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DESIGN AND IMPLEMENTATION OF MULTIPLE INTERFACE FOR INTEGRATED ELECTRIC WHEELCHAIR WITH INCORPORATED HOME AUTOMATION

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ABSTRACT

Assistive technology is a rapidly growing field in the area of science and technology and is considered to be the part and parcel of the present technological innovations. A wheelchair is the most common assistive device used globally to impart personal mobility among people with disabilities. This paper describes the design and implementation of an integrated electric wheelchair with multi-interface systems to address all classes of disabilities. The proposed system can respond to multiple inputs from the user based on the mode selected. The modes considered are speech, gesture and vision. An additional mode for autonomous navigation has also been implemented in the form of line/wall following principle. The wheelchair unit is incorporated with speech based home automation to make the users self-dependent. The integrated system aims at providing the user with multiple modes of control for mobility as well as control of appliances in the living environment.

Keywords: electric wheelchair, microcontroller, gesture, vision controlled, voice controlled, MATLAB, line following, wall following.

1. INTRODUCTION

Personal mobility is often defined as a precondition for the disabled people, to enjoy a life which is rich in human rights and dignity. One of the most commonly used device for the purpose of enhancing personal mobility is a wheelchair. It helps them to enjoy human rights and live in dignity without being dependent on others. It also helps them to contribute to the productivity in their respective community.

In any society, it is necessary to estimate the population of disability. It is estimated that 10% of the total population in the world is victim of physical disability and the numbers keep on increasing each year. A survey conducted by the Population Census 2011 as shown in Table-1 gives an insight that India alone contributes to about roughly 250 million disabled people, of which majority reside in the rural areas of the country. This is indeed a large amount of people and thereby requires an effective methodology to meet the needs of people in order to make their lives easy. The main objective to be considered is to make them self-dependent and henceforth motivate them to contribute to the growth of the society. Today's world is subject to a lot of technological advancements so as to meet the increasing needs of productivity. Hence, there sprouts a need for assistive devices that not only controls the wheelchair movements but also reduces the barriers and obstacles that prevent a disabled person from advancing in their respective workplace. Therefore the devices should address mobility issues, environmental accommodation and functional assistance for the people with developmental disabilities, physical impairments as well as cognitive disabilities. Also the devices should provide an easy to use platform for the people.

Wheelchairs are sub-divided into two main categories - manual wheelchairs and powered wheelchairs. The manual type chairs are designed to be propelled by an external attendant whereas the powered chairs are propelled by the means of a motor [8]. At present, the wheelchairs are designed to support specific sections of people with disabilities. For example, gesture controlled wheelchairs [2, 3], joystick controlled wheelchair, voice based wheelchair control [7], vision controlled wheelchair [1, 6, 9] etc. However these interfaces tend to develop a feeling of physical boredom and stress over continuous usage. It even leads to an environment where the user may not be fully independent as part of mobility. Hence there is a need to develop integrated device which addresses mobility issues and provides functional assistance to all sections of people with disabilities [11, 12].

Table-1. Types of disability based on Population Census 2011.

Disability	People	Male	Female
Vision	5032463	2638516	2393947
Hearing	5071007	2677544	2393463
Speech	1998535	1122896	875639
Movement	5436604	3370374	2066230
Mental Retardation	1505624	870708	634916
Mental Illness	722826	415732	307094
Any Other	4927011	2727828	2199183
Multiple Disability	2116487	1162604	953883
Total	26810557	14986202	11824355

This paper deals with the design and implementation of an integrated electric wheelchair which can be accessed by all types of people with disability. This is achieved by using the multiple interface features which

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can be selected by the user as per his/her requirement. The input parameters can be classified as manual, semi-autonomous and autonomous modes. The joystick is considered as a manual controller to define the directions of mobility for electric wheelchair. The other input methods considered are – gesture, voice and vision. The line following or wall following mode constitutes the autonomous mode of operation, specifically to be used in a localised environment such as home. Each mode of operations has been explained in detail in the following sections. Apart from the mobility control, the system is incorporated with a wireless voice based home automation mechanism which enables the user to control home appliances such as lights, fans, TV etc. within the home or work environment. The modes of operation can be selected by the user using manual switches, each corresponding to a particular control parameter.

