to measure the distance (between object and sensor) and send signal to microcontroller to reduce the voltage amount to the motor[16].

Since using sonar sensor produce a slow ping sound, Navchair has been developed by using ultrasonic sensor to detect the obstacles [6, 7]. Ultrasonics are the frequencies above the level of human hearing which is more than 20 kHz. Navchair developed by Simon P. Levine, David A. Bell, Lincoln A and their team to build a navigation system to reduce the cognitive and physical requirements of operating a power wheelchair for people with wide ranging impairments that limit their access to powered mobility.

Microphone added into Navchair to identify sound signal and transmits to computer and match it with joystick command to steer it to left or right. 12 Sonarsensors used as additional to improve the navigation. Sonar sensors alone is not good enough and possibility to make error is high. Error Eliminating Rapid Ultrasonic Firing (EERUF) techniques implemented to reduce the error and wheel counter keeping track of wheelchair's motion. Combination of this 2 obstacle detection method reduce the mistake in reading the signal to navigate the wheelchair better. Figure 1 below shows overview of Navchair Assistive Wheelchair Navigation System.

Same things done for SIAMO in 2001. A microphone equipped to add extra features to navigate the wheelchair to make it easier for the user. Signal from environment perception sensors (ultrasonic, infrared) is match with signal from human-machine Interfaces (microphone, head movement, joystick) to send information to motion controller to move based on commands[20]

Smart Pediatric Wheelchair developed by department of Electric and Electronic Engineering Imperial College London called Assistive Robot Transport for Youngsters (ARTY) in 2011[30]. Pediatrics powered wheelchair is difficult to develop due to safety concerns since young children can't follow instruction properly because their attention can easily change in any time. To make them focus, toys used to make sure they control ARTY to find hidden items placed around the lab. 10 sonar sensors installed under the rim bar to perceive the surrounding to prevent ARTY from hitting wall or obstacles.

TABLE 2. Sound Wave Detector Sensor

No	References	Target Group	Year Published
1	[10]	Adult	1990
2	[11]	Adult	1993
3	Tin Man[12]	Adult	1995
4	Senario[15]	Adult	1997
5	[16]	Adult	1997
6	3Wheelesley[17]	Adult	1998
7	Navchair[6, 7]	Adult	1999
8	[18]	Adult	2000
9	Maid[19]	Adult	2001
10	SIAMO[20]	Adult	2001
11	[23]	Adult	2003
12	[24]	Adult	2003
13	[30]	Adult	2011
14	[41]	Adult	2016
15	[42]	Adult	2016
16	[45]	Adult	2016
17	[47]	Adult	2016
18	[48]	Adult	2016
19	[50]	Adult	2016

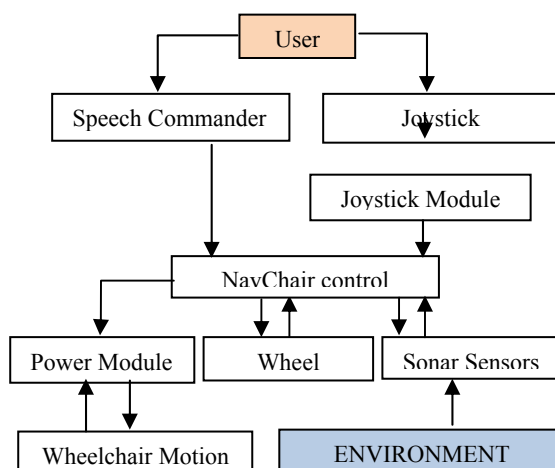


Fig. 1. Navchair Assistive Wheelchair Navigation System

C. Voice recognition

Voice or audio is an analog signal which is needed to be converted into digital signal in order for computer to read the signal. All speech patterns are stored inside the drive and when the system running, it will use the memory to match with what command send by user. Researcher installed microphone to record the analog signal and use that signal as command to control the wheelchair. For paraplegia and tetraplegia patient, producing audio signal is not a problem and that’s why it become choice for most researcher to gain signal to innovate current wheelchair.

However, some voice-recognition systems make errors by detecting sound from environment such as other people conversation, audio from television, radio and many more. These disturbance can produce false input and will affect the smoothness of wheelchair movement. To overcome this matter, Akira Sasou combining signal form user’s head gesture and voice to move the wheelchair [31]. As the result is average recognition accuracy was 99.7 %.

