A Better Engineering Design: Low Cost Assistance Kit for Manual Wheelchair Users with Enhanced Obstacle Detection

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Abstract. This paper proposes a better engineering design of an assistance kit for manual wheelchair users. The design is aimed to enhance the detection of obstacles in the travelling path of the wheelchair user at low cost. This is facilitated by microcontroller and sensor technologies. The proposed design provides the intended user with obstacle detection, light detection, a light emitting diode (LED) emergency light system, and an emergency alarm system. The microcontroller is the main controller that receives input from the sensors and produces output to the light crystal display (LCD) screen, the LED emergency light system, and the emergency alarm system. An ultrasonic sensor is used to detect the presence of obstacles directly behind the wheelchair. If any obstacle exists behind the wheelchair within a set range, the system will alert the wheelchair user through different alarm sounds. In the case of absence of light, the LED emergency light system is activated and turns on a light source, which is attached to the wheelchair to provide a bright and clear path for the user. The distance between the obstacle and the wheelchair, and the status of the LED emergency light system are displayed on the LCD screen.

Keywords: *assistance kit; microcontroller; obstacle detection; sensor; wheelchair.*

1 Introduction

Most disabled people face difficulties in independent use of manual wheelchairs [1]. For instance, they are confronted with mobility limitations and environmental barriers during the exercise of regular physical activities in daily life and with hidden obstacles that are nearly impossible to overcome [2]. The sensors often used in wheelchairs [3] measure the distance between an obstacle and the user. An ultrasonic sensor sends pulses to the object from its transmitter

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and receives the reflected ultrasound signal back through its receiver [4]. The prototype in [5] prevents the user from moving forward and turning, increasing the resistance of the wheels based on the proximity of the obstacle. The prototype in [6] was evaluated with four blindfolded able-bodied users and one individual who was blind but not mobility impaired.

Alternatively, some wheelchairs have been designed with a simple implementation using a PIC microcontroller [7] and a hand-glove control system [8]. Intended users control the system using the instrumented glove equipped with flex sensors to control the movement and direction of the wheelchair. This method is not suited for patients with a paralysed arm. A microcontroller based platform compatible with high-performance, unobtrusive, accurate cardio-respiratory and motor activity estimation of the wheelchair user is discussed in [9]. Intelligent wheelchairs, as a kind of rehabilitation robots, play an important role in helping handicapped and elderly people to live more independently at home [10]. A voice-activated powered wheelchair supplemented with joystick control allows physically disabled persons to manoeuvre the wheelchair easily without using hands [11]. Similarly, microcontroller based intelligent wheelchairs using voice activation [12] or an embedded control system [13] has been designed for the wheelchair community. Globally, the safety of the aged population has rapidly increased as the standard of living improved and medical technology has been developed [14].

Apart from these kinds of issues, wheelchair users also face a lack of visibility when there is no light source. This may lead to accidents due to hidden obstacles in the road. To counter this problem, a low-cost assistance kit for wheelchair users is needed to provide an emergency light system with sufficient light intensity.

Currently, electronically driven wheelchairs are much more expensive than manual wheelchairs. Hence there is a wide need to enhance the functionality of manually operated wheelchairs. With new engineering technology, an assistance kit can be designed at more affordable cost to assist the manual wheelchair user. It is an electronic device that provides disabled individuals who use a manual or self-operated wheelchair with the ability to sense obstructions behind them by using an ultrasonic sensor. It also provides an emergency alarm system and visibility during dark conditions by using a light detection sensor and LED emergency light system. This low-cost assistance kit for wheelchair users is an inexpensive solution providing support to disabled people who have to rely on the use of a manually operated wheelchair. The proposed design is based on the limitations faced by manual wheelchair users.

The rest of this paper is organized as follows. Section 2 presents the preliminary work required for the proposed design, Section 3 discusses the methodology, Section 4 discusses the results and Section 5 concludes the paper.

2 Preliminary Setup for the Proposed System

A block diagram of the proposed system is shown in Figure 1. By equipping the wheelchair with an intelligent controller, the control of the wheelchair is shared by the user and the controller. The microcontroller that acts as the main controller receives input from an obstacle detector and light detector sensors. The sensory details from the obstacle detector and light detector sensors are measured and the output is relayed to the main LCD screen, the emergency light system and the emergency alarm system. The LCD screen displays the distance of any obstacle behind the wheelchair and the status of the emergency light system. When the light detector sensors (photoresistors) detect an absence of light, the LCD screen alerts the user and the emergency light system. If an obstacles is sensed close to the backside of the wheelchair, the emergency alarm system gives an alert depending on the distance between the obstacle and the wheelchair.

