Towards Developing an Intelligent Wheelchair for People with Congenital Disabilities and Mobility Impairment

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***Abstract*—Physical disability in people may be either congenital or acquired. In either cases, the disable person requires an aid for movement in both indoor and outdoor environment. The most common form of assistance to provide support to the disabled is the wheelchair. In this research paper, we are presenting our prototyped and developed wheelchair that is designed to provide assistance to various types of mobility impairments. It has the provision for both - voice commands as well manual controls via a joystick. People suffering from various motor disorders are incapacitated and thus, need to use other ways to control the wheelchair. For this reason, the wheelchair includes customizable voice control system which is Bengali by default. Along with the modes of controls, the wheel chair incorporates a feature that can be used for asking help in case of a necessity. Thus informing a relative or caregiver has been simplified which notifies them if the user is in need. Along with this, the provision of continuous monitoring is also present for ease of caregivers to locate the user when help is asked or the caregiver is unable to be physically present with the user. Other features such as obstacle detection, speed control on ramps, lighting up of the headlight in dark environment, reclining of the wheelchair has been integrated in the wheel chair as well. The prototype was demonstrated and evaluated in a controlled environment, The outcome of the experiments proved its effectiveness and efficiency for the focused users.**

***Index Terms*—Intelligent system; eHealth; Congenital disability; Mobility impairment; Smart wheelchair**

I. Introduction

Disability is a disorder that hampers the daily life of the affected people by limiting the person's movement, senses, ability to think or act. Disability can either be congenital or acquired. Congenital disabilities are usually inherited while acquired disabilities occur due to any accident or illness. According to the report of Australian National University, disabilities can be of different types i.e. vision impairment, deaf or hard of hearing, mental health conditions, intellectual disability, acquired brain injury, autism spectrum disorder, physical or motor disability [1]. Motor disability is the partial or total loss in muscular functions of the body [2]. These disabilities include arthritis, cerebral palsy, multiple-sclerosis, muscular dystrophy, acquired spinal injury (paraplegia or quadriplegia), post-polio syndrome, spina bifida [3]. All of these disabilities inhibit the normal movement of the affected people.

Nearly 15% of the world's population consists of people having disabilities and 2-4% of them have serious problems in functioning [4]. According to a U.S. Census Bureau report

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during the period of 2008-2012, nearly 40% of people aged 65 and above had at least one disability and of those 15.7 million people, two-thirds of them were reported to have problems in either walking or climbing [5]. In 2014, 3.8 million veterans in US had a disability that was a result of a disease or injury during their service in the military [6]. Bangladesh has a population of 163 million [7] of which nearly 10% comprises of people with disability [8]. So, around 16.3 million people in Bangladesh are suffering from some kind of disabilities.

Despite the fact that, one of the most common aids for movement for the physically impaired people is the wheelchair, it is still not enough to meet the needs of all types of motor disabilities. Wheelchairs are mainly designed to help people suffering from disabilities in the lower limb area. As a result, people who have issues like tremor or problems in the upper limb area are unable to operate the wheelchair properly. Along with this problem,it is almost impossible to always provide assistance to the affected patient. Smart wheelchairs are widely used in developed countries to address these problems which costs roughly between $750 to $13000 [9]. Thus they are not affordable to the disabled people of developing countries like Bangladesh. Moreover, language barrier has been a barrier in adopting technology in Bangladesh. Keeping these problems in mind, a smart solution has been devised that incorporates the disabled patient to have the maximum control of the wheelchair and can be operated with the help of voice as well as a joystick. It also includes continuous monitoring so that caregivers can check on the patient without being physically present near the patient at all times. The main aim is to provide complete freedom of movement without any external assistance. The smart wheel is also integrated with other features such as reclining back to avoid muscle cramps, asking for help via SMS by a simple click, obstacle detection, lighting up the wheelchair's light in dark environment, and speed control to provide maximum ease to the patient.