Apart from the overall control of wheelchair's mobility, additional safety unit is also included in the form of IR and ultrasonic sensors which brings the electric wheel chair to a halt when an obstacle is detected in its path [5]. Hence it is proposed that the integrated system will help to create a more durable and cost effective mobility device over the long run. Moreover the system will be user friendly and more effective in providing ease of accessibility to even the illiterate section of the society.

2. METHODOLOGY

2.1 Block diagram

The overall schematic block diagram of the proposed system is shown in Figure-1.

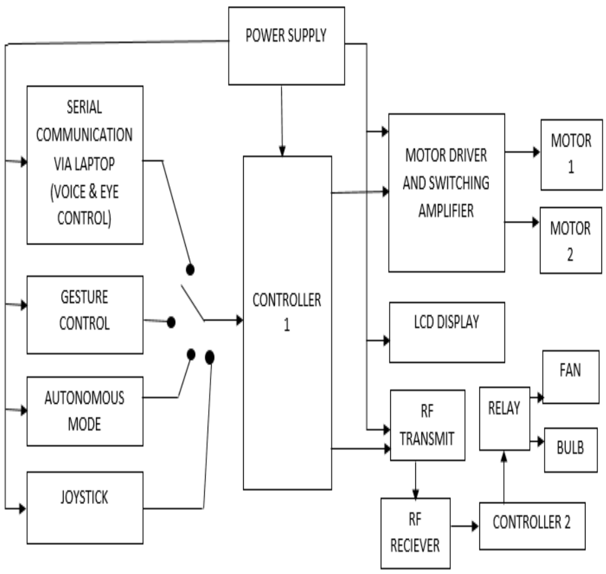

Figure-1. Block diagram of the proposed system.

The above diagram helps to understand the sequence and interfacing of the different input parameters and the corresponding output functionalities. The user can select the input mode using the select switches. In this project, 5 switches are considered for the various operating modes. For example, SW1 is used to select gesture controlled mode, SW2 for autonomous mode (line following, wall following), SW3 for voice controlled mode, SW4 for vision controlled mode and SW5 for joystick control. Depending on the key pressed, the corresponding data as shown in Table-2 is fed to the microcontroller. The controller recognizes the input mode that has been selected so as to carry out the corresponding action according to the program stored in its memory. The joystick mode is selected as the default mode of operation.

Table-2. Mode selection switches.

Switch	Data	Mode
SW1	1000	Gesture
SW2	0100	Autonomous
SW3	0010	Voice
SW4	0001	Vision
SW5	0000	Joystick

2.2 Joystick control

A joystick is a device which decides the direction of the mobility of a wheelchair based on the depression of the switches. In this paper 5 different position switches are considered to represent the mobility directions such as forward, backward, left, right and stop. Each switch is kept at active high initially. Whenever a switch is pressed, it becomes active low and the corresponding data is fed to the controller which in turn relays the data to motor drivers to perform the corresponding control action. The circuit diagram of the joystick module is shown in Figure-2. The switches A, B, C, D and E are associated with particular directions of mobility control.

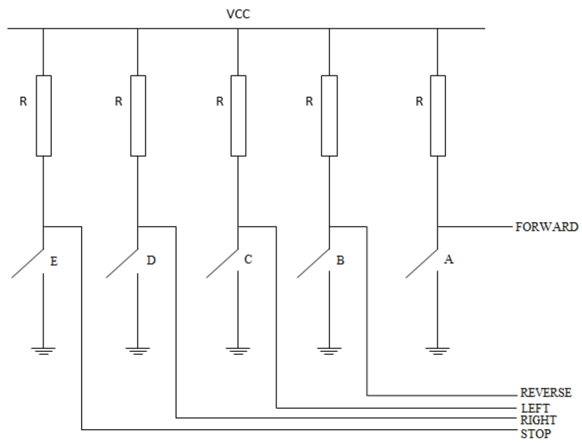

Figure-2. Circuit layout for joystick control.