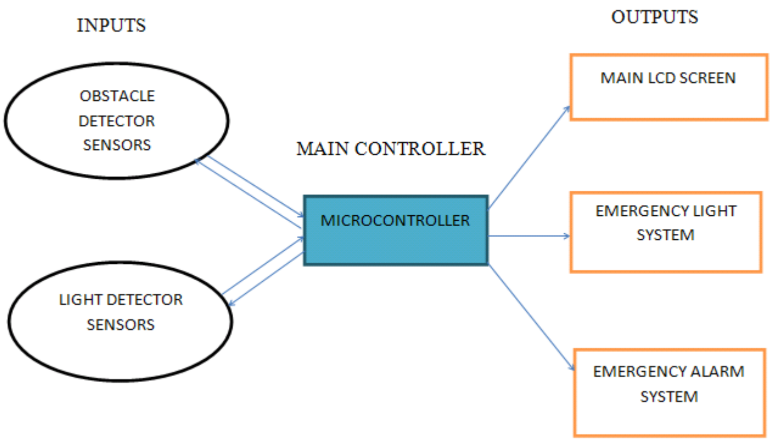

Figure 1 Block diagram of proposed system.

2.1 Obstacle Detection and Emergency Alarm System

The obstacle detection system utilizes ultrasonic sensors for obstacle detection. The system is designed to provide a fast and accurate response while detecting the obstacles that are behind the wheelchair. The sensors constantly read input and output concerning the range of the obstruction to the main display. They can detect objects up to three meters away from the wheelchair.

Each ultrasonic sensor sends out an ultrasonic pulse to the object from its transmitter and receives back the reflected ultrasonic signal through its receiver. The sensor measures the distance of the object by calculating the time it takes to receive back the reflected signal. The ultrasonic sensors send their individual data back to the microcontroller inside the main controller. The microcontroller displays the shortest distance to the object on the LCD screen. The microcontroller turns on an alarm buzzer if the shortest distance of the object is within one of three ranges. These ranges are 50-40 cm, 40-30 cm, and 30-10 cm respectively. The alarm produces a unique sound for each of these three ranges. The main process in the microcontroller sets the pulse width modulation value to generate different frequencies for the alarm buzzer.

2.2 Absence of Light Detection and Emergency Light System

In the absence of light, the emergency light system is activated. The light detector sensor consists of two photo-resistors that are used to measure the intensity of the light. The amount of light that is measured by the photoresistors determines the status of the emergency light system. If the light detection sensors detect an absence of light, the LCD alerts the user. The LED from the emergency light system is very bright and can easily illuminate a dark environment.

2.3 Interface of Arduino Mega 2560

Figure 2 shows a 54 pin Arduino Mega 2560 R3, a microcontroller board based on the ATmega2560 microcontroller. This is the brain of the wheelchair assistance kit. The kit uses 17 I/O pins in its design. It processes all sensory measurements from the components and outputs the required data to the LCD display, buzzer, and LED lighting system. The Mega 2560 is a fast processing microcontroller with clock speed 16 MHz. It uses a 9-volt battery as power source, which makes it portable.

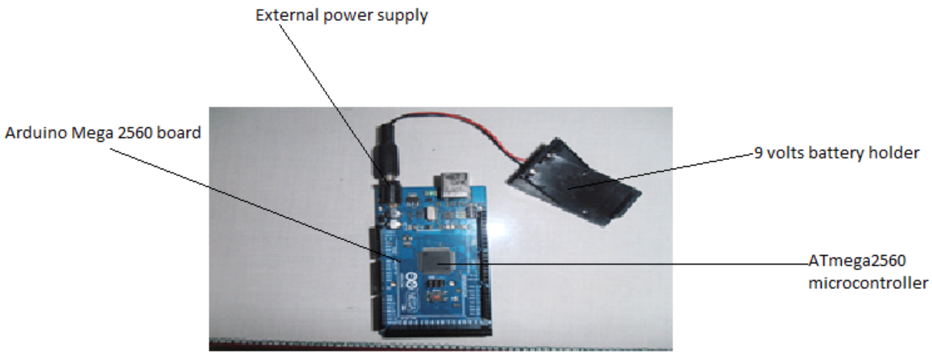

Figure 2 Arduino Mega 2560 R3.

2.4 Interface of Blue LCD Display

The LCD display is a 16×2 segment display that is illuminated by a blue backlight. The LCD displays the distance of obstructions and the status of the emergency lighting system. The LCD display is very user friendly and can be easily read and understood by the wheelchair user. It is placed on the front side of the enclosure with a 45-degree orientation and at a distance of about 30 cm from the user's eyes. It is connected to the I/O port of the Mega 2560 to generate the required output, as shown in Figure 3.