Therefore, the objective of this research is to solve the aforementioned problems by designing a prototype of a smart wheelchair that will provide maximum assistance to the disabled so that they can move with maximum independence.

In the following sections, Section II presents the overview of the Related Works, Section III comprises of the Conceptual Design of the System, Section IV discusses the Implementation of the System. The demonstration and evaluation results are discussed in Section V. Finally, Section VI contains the Conclusion.

II. Related Works

A significant part of the world population is being affected by the motor or physical impairment. Hence, researchers have been doing studies to ease their struggle. As a result, number of studies has already been carried out. A wheelchair was developed by Meena et al. [10] for paraplegic and other physically disabled people. A combination of voice recognition and use of joystick was done by controlling the locomotion of the wheelchair. Simpson et al. [11] developed Smart Power Assistance Module (SPAM) which was intended for physically disabled people who were also blind. Keeping vision impairment under consideration, the chair provided obstacle detection which reduced the number of collisions on a simple navigation task.

Ding et al. [12] proposed a personalized wheelchair navigation that will provide real-time navigation support which could be used in dynamic and complex environment. An electric wheelchair invented by Perry [13] was able to selectively position the wheelchair in a sitting position, standing position or a reclining position. Here, the transfer from a wheelchair to a bed was made easy since the pressure was relieved in the lower extremity, by adding the ability to recline the back of the wheelchair.

Braga et al. [14] introduced the concept for intelligent wheelchairs called IntellWheels that took inputs from traditional and USB joysticks, keyboard ,head movement as well as facial expressions.

An intelligent wheelchair using voice and touch screen is described in the research work by Prathyusha et al. [15] where programmable voice recognition circuit was used for voice commands.

Mazo et al.'s [16] discussed a wheelchair that can work on voice commands as well as by autonomous driving which is able to detect obstacle,like holes, walls etc.

The research work on "Hephaestus Smart Wheelchair System" [17] is imagined as a progression of parts that clinicians and wheelchair makers will have the capacity to attach to standard power wheelchairs to change over them into "smart wheelchairs". This research work describes a prototype that represents the development of a commercially used smart wheelchair system that is compatible with power wheelchairs.

Nishimori et al. [18] proposed a system where a person will be able to control the wheelchair with voice commands. They proposed three types of commands, the basic reaction command, the short moving reaction command, and the verification command. The paper by Simpson and Levine [19] discussed about the problems that arise from the inability to recognize voice in voice recognition interfaces with the wheelchair and also worked with obstacle avoidance in case of failure to interpret voice commands .

Standard joystick interfaces are not always efficient for all users to navigate properly. Yanco [20] came up with a solution of a robotic wheelchair system, Wheelesley which provides navigational assistance for the user and takes high level directional commands. The chair makes it accessible for the disabled to move in areas having ramps , doorways with sufficient width for the user to pass.

In a clinical survey, Fehr et al. [21] talked about the inadequacy of the electrical wheelchair at current times since people with severe disabilities will not be able to steer power wheelchair in areas where space is limited.To find the adequacy of control interfaces, control methods such as joystick, sip-and-puff and head or chin controls were used.

Levine et al. [22] developed the NavChair Assistive Wheelchair Navigation System for users of large range of disabilities. The proper level of assistance was offered by using

ultrasonic sensors, joystick and an interface module. It also had obstacle avoidance, door passage and automatic wall following and was able to move through crowds and make abrupt change in directions with minimal reduction in speed.
Patterson [23] proposed a customized wheelchair which consisted of an actuator to move the seat support bar forward or rearward, length wise, within the wheel base of the wheelchair and a control switch was used for this.
A voice commandable wheelchair was built that not only had the advantage of having a speech interface but also had sensors to perceive the wheelchair's surroundings. This came with additional location determination at room level and also saved the previously named location which made it easy to go that location [24].