Bharati Vidyapeeth University did the same thing by implementing additional sensor to reduce mistake in interpreting signal by adding infrared to their wheelchair[33]. Stored voice commands are Forward, Reverse, Left, Right and Stop and user need to use all these 5 commands to control the wheelchair. Voice signal recognize from microphone will be recognize the pattern by Matlab and at the same time signal from infrared come together to detect obstacles at the surrounding. All these 2 signals will be processed and if there is obstacle in the way, buzzer will beep and stop the wheelchair to prevent any bad things happens as in Figure 2.

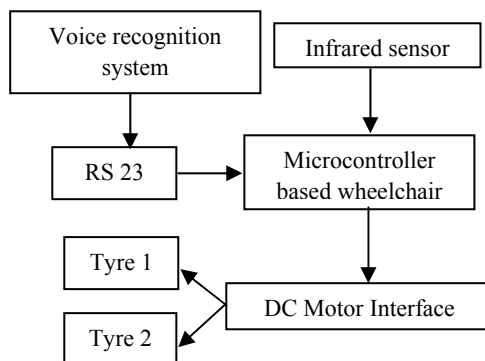


Fig. 2. Overview of navigation system

Fig 1 TABLE 3. Voice Recognition

No	References	Target Group	Year Published
1	Senario[15]	Adult	1997
2	Navchair[6, 7]	Adult	1999
3	[24]	Adult	2003
4	[31]	Adult	2011
5	[33]	Adult	2013
6	[48]	Adult	2016
7	[49]	Adult	2016
8	[50]	Adult	2016

#### D. Infrared

Infrared works almost same as ultrasonic and sonar. Both has emitter and receiver to detect object’s distance in front of us. Normally infrared is used to measure thermal energy in certain object that produce heat. But in this case Maid has used it as short-range motion detector[19]. Laser finder and sonar installed together to navigate Maid for its main task which is navigating in a crowded areas is to reach a targeted area without hitting any objects.

Navigating in crowded area require Maid’s computer to has maneuver for every 0.3s because of using short range motion detector that need to detect fast to avoid collision. Even though infrared maneuver is around 70ms, but since it connected to low transmission rate of the range-finder it become 0.3s. Maid tested in central station of Ulm Germany duringrush-hour and in the exhibition halls of the Hannover Messe and it lasted for 36 hours in public, crowded environments with heavy passenger traffic.

MIT developed Wheelesley which used 3 type of sensors, infrared, sonar and Hall Effect sensor. All these 3 sensors are used especially in indoor environment to provide users with driving assistance, taking over low-level navigation to allow its user to travel efficiently[17]. For wheelesley, infrared sensor which give binary readings that indicate if there is something blocking in one foot distance if sonar sensors unable to detect it.

Sonar reading sometimes effected because of noisy environment and will send wrong signal to controller. So infrared act more dominantly compare to sonar sensor. Hall effect sensor is attached to wheelchair bumper as last obstacle detector. It has been tested and bumper hit the obstacle only once for the whole time (10 hours testing time).

TABLE 4. Infrared Sensor

No	References	Target Group	Year Published
1	[10]	Adult	1990
2	[11]	Adult	1993
3	Tin Man[12]	Adult	1995
4	Wheelesley[17]	Adult	1998
5	SIAMO[20]	All	2001
6	[30]	Paeds	2011
7	[33]	Adult	2013
8	[42]	Adult	2016
9	[49]	Adult	2016
10	[50]	Adult	2016
11	[54]	Adult	2016
12	[60]	Adult	2016
13	HanGes[61]	Adult	2016

*E. Image detection*

Image detection device or camera also has been used to provide guidance in controlling electric wheelchair. Nara Institute of Science and Technology developed a wheelchair (Watson) that can be controlled by using head and gaze motion[21]. Image recorded by a CCD camera which mounted 15° lower than user head position for easier to observe the irises position because of eyelids tend to occlude the irises when looking and not to block user view. Vertical and horizontal head turning angle observed by camera to either user want to stop, start, turn left or right and speed control. For stop and start, user need to nod their head for 20° up and down for 2s. Head turning determine the direction of wheelchair and if movement of head and gaze are not same, Watson will slowdown and turning radius also become bigger to avoid hitting obstacle when the user is not focus.

Intelligent Robotic Chair (IRC) is an autonomous intelligent wheelchair developed based on modified wheelchair called Nosokoma use camera 3D objects by using synthesis of 2D views[34]. In order to recognize it, IRC need to use image segmentation, wavelets, Regions Synthesis Local-Global graphs, and an object-Database (DB).