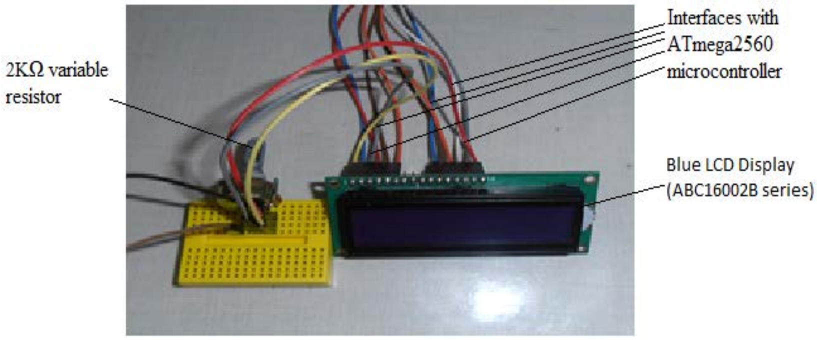

Figure 3 Blue LCD display set up.

2.5 Interface of Obstacle Detection Sensors

In total five ultrasonic sensors are used in this design. The microcontroller controls the 5 proximate sensors one by one. First, the first sensor is directed to send an ultrasonic pulse for 2 microseconds. Then the sensor stops the pulse and begins to receive the data for 5 microseconds. The sensor is finally turned off and the process is repeated with the next sensor [6]. This continues through to the 5th sensor and then the process is repeated starting again with the first sensor. The microcontroller compares the data to find the shortest distance to the object. That distance is relayed to the LCD screen.

The buzzer sounds if this distance is less than 50 cm. A distance between 50 and 40 cm generates an alarm sound with a frequency of 250 Hz. A distance between 40 and 30 cm generates an alarm sound with a frequency of 150 Hz. A distance less than 30 cm generates a sound of 100 Hz. The ultrasonic sensors are connected to a 5-volt regulator, while the signal pins are connected to the I/O pins of the Mega 2560 as shown in Figure 4.

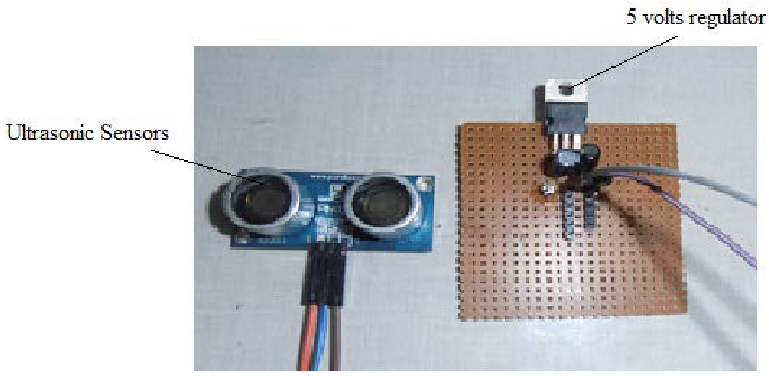

Figure 4 Ultrasonic sensor connected to 5V regulator.

2.6 Design of Emergency Alarm System

The Mini 6VDC Buzzer is a 0 to 500 Hz buzzer that works together with the obstacle detection system. It informs the user with various sound frequencies that correspond to the distance detected by the obstacle detection sensors. A BJT transistor is connected between the Mini 6V DC Buzzer and a 6-volt power supply from a 6-volt regulator as shown in Figure 5. The BJT transistor is used to amplify the signal from the microcontroller. The microcontroller switches on the BJT transistor depending on the distance of the object within the three ranges mentioned before and displayed in Table 1.

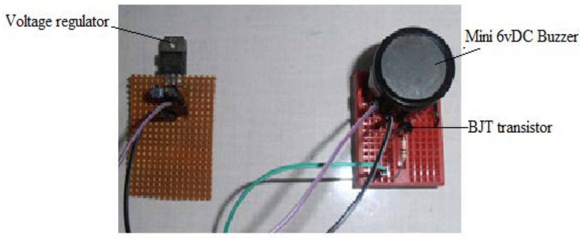

Figure 5 Emergency alarm system connected to 6-volt regulator.

Table 1 Distance Range vs Alarm Frequency.

Distance range	Alarm frequency
10-30 cm	100 Hz
30-40 cm	150 Hz
40-50 cm	250 Hz

Note: The calculation is only applicable to manual wheelchairs.

The circuit design of the 3 PING ultrasonic sonic sensors is shown in Figure 6. From the data sheet, the width of the wheelchair's back is 52 cm. Only three ultrasonic sensors are required to cover the width of the wheelchair to detect objects in the horizontal plane at a distance of 30 cm. A distance of 30 cm between the wheelchair and the object is the minimum space required for the wheelchair to make a U-turn. Based on the data sheet of the ultrasonic sensors and the width of the wheelchair, the sensor can be placed using the Eq. (1):

$$X = 30\ cm \times \tan 20° \quad (1)$$

X = 10.9 cm

where 30 cm is the minimum space in which the wheelchair can make a U-turn, 20° is the sensor's peripheral angle, and X is the length to cover the width of the wheelchair. The sensors can be placed at 10.9 cm from each other.