A Smart Chair [25] was built that focused on parallel computer processing where hardware, software and sensor technology was integrated. Computer motion control program, path planning, vision enhancement for terrain perception are included in the wheelchair. The system is designed in such a way that the human takes the decision and the rest of it's motion is controlled by the smart control technology.

An Android Controlled Smart Wheelchair [26] was built which reduced the need for external assistance by designing the control architecture in such a way that an android device can operate the wheelchair. It includes the driving command as well the break command. It also included biometric feature to alert the surrounding people in critical conditions.
The Smart Wheelchair Component System [27] was developed that could be added to exisiting wheelchairs with minimal modification. It was mainly based on detecting obstacles at a definite range along with the size of the obstacle. Obstacles at various directions either singularly or presence in both directions was also tested.Along with this, drop-off detection for curbs and staircases were also included where the wheelchair slowed down gradually. It was then tested across four existing wheelchair models.
A smart wheelchair was developed that used eye movements to drive the wheelchair [28] . The web camera has been used to detect the eye movement and an error handling mechanism has been used to calibrate values of threshold for the eye movement for the user.

To sum up, most of the mentioned wheelchairs did not contain any continuous monitoring. Again, a very limited number of works will be able to help people of Bangladesh in terms of cost and voice commands. Along with these, the provision of light and speed control for ramps was not handled properly. Therefore, this research concentrates on building a smart intelligent wheel chair with continuous monitoring using Bengali command. This paper handles the aforementioned limitations which in turn paved the way towards an affordable wheelchair option with multiple functionality that can provide maximum support in a affordable cost to the disabled. The proposed system in this paper tries to use the existing technology in a new manner to help physically impaired people in Bangladesh.

III. Conceptual Design of the System

The proposed system is a voice controlled smart wheelchair which supports any language but Bengali has been chosen in order to support the physically impaired people of Bangladesh. Along with the voice control, it also supports manual control. The two methods have been kept for reaching out to various types of mobility impairments. Figure 1 represents the basic work flow of the wheelchair. .

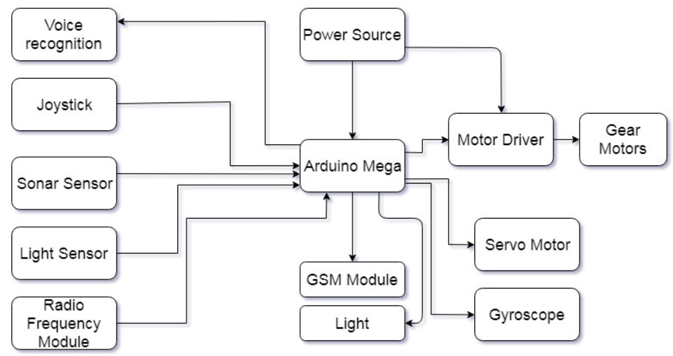

Fig. 1. Architecture of The Proposed Smart Wheelchair

A. Features of the smart wheelchair

The smart wheelchair will include the following features to attain the objective of this research:

1) *Manual control*: Manual control is for those disabled people who are able to use their hands for controlling the movement of the wheelchair. A joystick is used for enabling the manual control which will move the wheelchair in the forward, backward, right and left direction.The joy stick is not fixed with the body rather it is wirelessly connected and movable.
2) *Controlling through voice commands*: Disabilities like quadriplegia make the users unable to use manual control for wheelchair for which voice commands has been incorporated with the system. The commands can be customized to any language. For this project Bengali language has been considered. The commands are 'Dane', 'Bame', 'Samne', 'Pichone', 'Thamo' which interpret in English as 'Right', 'Left', 'Forward', 'Backward' and 'Stop' respectively.
3) *Sending SMS for help*: Despite the various precautions taken, the user might still fall down from the wheelchair or need external help. For this, the voice command, 'Shahajjo' (help) will send an SMS including the chair's current location to the user's caregiver asking for assistance. Figure 2 represents the working procedure of the system for Sending SMS.
4) *Longitudinal obstacle detection* : Obstacle detection is required so that the wheelchair does not bump into pillars, walls or any other object even if the user gives gives commands that would accidentally cause collision. Therefore, upon detecting, the wheelchair will automatically stop when a certain obstacle is present at the front

