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An autonomous robot for crack detection in railway track

David Okene and Emmanuel I. Okhueleigbe
Department of Electrical and Electronics Engineering, Federal University of Petroleum Resources, Effurun, Nigeria
E-mail: okhueleigbe.emmanuel@fupre.edu.ng, okene.david@fupre.edu.ng

Abstract

Cracks in railway tracks have resulted in several train accidents involving huge loss of human lives in many developing countries including Nigeria. Railway transport is vitally important for the economic and industrial development of any nation. In order to make this means of transportation safer in Nigeria, manual methods are currently been used to check for cracks on railway tracks. These manual methods are tedious and time-consuming. And sometimes with the manual methods, cracks may go unnoticed, thereby, resulting in accidents. In order to overcome this shortcoming which has resulted in tragic but avoidable accidents, this research was conceived. The autonomous robotic vehicle designed in this project uses an ATMEGA 328 Microcontroller on board arduino, a light emitting diode (LED)/light dependent resistor (LDR) assembly, a bluetooth module, servo and DC geared motors and a lithium battery power supply. In this design, the LED was attached to one side of the rails and the LDR to the opposite side. The principle of operation is such that, during normal operation when there are no cracks, the LED light does not fall on the LDR and hence the LDR resistance is high. However, when the LED light falls on the LDR, the resistance of the LDR gets reduced and the drop in resistance will be approximately proportional to the intensity of the incident light. This change in resistance indicates the presence of a crack or some other similar structural defect on the rail track. Two unique features in this design include, the use of the differential drive method in the control of the robotic vehicle because it's a 2-wheeled vehicle compared to other popular designs; and the introduction of a mobile app (not common with any existing system) which can be used to remotely control the movement of the vehicle.

Keywords: Robotic systems, Bluetooth module, Atmega328p microcontroller, Railway crack detection

1.0 Introduction

In recent times there has been an upsurge in rail accidents in Nigeria. In June 2016, a rail incident occurred in Jebba in Kwara State, Nigeria killing not less than four people (Nwogu, 2016). Also, another fatal incident occurred recently in 2017 leaving unconfirmed numbers of people dead according to (Onyegbula, 2017). It was further revealed statistically that approximately 60% of the train accidents were as a result of derailments of which 90% were due to cracks on the rail tracks (Bhargavi & Janardhana, 2014; Karthick et al, 2017). These cracks and other associated problems with the rail usually go unnoticed due to improper maintenance culture and lack of technological knowhow to detect cracks. However, in the Nigerian scenario, the visual form of inspection is widely used though it produces the poorest results of all the methods. It is now becoming widely accepted that even surface cracking often cannot be seen with the naked eyes. As a result this method can be costly, time consuming and ineffective for large and complex structural systems such as the rail track (Karthick et al, 2017).

In many countries commonly employed rail crack detection schemes are usually ultrasonic or eddy current based techniques which boast of reasonably good accuracy in most cases. However, the one characteristic common with all the methods mentioned above is that they are expensive, which makes them unattractive in the Nigerian environment. Also, ultrasonic can only inspect the core of materials; that is, the method cannot check for surface and near-surface cracking where many of the faults are located. In addition, ultrasonic inspection of rails is usually restricted to low speeds of around 20-30mph, which limits the viability of testing many tracks regularly. Many of the most serious defects that can develop in the rail head can be very difficult to detect using the currently available inspection equipment. Generally, one of the reasons for slow inspection speeds using conventional NDT is the need for couplant between the transducer and the track using either liquid or dry couplant materials. The Laser solution that we considered initially, offered some advantages in terms of cost but altogether it was inefficient due to the high power needed to power the laser and also the limitations inherent to laser. The main problem was that as lasers generally have long wavelengths, they tend to cut through reflecting surfaces instead of getting reflected back which poses a serious problem in a rail crack detection system. Furthermore human eyes are sensitive to laser light and therefore in case of a problem with the operation, the exposure to harmful laser light poses a safety hazard (Karthick et al, 2017; Jenkin & Dudek 2018; Theraja & Theraja 2005).