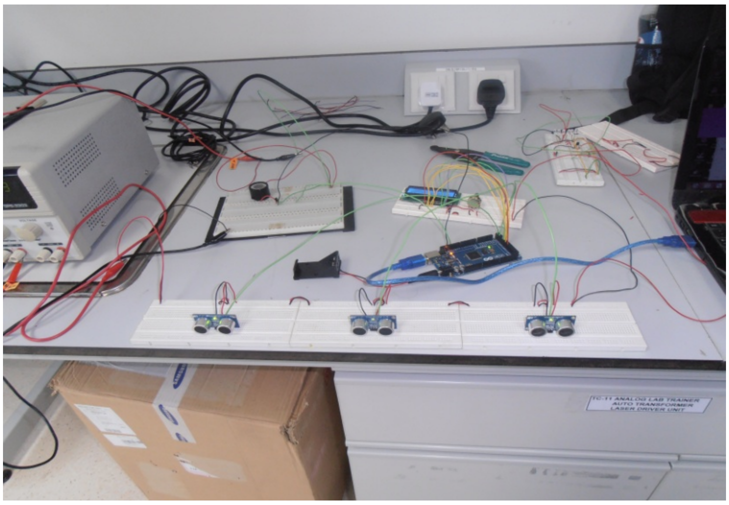

Figure 6 The design circuit of 3 PING))) Ultrasonic Sonic Sensors.

To cover the width of the wheelchair: 3 sensors x 10.9 cm = 32.7 cm

Actually the width of the wheelchair is 52 cm. Due to interference of the right and left wheel of the wheelchair,

(the actual width of the wheelchair's back) cm – 32.7 cm = 19.3 cm

Therefore, the above result, 19.3 cm, is divided by the number of side wheels of the wheelchair (2) = 9.65 = 9.7 cm.

As a result, the sensors are attached to the wheelchair's back at 9.7 cm on both sides in order to avoid interference of the wheels. As a result, only 3 ultrasonic sensors are required, since the peripheral angle of the sensors is 20°. The circuit design of the emergency alarm system is shown in Figure 7.

Figure 7 The circuit design of emergency alarm system.

2.7 Design of Light Detection Sensor

CdS (cadmium sulphide) photo-resistors are used to detect and measure the light intensity level around the wheelchair. The light detector system uses two photo-resistors so that the collected light intensity result is more accurate. The amount of light that is measured by the photo-resistors determines the status of the LED emergency light system, which switches on or off [7]. When the light detection sensors detect a low light intensity level (i.e. < 3V), the LCD alerts the user and the lighting system will be activated. Each photo-resistor is connected in series with a 10 kilo ohm resistor. A 5-volt voltage runs through the photo-resistor, through the 10 kilo ohm resistor and to ground. A wire is attached between the photo-resistor and the 10 kilo ohm resistor. This wire is connected directly to the microcontroller in the main controller, as shown in Figure 8. The microcontroller measures the voltage between the two sensors. A high voltage indicates that there is a high light intensity level. A lower voltage indicates a low light intensity level. The highest voltage output that the light sensor produces is 3 volt.

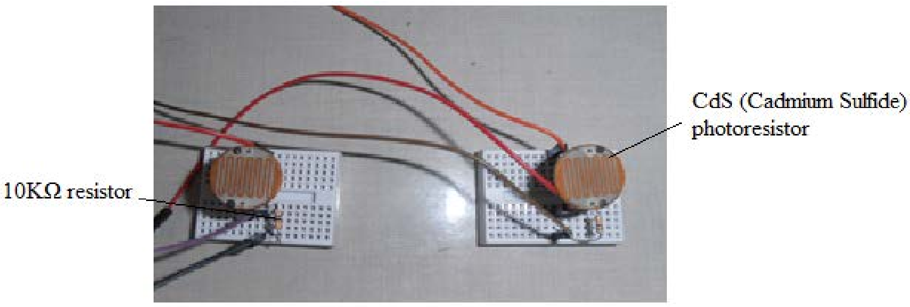

Figure 8 Light detection sensor.

2.8 Design of LED Emergency Light System

In low light intensity level conditions, the LED emergency light system is activated. The emergency light system comprises of 6 bright crystal LEDs. A BJT transistor is connected between the LED light system and a 12-volt power source, as shown in Figure 9. The microcontroller switches on the BJT transistor depending on the voltage from the photo-resistors and the BJT amplifies the voltage signal from the microcontroller to the LEDs.