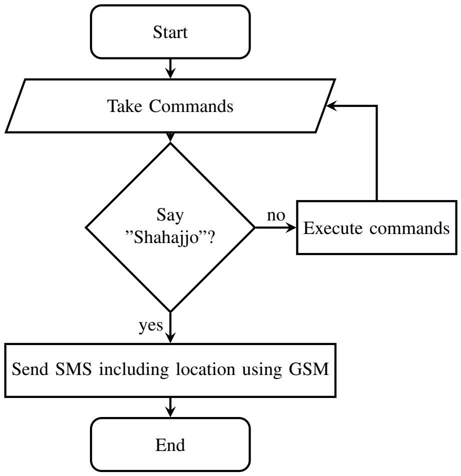

Fig. 2. Working Procedure for Sending SMS

or rear and will not execute any given command in that direction.

5) *Speed Control*: While going up and down the ramp, the speed needs to automatically counteract the increasing or decreasing speed due to gravity. So, for slopes or ramps, depending on the upward or downward direction the speed will automatically increase and decrease respectively.It works for both forward and backward direction. Figure 3 shows the working procedure of the process of speed control.

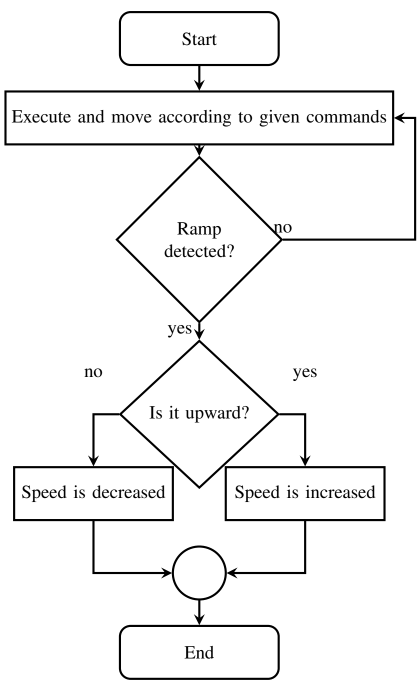

Fig. 3. Working procedure of Speed Control

6) *Continuous Monitoring*: Many disabled people often have caregivers. Since it's not always possible for them to be present at sight, the continuous monitoring is kept so that the user's movement can be tracked with current location.
Its done by receiving the satellite data through GPS. Then the WIFI module gets that data, decodes it into latitude and longitude and sends it to the cloud server. Thus the wheelchair's location can be accessed from the mobile phone. Figure 4 describes the architecture of Continuous monitoring using GPS and Wi-Fi Module.

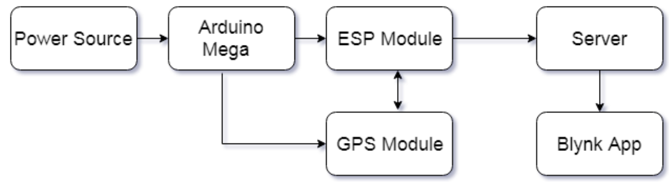

Fig. 4. Block Diagram of Continuous Monitoring

7) *Reclining the wheelchair*: Sitting down continuously in the same position is not good for the health of the user [29]. Moreover user's comfort have to be considered as well. So, option of reclining is kept to break the monotonicity and making it more comfortable. Therefore the back of the wheelchair can be reclined to any position as per the user's comfort.
8) *Light Up*: The user might have to move in indoor or outdoor environment with insufficient light or there might be unavailability of light due to power outage. In these circumstances the wheelchair will sense the shortage of light and automatically light up. Figure 5 demonstrates the working procedure of this feature.
9) *Controlling the Wheelchair from a distance*: The user will be benefited by this feature when he is not on the wheelchair. The user can give command from a certain distance and the wheelchair will move according to the command. This will prove to be helpful when the user is lying on the bed and the wheelchair has been moved away from him. We have preferred to use Bengali language for this.