2.3 Gesture control

The gesture control mode comprises of an accelerometer to provide the orientation input to control the wheelchair accordingly. The accelerometers are available in analog as well as digital format and work at an input voltage of up to 5V. The accelerometer is attached to a wrist band and placed on the user's arm. Based on the

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relative motion of user's hand, the corresponding directional control of wheelchair takes place.

The accelerometer comprises of three axis to detect the orientation and position in the workspace, namely X-axis, Y-axis and Z-axis (i.e. 3 analog inputs for x, y, z). The conditions for the orientation are defined during the programming and checked for during the operational sequence. Based on the conditions, the corresponding 4-bit data is transmitted to the wheelchair to control the navigational directions. The conditions and the corresponding data bits for the accelerometer based gesture control are shown in Table-3.

Table-3. Conditions for gesture control.

Conditions	Corresponding 4-Bit data	Mobility action
Y > 380	1001	Right
Y < 290	1010	Left
X > 380	1100	Forward
X < 290	1101	Backward
Any other conditions	1000	Stop

2.4 Autonomous mode of control

The proposed integrated electric wheelchair can operate in two autonomous modes. They are:

- Line Following Mode
- Wall Following Mode

Both the above modes are useful to reduce stress among the user in a localized known environment such as home or workplace. The mode makes use of input from IR sensors placed on the wheelchairs. The line following mechanism is defined as an autonomous navigation method in which the target body will move by tracking the black strip on the ground. The microcontroller accepts input in the form of binary '0' and '1' where 1 represents black region and 0 represents white region along the predefined pathway. Table-4 shows the control sequence for line follower based on inputs from two IR sensors IR1 and IR2 respectively.

Table-4. Control sequence for line follower.

IR Logic		LM1	LM2	RM1	RM2	Action
IR1	IR2					
1	1	0	0	0	0	Stop
1	0	0	1	1	0	Left
0	1	1	0	0	1	Right
0	0	1	0	1	0	Forward

LM1 - Left Motor Forward
LM2 - Left Motor Reverse
RM1 - Right Motor Forward
RM2 - Right Motor Reverse

The wall following mechanism is much simpler in operation as it makes use of only one IR sensor. Here, the wheelchair moves along the wall by continuously tracking the distance between itself and the wall. When the IR sensor depicts a logic 0, the wheelchair stops and for logic 1, the wheelchair moves forward.

2.5 Voice control

This mode of control not only deals with the mobility, but is also responsible for the control of home appliances such as bulb or fan within the known environment. The mode uses MATLAB based processing of voice signals and transmits the corresponding data signals to the on-board microcontroller to take the necessary actions. An additional hardware in the form of microphone is required to provide voice input for necessary operations. The first step is to train the voice of user for each command and store it in the processor. This is done to ensure user-specific operations. Figure-3 shows the details of recording tool using MATLAB for each command. The speech recognition part is programmed in such a way that it can respond to only certain commands such as STOP, FORWARD, BACKWARD, LEFT, RIGHT, ON and OFF. These commands are stored in the library during the development of program. Once the training of voice commands is done, the program is run and the voice input from user is compared with respect to the voice stored in the memory during training session. If match occurs, the corresponding action takes place else the system remains idle.