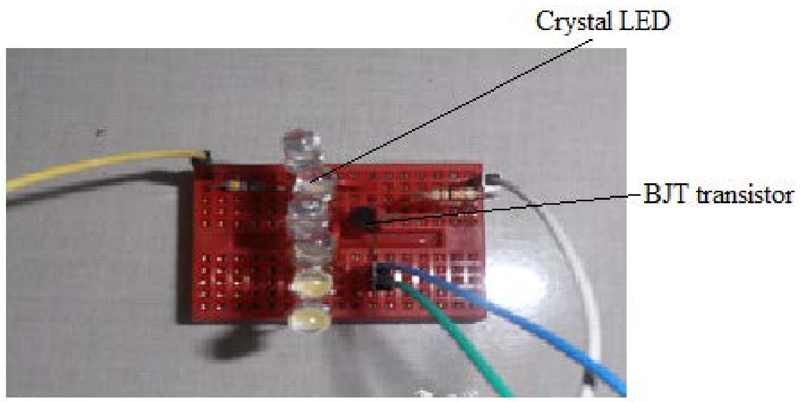

Figure 9 LED emergency light system.

The photoresistors are simple resistors that alter resistance depending on the amount of light placed over them. Higher light intensity indicates less resistance. The photo-resistor is implemented in two ways:

1. Voltage increases with light
2. Voltage decreases with light

In this design, voltage increases with light was chosen. The circuit design is shown in Figure 10. Each photo-resistor is connected in series with a resistor. The choice of resistor is determined based on the following two situations:

1. Situation with dark environment
2. Situation with bright light

Now, from the product of resistance values, the square root of the total value is calculated. This is the resistance is determined by,
Resistance = sqrt (R_dark x R_bright)

1. For dark environment = 200 kilo ohm
2. For bright light = 500 ohm

Therefore,

Resistance R = Sqrt (200000 x 500) = 10 000 ohm = 10 kilo ohm

Figure 11 shows the circuit design of the emergency light system. Its response to different lighting conditions is shown in Table 2.

Table 2 Various lighting conditions.

Photoresistor voltage drop	Emergency light status
>3 volt (bright surrounding)	OFF
<3 volt (dark surrounding)	ON

Voltage requirements: 12V power supply.

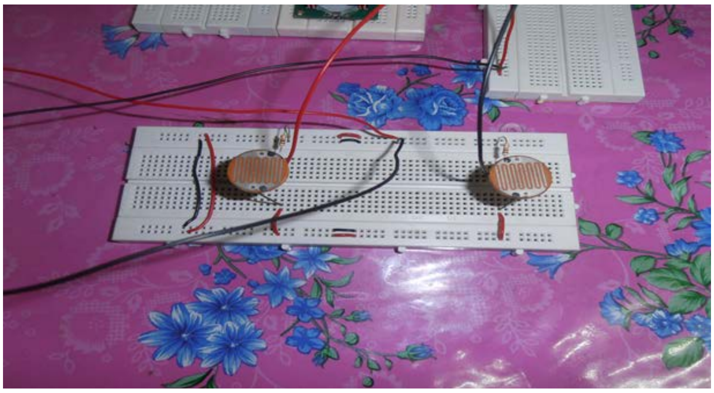

Figure 10 Circuit design of the light detection sensors.

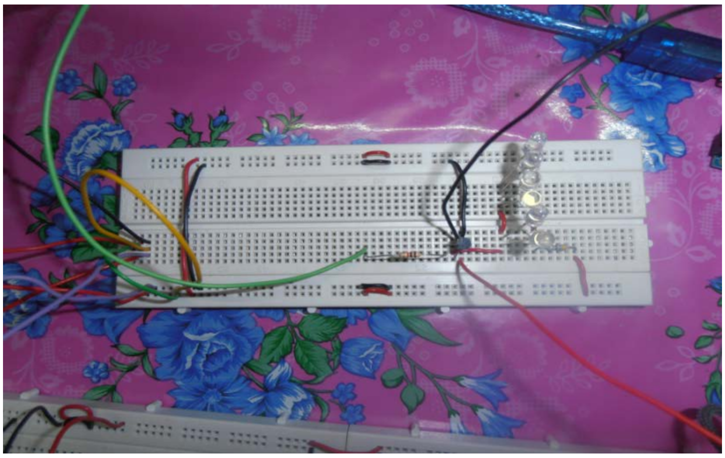

Figure 11 Circuit design of the LED emergency light system.

3 Implementation of the Proposed Method

The proposed low-cost assistance kit design integrates all the interfacing units described in Section 2. The flow chart shows the overall flow of the kit. Figure 12 shows the circuit schematic of the proposed design. A total of 17 of the 70 I/O ports are used. The unused I/O ports allow for future upgrades of the device.