Some objects have been stored in IRC’s database and it make easier for it to detect the location in providing better guidance. IRC also has ability to detect new objects by combining the image from database and interact with human subject to confirm it as obstacle and then save it to improve its knowledge. After recognition stage, the signal is use in process of object detection and tracking. This is where object’s distance, size and location are calculated by computer so that IRC’s robotic arm-hand can grasp the object as desired by human subject or user. Neural nets and fuzzy algorithms developed to control the robotic arm-hand in grasping method to prevent from breaking the object. Tested on picking up an egg and successfully grasping it and deliver to human subject with breaking it. Cameras are not equipped to detect object location only, it also used to detect human subject location to deliver the desired item. Human subject can be anywhere inside the room and give instructions to IRC via voice interaction system without riding it to picking up anything that they want. Figure 3 shows overview of IRC Navigation system.

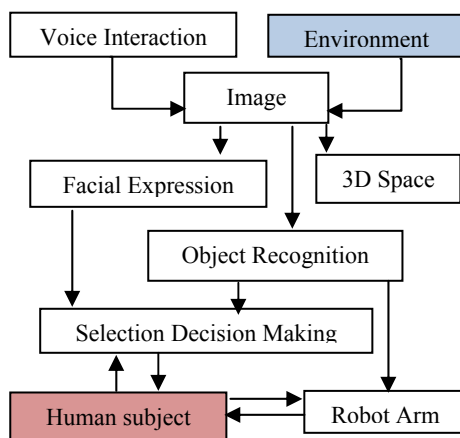


Fig. 3 . Overview of IRC navigation system

Table 5. Image Detection

No	References	Target Group	Year Published
1	[13]	Adult	1996
2	SIAMO[20]	All	2001
3	WATSON[21]	Adult	2001
4	[23]	Adult	2003
5	[24]	Adult	2003
6	Smartchair [25]	Adult	2003
8	[32]	Adult	2012
7	IRC[34]	Adult	2014
9	[38]	Adult	2015
10	[39]	Adult	2016
11	[40]	Adult	2016
12	[47]	Adult	2016

*F. Muscle contraction detector*

Every movement of human part is because of muscle. Muscle can do two type of contraction, isometric and isotonic. Isometric when a muscle contracts with no any movement happen and isotonic when muscle shortens (concentric) or lengthens (eccentric). Before all these 3 movement happen, motor neurons transmit electrical signals that cause muscles to contract. Researchers use that electric signal to translate into graphs, sound or numerical values to control wheelchair known as electromyography (EMG).

Researchers from Korea Orthopedics and Rehabilitation Engineering Center proposing to build a robotic wheelchair can be controlled using on electromyogram (EMG) signal, face directional gesture, and voice. Detected signal transfer to human-computer interface to process and wheelchair move as intended by the user. 2 EMG sensors located on both side of levator scapulae muscle (LSM) of user and the signal generated from elevation motions of shoulder. Left shoulder elevation will send signal to turn left and same goes to elevation of right shoulder, it will turn right. Same movement of both levator scapulae muscle will signal the wheelchair to stop and go.

Biswajeet Champaty, Jobin Jose, Kunal Pal control the wheelchair using Electrooculogram (EOG)[35]. They believed that EOG signals is an attractive mechanism for developing human-machine interface because even the terminally-ill patients still has residual eye movement that can be convert into EOG signals. EOG signals appear over the skin surface during the movement of the eye because of the difference in the dipole moment between the retina and the cornea of the eye[64]. Obtained signal from eye movement transfer to LABview to do better filtering for a better result. Then, the signal transmit through radio frequency (RF) to 4 microcontroller to process the signal from 5 EOG sensor before any action taken by the motor. Up, Down, Left, Right and blink represent forward, backward, left, right and stop movement of the wheelchair.



S. Sathish, K. Nithyakalyani and their team members develop an control system by using EMG signal to control robotic wheelchair for paralysed persons[55]. Flow of the signal process as shown in figure 7. Start from electronic current converted by Ag-AgCl surface electrodes from contraction of muscles. Voltage for EMG signal is between 0 to 5mV and the frequency is between 0 to 500Hz. But normally the frequency will be between 50 to 150Hz only and noise will be 0 to 10 Hz and 500Hz. 0 to 10 Hz is due to vibration of the equipment and 500Hz because there is a movement between EMG electrode and user's skin. High-pass filter used to eliminate the 500Hz noise and low-cut filter is for low frequency noise. Filtered signal amplified to 5V before goes to microprocessor. Microprocessor works at 5V. In the amplifier stage, precision rectifier installed to convert bipolar EMG signal to unipolar signal. When user's head is moving, both electrodes will produce different voltage and comparator used to recognize it to determine the direction of movement. Pattern of signal will be recognize by microprocessor to instruct the wheelchair to move forward, turn left or right. Their system tested on prototype and the result is it move forward smoothly but turn left and right need improvement for precise sharp turn.