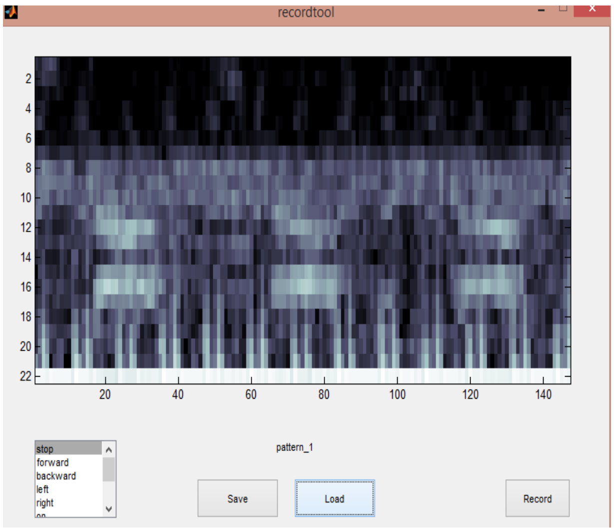

Figure-3. Voice recording tool using MATLAB.

The acquired signal needs to be processed so as to reduce the effect of noise and hence make the system more reliable. Mainly, the system must be able to respond to voice commands. Each of the keyword has a unique peak frequency associated with it. The Fast Fourier Transform (FFT) is one of the traditional method used for estimating the spectral density of the signal. In case of FFT, the signal is assumed to be the sinusoidal sum of basis functions. Although FFT is considered as an efficient

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and fast computational algorithm, it does not provide robust performance in presence of enough noise. Figure-4 shows the FFT based plot of a given keyword.

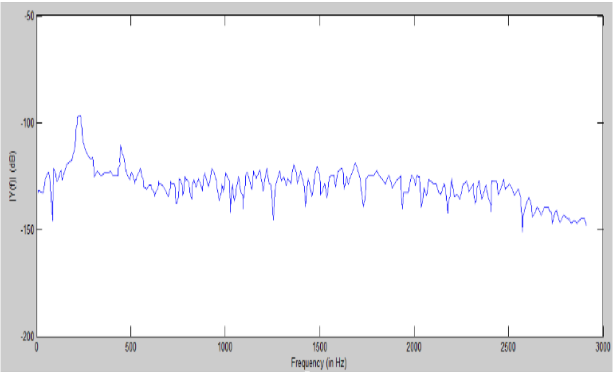

Figure-4. Frequency domain FFT output.

To overcome the poor spectral resolution of FFT during short data length, a parametric method in the form of Autoregressive (AR) modelling using Burg method is considered. The AR modelling method is able to predict the present sample value as a linear weighted sum of 'p' previous samples. Hence, a faster actuation is available even for short time segments by providing higher resolution.

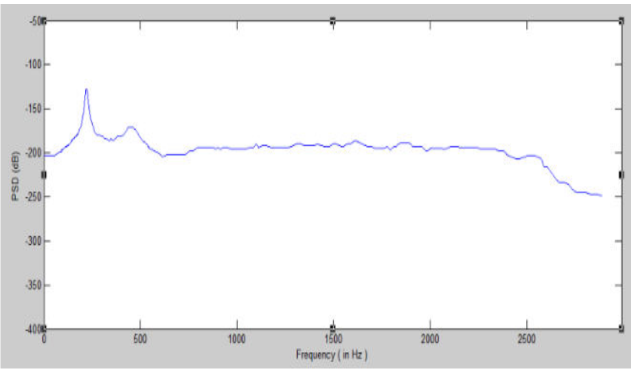

Figure-5. Frequency domain AR Burg method.

Figure-5 depicts the AR based output for the signal acquired at the same frequency as used for FFT, based on the computational formula as shown below:

$$X_N[n]=-\sum_{y=1}^{m} A_y X_N[n-y]+e[n]$$

Where Ay is defined as the modelling coefficient's sequence and e[n] constitutes the error. The model order is depicted by the variable 'm'. The value of m is proportional to the number of previous samples required to predict the value of present sample. It must be noted that more the order (m), more precise and smooth is the output. Clearly, the peak frequency obtained using both techniques remain the same. However, the fluctuations are greatly reduced in the AR Burg method. Table-5 depicts the control sequence for voice mode.

Table-5. Control sequence for voice mode.