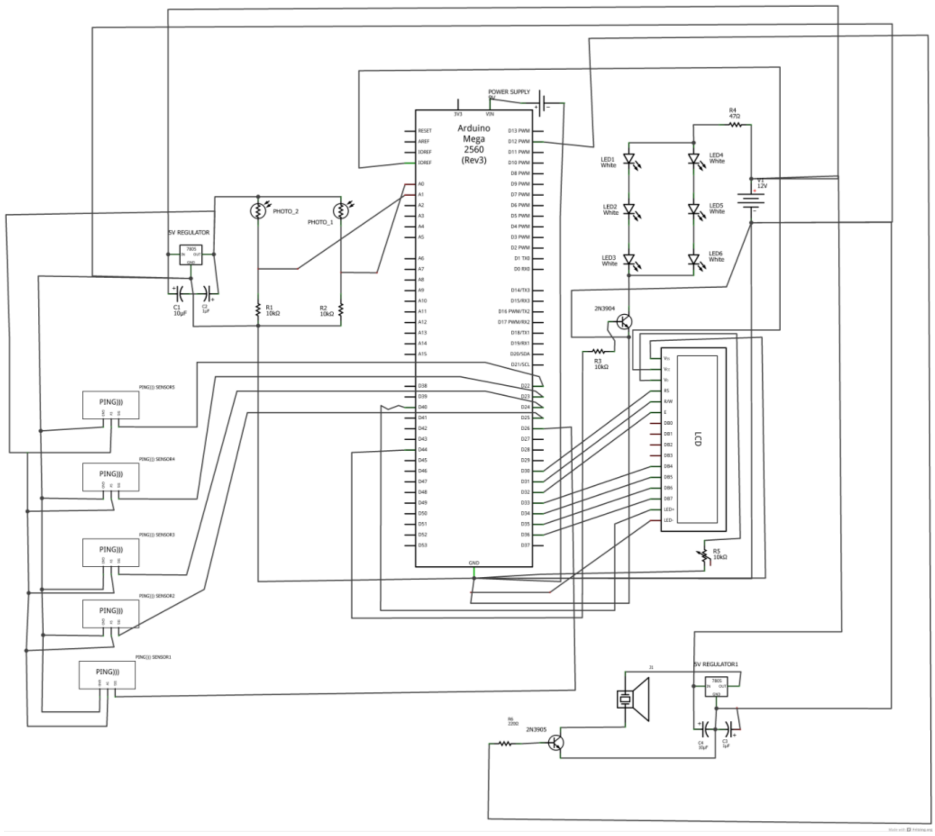

Figure 12 Schematic diagram of low-cost assistance kit.

Figure 13 illustrates the working of the proposed design. The assistance kit is divided into an obstacle detection system and a light detection system. The typical sensors that have been used in this design are ultrasonic sensors and cadmium sulphide photo-resistor sensors. The ultrasonic sensors are designed to give the highest speed and most accurate reading when detecting obstacles behind the wheelchair. The sensors work by transmitting an ultrasonic (more than 2MHz) burst and providing an output pulse that corresponds to the time required for the burst echo to return to the sensor [1]. By measuring the echo pulse width, the distance to an object can easily be calculated. In this design, the sensors are attached behind the user. These sensors constantly read input and produce output about obstructions at a distance of up to 3 meters to the main display with a refresh rate of 7 milliseconds.