TABLE 5. Muscle contraction detector sensor

No	References	Target group	Year Published
1	[24]	Adult	2003
2	[35]	Adult	2014
3	[37]	Adult	2015
4	[38]	Adult	2015
5	[43]	Adult	2016
6	[51]	Adult	2016
8	[53]	Adult	2016
7	[55]	Adult	2016
9	[57]	Adult	2016
10	[58]	Adult	2016
11	[59]	Adult	2016
12	[62]	Adult	2016
13	[63]	Adult	2016

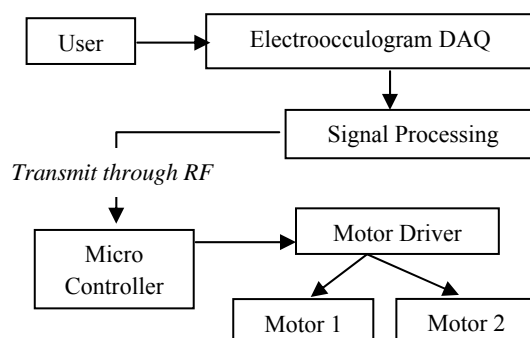


Fig 4 . Overview of navigation system

#### 4. DESIGN

Since electric wheelchair is for chronic patient which can't use their upper limb to propel the normal one. It equipped with joystick to control both motors that located on both wheel to remove propulsion effort. Researchers use this advantages to enhance it to fit patient group based on their disability to improve mobility for user. In 1995, DAVID R MILLER developed a low cost robotic wheelchair call TinMan by adding extra control features to a normal electric wheelchair made by Vector Wheelchair Corp[12]. Most of researchers improve current automatic wheelchair with installing another controlling system for the user.

But for companies, in order to build a wheelchair that fit to man as possible, they improve on the capability of their product. Such as ROVI® MOBILITY, Ltd launched a new automatic wheelchair ROVI X3 that already improved in last longer battery. As we know, automatic wheelchair is very weight and need big amount of energy to move around. A good battery is needed for when the user going outside, their wheelchair have enough power to return to their home.

One of main problem for wheelchair user to move between floors when there is no lift provided in that building. DEKA and Johnson and Johnson's Independence Technology division has taken this matter seriously and built iBOT to overcome this problem. iBOT has two sets of wheel so that it can climb and go down stairs without any problem. It equipped with gyroscopes so that it can stand on 2 wheels to reach something higher.

These gyroscopes features used in Solax Via to stand on two wheels and can be controlled by using user body. Solax Via will move forward, backwards, turn and remain stationary when user shift their body's center of gravity. Hand controls in the tiller will control to turn left or right. Via is built for user who like to play sport such as basketball that needs fast reaction to move and need both hand to play. So Solax provide a wheelchair that can move without joystick

Pride Quantum 6000 Rehab Power Wheelchair developed by Quantum Rehab® to provide almost the same features as iBOT. But quantum 6000 can't raise its seat level to reach something higher. Even though it's called rehab wheelchair, it not providing rehab exercise for the patient. Quantum 6000 has extra capability by reclining 85° - 175° for the user to lay on their wheelchair. So the patient can do rehab while laying on it.

## 5. ELECTRIC WHEELCHAIR FOR REHABILITATION

Rehabilitation is an important process for the patient to recover after suffered a stroke. The effect is they have hard time to move their body parts based on what they desire. So they need to relearn to improve their movement to ease daily life and get back to work as soon as possible[65]. In rehabilitation process, there are physiotherapy treatments to do physical work such as to move their body part. In this treatment, patients taught by physiotherapist on how to move in a correct way, monitor to see any improvement and design type of rehabilitation exercise that suitable according to patient's condition. Full attention are needed to make sure speedy recovery progress. However, numbers of physiotherapist is a main constraint on giving full attention on each patients[66]. Rehabilitation tools are needed to replace them.

Shuang Chen, Fang-fa Fu and their team members comes out with an idea to build intelligent rehabilitation training tool which has tele-doctor-patient interaction system[47]. They installed 4 linear motors on electric wheelchair to provide lower limb training function and Bluetooth communication system to send information to the doctor or physiotherapist for monitoring patient's recovery process. Pressure sensor located at the foot rest and user needs to move their center of gravity to give different amount of pressure onto it. Different pressure will decide the movement of airplane to reach bombs and diamonds in a video game as in Figure 5. Patients will play and at the same time it becomes rehabilitation exercise for them.