IV. Implementation of the System

A prototype has been developed for demonstrating the above mentioned features which has been shown in Figure 6. The whole implementation was carried out in an academic environment. The wheelchair is powered with the help of two batteries. One low voltage battery is used to power up the Arduino which is programmed to control the wheelchair and another high voltage battery is used to power up the motor driver. The motor driver is able to drive only two motors. Therefore two pairs of motors on each side are connected in parallel and is being driven by the motor driver. There are four wheels for each of the gear motors.
The main hardware components are the different modules that are connected with the Arduino. An Arduino Uno is used for controlling the wheelchair from remote distance. Radio Frequency module is used for this purpose. Two Arduino Mega are used for integrating all other modules implanted on the

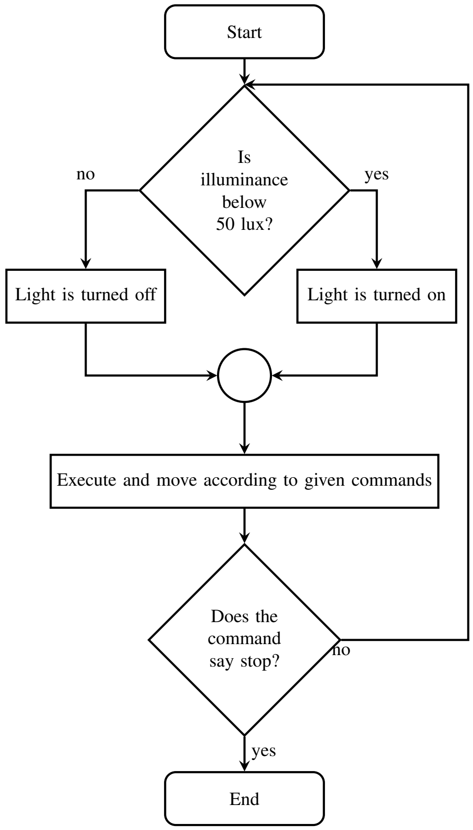

Fig. 5. Working Procedure of Light Up

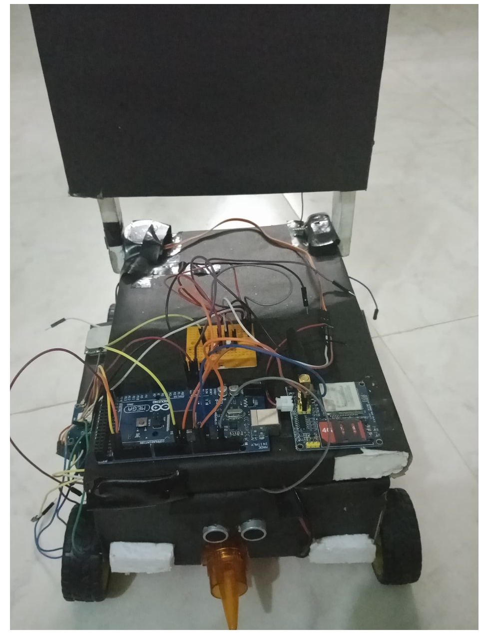

Fig. 6. Real Image of the Prototype

wheelchair body. It could be done using one Arduino Mega. But to distribute the load and for proper wiring two Arduino Mega have been used.
A Joystick is used for controlling the wheelchair manually. Five commands can be given through this joystick. The commands are for forward movement, backward movement, right movement, left movement and stopping the movement.
Controlling the wheelchair by voice command has been done using voice recognition module. Firstly, the voice recognition module has to be trained. Based on the training, it recognizes the commands and moves accordingly. This wheelchair can be trained in any language. But the Bengali language has been chosen for our academic work. The commands are same as manual commands but in addition to that one more voice command has been added.
In case of danger or emergency,the user can speak out the voice command ”Shahajjo” which means ”help” in English. Then, it will execute the command and the current location of the wheelchair will be sent by SMS to the previously saved number with the help of GSM module. The current location of the wheelchair is computed from the data of the GPS module.
An additional pre-existing ”Blynk” [30] application has been used for viewing the location for continuous monitoring. For this purpose, GPS module and WiFi module is paired up. GPS module collects the latitude and longitude of the current location of the wheelchair and sends to the Blynk app server using WiFi module.
In order to go up and down the ramps with constant speed, the previously mentioned setting of the wheelchair is not enough. So, a Gyrometer has been utilized for detecting the slopes and it has been programmed in such a way that the speed will increase while going up and decrease while coming down to combat the effect of gravity.
Two ultra-sonic sonar sensors have been used to detect obstacles. Inspite of getting command to move, if the sonar sensors sense obstacle in the forward or in the backward direction, the wheelchair will stop moving automatically and it will not further execute any commands in that particular direction till it is away from the obstacle.