Command	4-Bit data	Mobility action
Right	1001	Right
Left	1010	Left
Forward	1100	Forward
Backward	1101	Backward
Stop	1000	Stop
On	0001	Appliance On
Off	0000	Appliance Off

2.6 Vision control

This mode of mobility control utilizes the Scale Invariant Feature Transform (SIFT) algorithm. This method requires an additional camera to be mounted in front of the eyes of the user with proper lighting so as to track the movement of iris clearly and more efficiently. Figure-6 depicts the architectural setup for vision based control of the wheelchair unit.

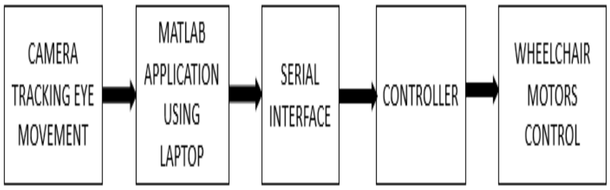

Figure-6. Architecture of vision controlled wheelchair.

The functional flow of the SIFT algorithm is illustrated in Figure-7. It is useful in tracking and identifying similarity among images of different rotation, illumination, view points and scales. The SIFT algorithm is implemented using MATLAB application and transmits the signal indicating the desired movement to the microcontroller through serial interface.

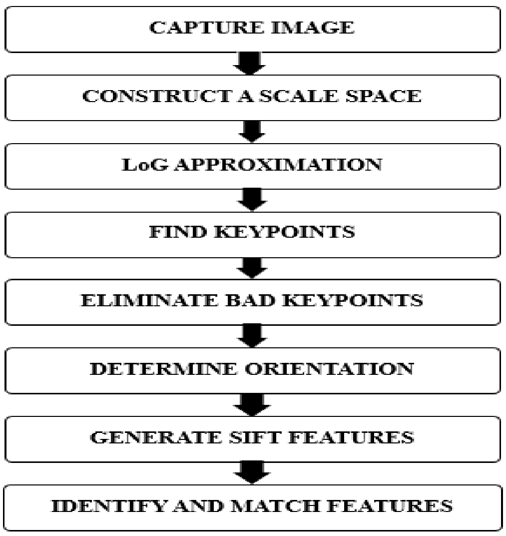

Figure-7. Functional flow diagram of SIFT algorithm.

The images as shown in Figure-8 are stored in the database of the MATLAB library so as to act as reference for computational purpose during run-time of the program.

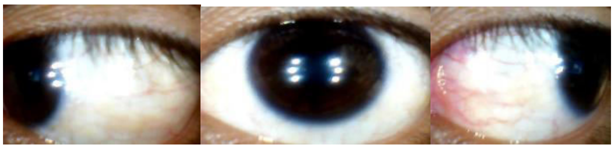

Figure-8. Reference images for eye tracking

Once the image is captured by the camera, a scale space is created by progressively generating blur images using Gaussian Blur as shown in Figure-9. This is done to get rid of unwanted details from the original image without introducing new details. The image is resized to half of the original image during the Gaussian blur, where each cycle of same size images are known as octaves.

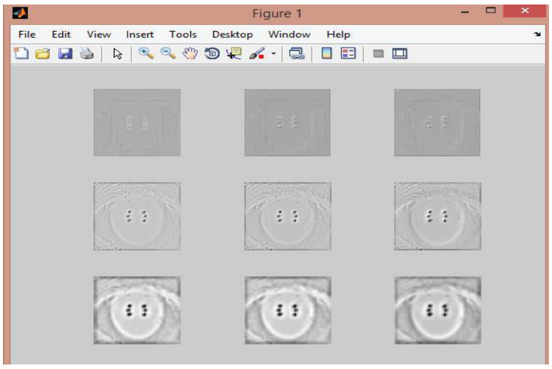

Figure-9. Gaussian blurring in MATLAB

The blurring is defined as the mathematical convolution of image and the Gaussian operator as shown below:

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y)$$

Where,

L	Represents the blur image
I	Original Image
x,y	Co-ordinates of location
σ	Scale parameter
*	Convolution operation in x and y

More the value of scale parameter more is the blur. The next step is to find the Laplacian of Gaussian (LoG) where the difference between two consecutive images in each octave is computed. Thereafter the key points are determined by calculating the maxima and minima from the result obtained during LoG. Now the bad points such as edges and low contrast are eliminated to make the system more efficient and robust. The next step is to assign orientation for the determined key point making it rotation invariant. Finally a new feature representation is generated which is rotation as well as scale invariant and is utilized to identify the feature one is looking for. Table-6 shows the orientation conditions and the corresponding directional control.