For pediatrics, Laura Marchal-Crespo, Jan Furumasu and David J Reinkensmeyer developed a robotic wheelchair trainer to reduce time for hand-over-hand assistance from a skilled therapist called ROLY (Robot assisted Learning for Young drivers) as Figure 56 . Their robotic wheelchair trainer will move itself follow along a line on the floor using computer vision to show the correct joystick control technique. A mobile robot equipped with line following system placed at the front of the wheelchair to attract user's attention to catch it as motivation for them to do the training. Tested on two groups of children, one is a normal children and children with a severe motor impairment due to cerebral palsy. Normal children drive the ROLY without guidance by joystick in front of them but for cerebral palsy impairment children guidance is provided. After the training session, cerebral palsy impairment children improved steering ability better than normal children.



Fig. 5. Interface of Rehabilitation Game

Table 6. Rehabilitation Wheelchair

No	References	Degree of freedom	Target group	Function	Modifications	Year Published
1	[67]	2	paeds	Rehab	Line follower, robot	2010
2	[47]	2	adult	Rehab and mobility	Tele-conference, pressure sensor	2017

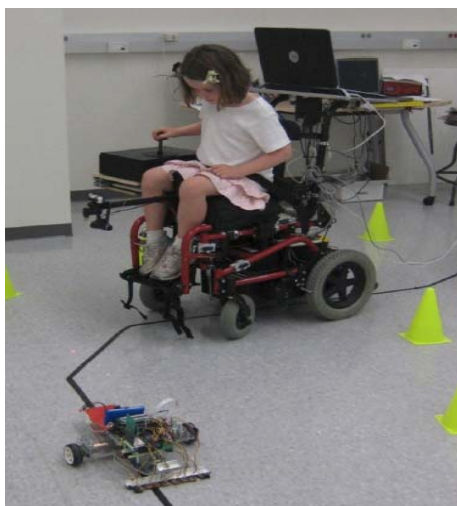


Figure 6. Roly

### 6. CHALLENGE IN DEVELOPING WHEELCHAIR

On January 12, 2010, an earthquake struck Haiti and lots of people died and injured. Some of them paralyzed and they need wheelchair to continue live their life. Due to cost, some of facilities neglected patients who need rehabilitation and refuse to treat them[68]. Cost is very important aspect researchers need to look into because not all patients has capacity to buy expensive rehabilitation tools [69-71].

Easy for maintenance and parts are available anywhere is one of the challenge in developing a wheelchair for spinal cord injury patients[72]. In a poor country, a wheelchair will be used in anywhere even it's not built for that kind of environment because of lack of equipment available on market[73]. Too high level of technology installed will make the wheelchair prone to damage and make it more difficult to maintain or repair. That's why the mechanism should be as simple as possible and spare part is available anywhere.

Keep patient motivated to continue the rehabilitation exercise must be considered by motion-based game interaction wheelchair. Different ages of user need different type of games[74]. As age increased, patient's ability will decrease due to reduction of muscle mass, stamina and strength[75]. Same things will happen to their hearing, vision and reaction will decrease from time to time [76]. Researcher should provide few type of games that can be selected based on user's age, abilities or the one that they are interested.

Each of wheelchair available on market must meet requirement from American National Standards Institute (ANSI) or Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) standards to make sure all user are safe during operating the equipment. Any innovation done on electric wheelchair must be follow these requirement before tested on user in order to prevent bad things from happen.

### 7. CONCLUSION

Numbers of research on improving quality of life for spinal cord impairment patient shows humanity in our society still exist. Everybody can contribute to others in different ways to make sure these unlucky people are not left behind in every aspect. Advancement in technology contributing in building a better wheelchair for disabilities. As we can see, after technology for muscle contraction detector is available, the numbers of sensors installed in an electric wheelchair is reduced to only one. Better algorithm developed to reduced accident happens due to misread of signal by the sensors. And different approach used to increase motivation and recovery process for the patient to regain their ability back to return to work.

Manufacturers should be do collaboration with the researchers to market the innovated wheelchair to reach more people who are suffering same disability. They may manufacture the same innovated wheelchair for commercialization or gather all the information and result done by researchers to produce a better wheelchair that can fulfil the need from different group of disabilities. Combinations from different sensors needs different hardware to make it a system but all of them produce same result in navigating the wheelchair. Almost all produce a good result and just a few need small improvements to make it perfect.

Adding rehabilitation features into a wheelchair is a good innovation to reduce the cost, space and time for patients to speed up their recovery process. Cost for them to go to rehabilitation can be reduced if they are able to do the exercise at home and eliminate space to place rehabilitation tools. And most important thing is save time. They can do rehabilitation exercise during living their daily life by riding the wheelchair.

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