If the illuminance of the wheelchair environment is below 50 lux, light sensor will sense this and a headlight which is placed in front of the wheelchair will automatically light up. When there is sufficient illuminance, the headlight will not turn on automatically.
Servo motor is used at the back of the wheel chair to recline the wheelchair according to user comfort. Two switches are placed in the wheelchair to recline the upper part of the wheelchair. Servo motor has been used for the prototype, but for actual implementation it might not be sufficient to balance the weight. The total cost for making the prototype was near about 10,260 BDT. List of equipments and their costs are given in Table I.

V. Test and Evaluation

The evaluation study was conducted at Software Engineering Laboratory of the author's institute. The system was tested in a room of rectangular shape with 8 feet length and 6 feet width. The route and milestone points are showed in Figure 7. To test the effectiveness and efficiency of the system, a number of scenarios were trailed, that includes: (a) rthe system

TABLE I
LIST OF EQUIPMENTS WITH COST

Name of the Component	Quantity	Unit Price (BDT)	Total Price (BDT)
Arduino Mega	2	750	1500
Voice Recognition module	1	2400	2400
Frame for Prototype	1	100	100
Joystick	1	95	95
GPS Module	1	870	870
Gyroscope	1	230	230
Sonar Sensor	2	95	190
Light Sensor	1	160	160
Wifi Module	1	325	325
GSM module	1	1850	1850
Battery 11.1V	1	1000	1000
Arduino Uno	1	410	410
Breadboard	2	40	80
RF Module	2	160	320
Light + 9V battery	1	50	50
Servo Motor	1	20	20
Gear Motor	4	71	284
Motor Driver	1	376	376

TABLE II
EXPERIMENTATION

Point	Time	Number of Attempts	Sequence of Commands	Collision	Command
A-B	12 sec	1	f	0	Forward
B-C	23 sec	1	r,s,l,s,l,s,f	0	Right, Stop, Left, Forward
C-D	11 sec	2	1st attempt: r; 2nd attempt: f	0	Right, Forward
D-A	4 sec	2	1st attempt, 2nd attempt: f	0	Forward

TABLE III
SUMMARY OF THE EXPERIMENT RESULTS

Feature	Experimental Scenario	Findings
Manual control	(a)	Left, Right, Forward and Backward command works properly and successfully complete the route. No difference was noticed between the manual and voice command.
Controlling through voice command	(a)	
Sending SMS for help	(b)	SMS were well successfully received with the location of wheelchair at mobile phone (used by the caregiver)
Longitudinal obstacle detection	(a)	The wheelchair was stopped in each obstacle/end of the route like at point A, B, C, and D (see figure 7)
Speed control	(a)	Accurately executed (observed the Increases and decreases the speed of the wheelchair)
Continuous monitoring	(c)	The present location of the wheelchair was consistently possible to monitor from the mobile phone (used by the caregiver)
Reclining the wheelchair	(d)	Accurately executed (observed the reclining of the wheelchair to different position)
Automatic light turns on	(e)	Light turns on automatically in absence of light in every trial-cases
Controlling/calling the wheelchair remotely	(f)	The wheelchair reached to the caller position successfully using Bangla voice command