Table-6. Conditions for vision based control.

Orientation condition	4-Bit data	Mobility action
if((x>0 and x<200) && (y>280 and y<320))	1001	RIGHT
if((x>0 and x<200) && (y>130 and y<230))	1100	FORWARD
if((x>0 and x<200) &&(y>0 and y<75))	1010	LEFT

3. RESULT

A simple prototype has been designed to implement the integrated wheelchair concept in real-time. The user specific functional modes can be selected using switches. Each switch corresponds to a particular mode – manual, gesture, autonomous, voice and vision.

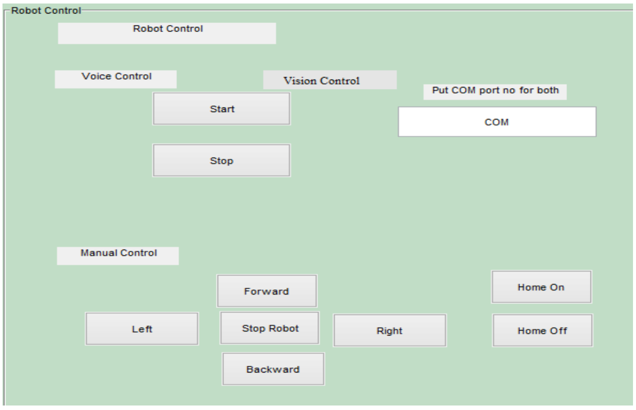

Figure-10. MATLAB GUI for integrated system

Figure-10 shows the MATLAB GUI for the overall system which provides ease of access to the end user. The voice controlled home automation was implemented using a small motor based fan and lamp. The small mobile robot as shown in Figure-11 was developed to replicate the mobility constraints of an integrated electric wheelchair as per the user mode selection.

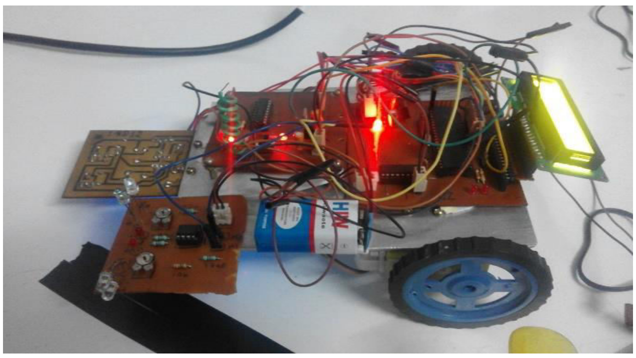

Figure-11. Mobile wheelchair unit.

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The various modes of operations have been depicted in Figure-12. The images titled 12(a) and 12(b) depicts the line following and wall following autonomous methods respectively which can be used in a familiar environment such as home.