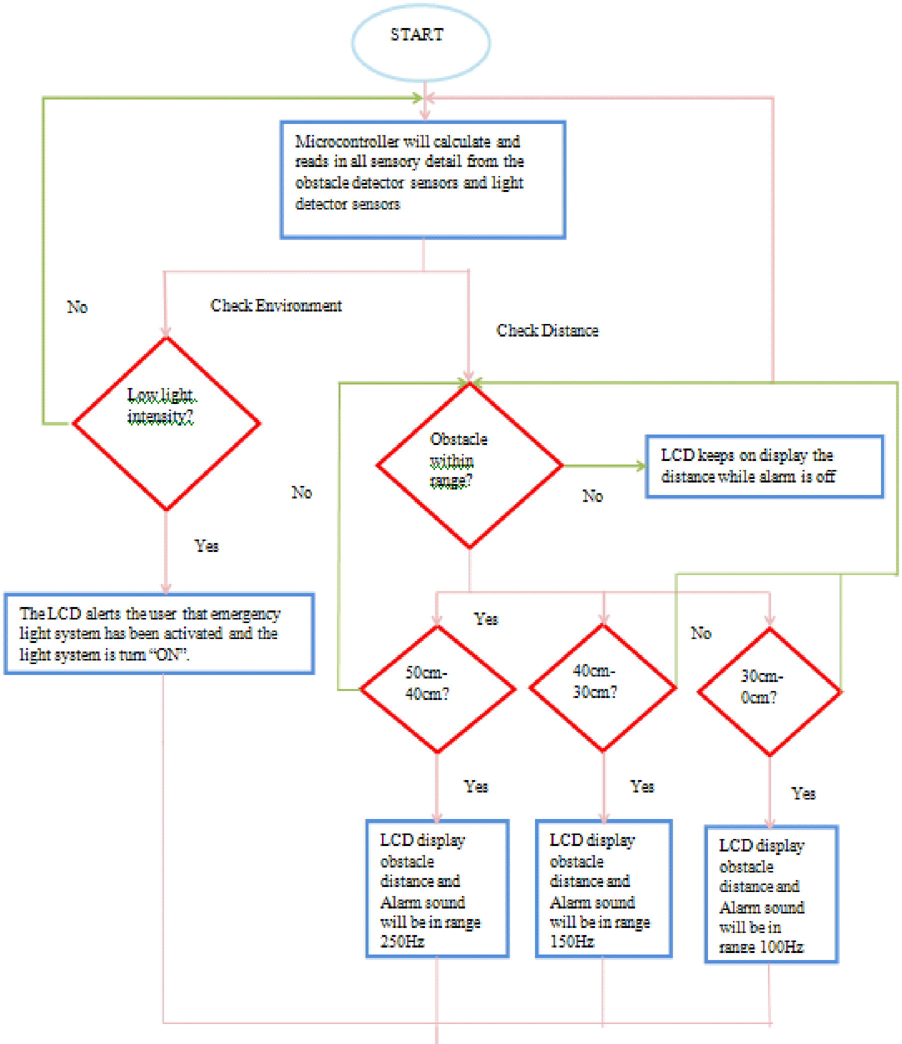

Figure 13 Work flow of the proposed design.

The light detection system consists of two photo-resistors that are adequate to measure the light intensity of the surroundings. The condition for the emergency light to turn on or off is determined by the output of the two photo-resistor, which depends on how dark the environment is [2]. The status of the LED emergency light system is sent to the main display.

The second part of the kit consists of an Arduino Mega 2560 R3 microcontroller (the main controller), LCD screen, LED emergency light system, and emergency alarm system. The microcontroller allows processing of the signals from the obstacle detection sensors and light detection sensors. It sends information to the main display, emergency alarm system and LED emergency light system to work under various conditions. The LCD screen is an important feature because it displays the distance between the obstacle and the back of the wheelchair, and the status of the LED emergency light system. When the light detection sensors detect low light intensity, the LCD will alert the user and the LED emergency lighting system will be switched on. When an obstacle comes in close proximity to the wheelchair from behind, the emergency alarm system will start to sound at a frequency depending on the distance range of the obstacle.

4 Results and Discussion

The utility of the proposed design was confirmed by our test results.

4.1 Obstacle Detection

While designing the ultrasonic sensor enclosure, three main specifications were considered: the range of the sensors being 2-3 cm, the peripheral angle of the sensors to detect objects in the horizontal plane being 20°, and the width of the wheelchair's back being 52 cm. According to the data sheet of the ultrasonic sensors and the width of the wheelchair's back, only three ultrasonic sensors are required to cover the width of the wheelchair to detect objects at a distance of 30 cm (the minimum space for the wheelchair to make a U-turn). The sensors could be placed at 10.9 cm intervals on the surface of the wheelchair's back. However, when the sensors were tested in this configuration, they failed to cover the width of the wheelchair. It turned out that the sensor's peripheral angle is only 20°. Hence, based on the test results of the ultrasonic sensors, the design requires 5 ultrasonic sensors to cover the width of the wheelchair's back. A test showed that objects could be detected but there still was a blind area. As a result, five ultrasonic sensors have to be used in order to cover the blind area, as shown in Figure 14.

The backup sensors can simply be clamped onto the back of the wheelchair. The LCD/emergency light source rail can be clamped onto the arm of the wheelchair with the included wrap-around clamp.

The component kit is functional once it is powered. The emergency light system can also be controlled manually by a switch.

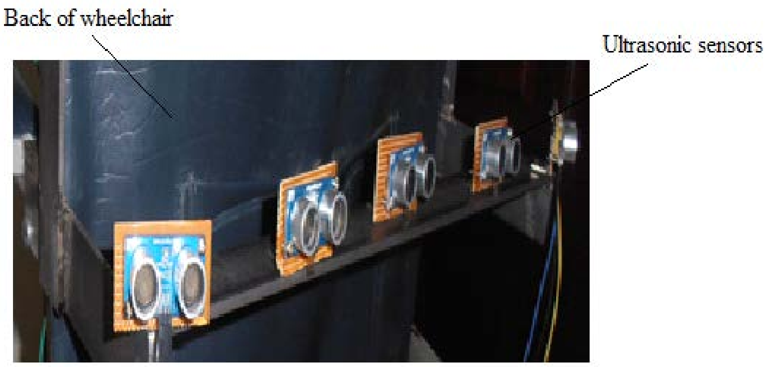

Figure 14 Installation of 5 ultrasonic sensors.