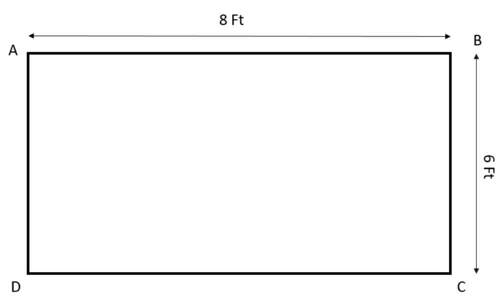

Fig. 7. Map of the Place of Experimentation

was run using joystick and then by Bengali voice command ('Dane, <Right>', 'Bame <Left>', 'Shamne <Forward>', 'Pichone <Backward>', 'Thamo <Stop>' from point A and ended at A via B, C, and D. (b) Help request were sent through a Bengali voice command 'Shahajjo <Help>'. (c) While the system was moving forward or backward the present location of the wheelchair was monitored via a mobile phone (that was supposed to be used by the caregiver). (d) the wheelchair was reclined in different position. (e) the wheelchair was run both in absence and presence of light (f) The wheelchair was called by Bengali voice command from facilitator positioned at point A, while the wheelchair was positioned at point C.

To test the system, at first, the system was run along the length, from point A to B. Only forward command was given using voice and it took 12 seconds to reach to B. Since the entire path is enclosed, the wheelchair stopped at B. The sonar worked successfully since the obstacle was detected. Next, to reach to C, a turn to the right had to be made in order for the wheelchair to be aligned across the path towards C. One of the drawbacks of the prototype was that the speed was more while turning right and was less in comparison while turning left. So, initially when the right command was given, it had to be stopped first using the stop command and then the left command was used to align it properly. After the wheelchair was lined up properly, the forward command was given, to reach to the destination C. Since readjustments were required while turning, the overall time required to reach to C was comparatively more than before in spite of the distance being lesser than before. When moving from C to D, two attempts were required. In the first attempt, the right command wasn't working and the system had to be restarted. Then the forward command was given to move it from C to D. In the last traversal from D to A, two attempts had to be taken as well. The first attempt resulted in the failure of the voice commands since the transmitter's reception was hampered due to the surrounding noise. In the second attempt, the forward command worked successfully and it took only 4 seconds to reach A. In all of the mentioned steps of testing, the obstacle detection mechanism worked successfully.

VI. Conclusion

The wheelchair provides the means for people with disability to move around freely without requiring much help from the caregivers. It supports them by enabling voice command as well as manual command in order to cater to a large group of disabilities. Along with these, the features of continuous monitoring, sending SMS when in need, obstacle detection, speed control, ability to recline back and lighting up in dark environment work hand in hand to allow the disabled person to have maximum comfort. All of these combine to ensure relief for the disabled people. The prototype required an additional cost of Tk 10 thousand apart from the cost of the wheelchair itself which is cheaper than available wheelchairs based on the wide range of obtained functionalities.

Thus this can be affordable to the people of Bangladesh compared to the availbale ones in the market. One of the limitations of this prototype was the inability to test out the wheelchair on disabled people since only a miniature version of the actual wheelchair was constructed.

The plan for the future is to construct a normal sized wheelchair with the features mentioned above with the addition to autonomous blind navigation. This would provide the opportunity to create a wheelchair that can be used by disabled patients and required changes can be made according to the feedback obtained from them.

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