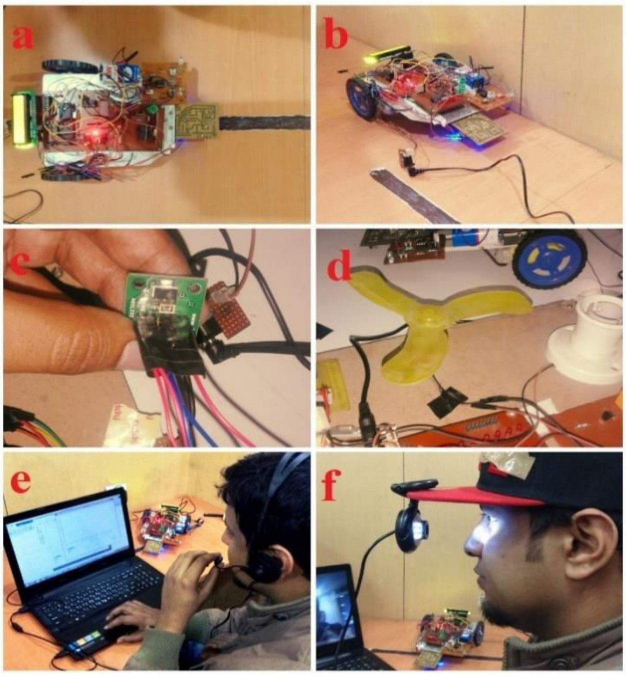

Figure-12. Various modes of user interface.

Figure-12(c) depicts the accelerometer based gesture controlled mode of operation whereas Figure-12(d) illustrates the experimental setup for voice based home automation which can control small appliances such as fan and lights. The voice controlled mobility technique requires a microphone to be placed on the user's head as shown in Figure-12(e). Vision controlled mode of mobility with external camera mounted on a user's cap is shown in Figure-12(f). The response of the system for various modes were observed to be fast. The overall system configuration and assembly is depicted in Figure-13.

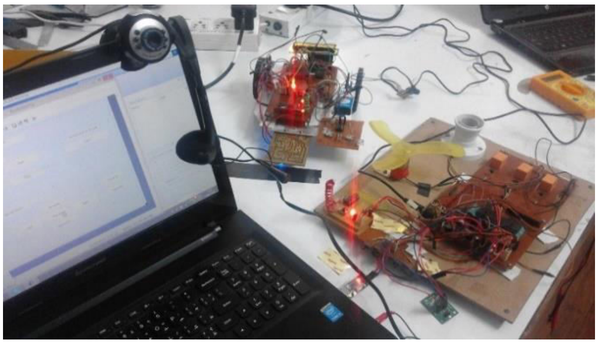

Figure-13. Overall system assembly.

4. CONCLUSIONS

The proposed method gives an efficient control mechanism for disabled people in the home as well as outdoor environment. The integration of various input parameters onto a single system minimizes the level of physical stress and boredom inducted in the long usage of wheelchair. It also helps in improving the redundancy feature in case of failure of system components. More than the mobility constraints, the project helps in motivating the disabled sections of the society by inducting an emotion of physical independence. This can thereby help them to contribute to the overall growth of the nation.

The wall follower method was observed to have a limitation of not able to track right angled walls. Also, the vision controlled mode is efficient only with proper illumination of the image capturing environment. It must also be noted that the camera is placed at an apt distance from the user's eye i.e. 15cm typically. However, the system is redundant to failures and thereby reduces maintenance cost. Table-7 shows the comparison results of existing systems used in the wheelchair designs and the proposed system.

Table-7. Comparison between the existing and proposed system.

Existing Systems	Proposed System
Single function input parameter (e.g. Voice, sensors, imaging, eye etc.).	Multi-functional input Parameters.
Targets only specific sections of disabled population.	Targets almost entire sections of disabled population due to multi-functionality.
Continuous usage can create a sense of physical stress and boredom among the end-user.	The user can toggle between different options as per his need, so as to reduce the physical stress and making mobility interesting.
The user feels independent only in terms of mobility.	The user can control appliances in the environment, thereby making the user to feel more independent.
When the input parameter becomes dysfunctional, the entire system doesn't work.	Even if one parameter becomes dysfunctional, the system is not affected as other input parameters can be used.

The future scopes of the project include addition of neural based input parameter (EEG) to control movement as well as appliances in the vicinity. The control features can be extended to various functionalities to provide accessibility for disabled people such as ATM, Voting Machines etc. One important feature that can be improvised is the incorporation of overall system onto an android platform based smartphone, thereby bringing down the overall manufacturing cost. In addition, safety features such as GPS/GSM based emergency notification can be included to notify the respective physicians or relatives when the condition of patient deteriorates.

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