Figure 15 shows the different operating frequencies for the three different distance ranges. The alarm frequency values are based on Table 1 and different lighting conditions are operated based on the following details with the recommended voltage of 6V:

Photo-resistor Voltage Drop Emergency Light Status
> 3V (bright surrounding)............OFF
< 3V (dark surrounding)..............ON

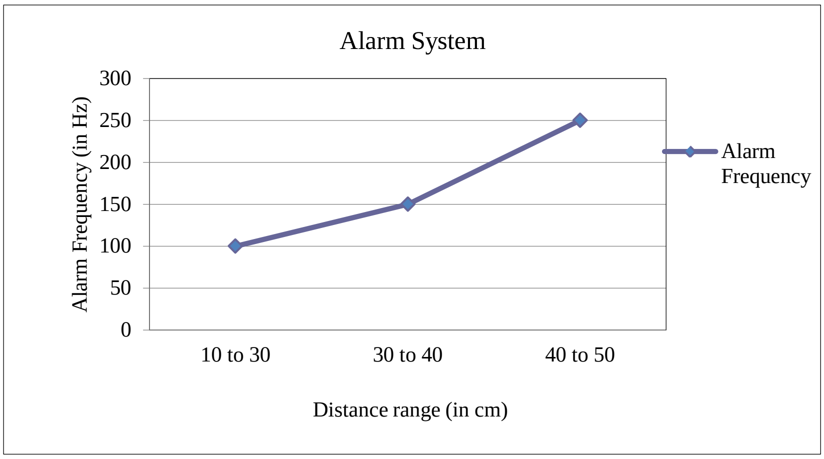

Figure 15 Distance vs alarm frequency.

4.2 Light Detection Sensor and LED Emergency Light System

Each photo-resistor is connected in series with a resistor. The resistance is determined using Eq. (2). The use of the resistor is decided by evaluating the resistance across the photo-resistor in two situations. The first situation is the lowest light intensity level (dark) and second is the condition with the highest light intensity level (very bright).

$$R = \sqrt[2]{R_{dark} \times R_{bright}}, \quad (2)$$

where R_{dark}= 200 kilo ohms and R_{bright}= 500 ohms.

Therefore,

$$R = \sqrt{200K \times 500}$$

$$R = 10\ K\Omega$$

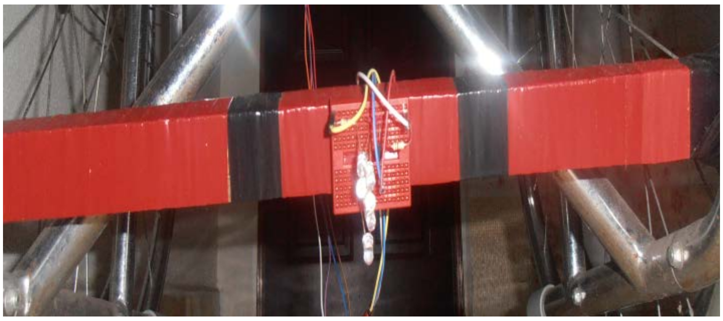

Figure 16 Emergency light system.

(a) (b) (c)

Figure 17 (a) Back view (b) front view, (c) top view of proposed wheelchair kit.

After the designing the obstacle detection sensor, emergency alarm system, light detection sensor, LED emergency light system and LCD interface, the assistance kit was assembled as shown in figures 15 and 16. All the components worked properly after interfacing all of them together. Multiple conditions were simulated to test the complete design of the assistance kit and it responded as expected. Whenever any obstacle was within a certain range it produced an alarm sound with the distance displayed on the LCD. In dark conditions, the

LED emergency light system automatically switched on and its status was displayed on the LCD. Figure 17 shows back, front and top views of the complete design.

5 Conclusion

The low cost assistance kit for manual wheelchair users is an electronic device that enhances the ability of the wheelchair users to detect obstructions behind them and to see in dark conditions. It has been successfully constructed to work in conjunction with manual wheelchairs. The completion of the assistance kit is a new step in improving people's lives and adapting to the needs of people with physical disabilities. The proposed design can be enhanced by concentrating on adding features such as speech recognition, voice control, or automated wheelchair movement based on the detection of obstacles or no-light environments. Future improvements may include heart pulse monitoring, a medical alarm system, and back-up batteries. The heart pulse monitor and medical alarm system could prevent medical emergencies such as heart attacks or low blood pressure.

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