Thus after having weighed up all our options, we have chosen the cheaper means of a LED-LDR based detection which provides us with ruggedness and reasonably accurate crack detection.

2.0 Methodology and system design

In designing this autonomous ground robotic vehicle, choices were made on what type of platform, software components and hardware components to be used.

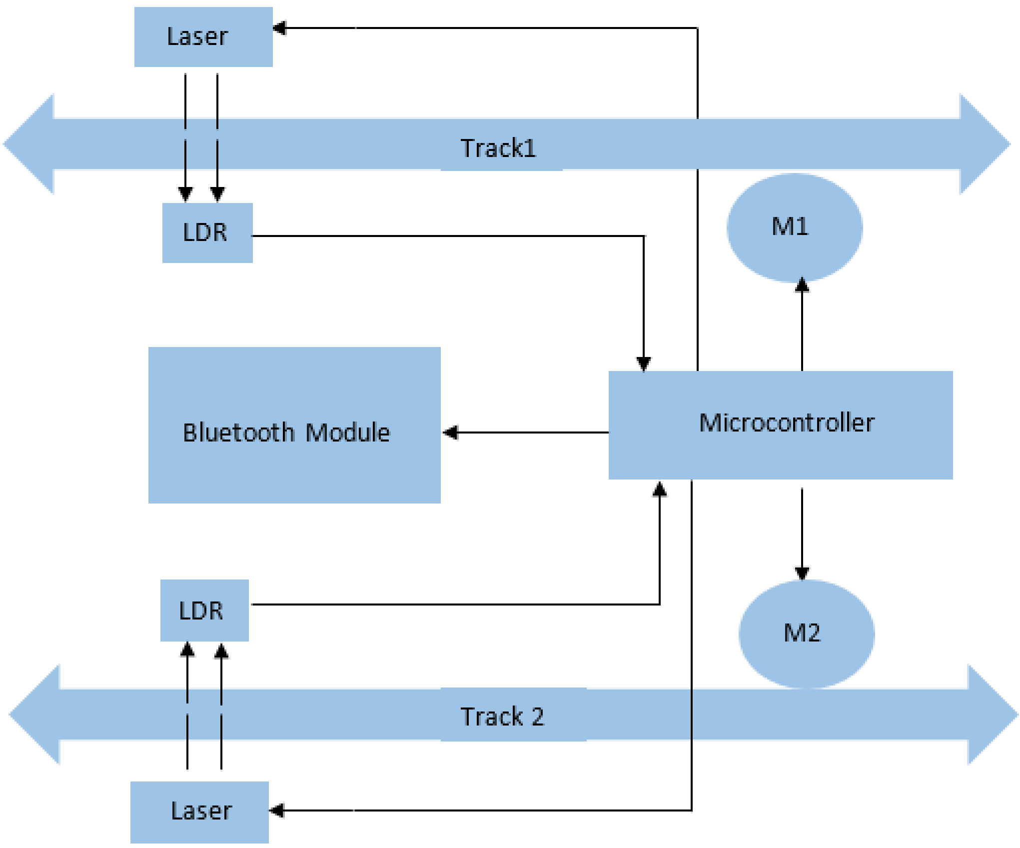

Figure 1: Block diagram of the system design

These choices made were based on certain considerations such as low cost, availability, reliability, flexibility and simplicity. As shown in the block diagram in Figure 1, some of components that make up the system include an LDR, Laser diode, Bluetooth module, a Micro-controller and Motor drivers. The photo resistor or light dependent resistor was chosen because of its ability to detect the presence or the intensity of light. Although other devices such as photodiodes or photo-transistor can also be used, LDRs or photo-resistors are a particularly much more convenient to use. Also, they provide large change in resistance for slight changes in light intensity. The next consideration in this project was to ascertain which method was most suitable for steering the robotic vehicle on the railway track. The differential drive method was considered because it supports a robot with two wheels that can turn at different rates (speeds) with the aid of motors connected to them (Jenkin & Dudek, 2018; Theraja & Theraja, 2005; Kramer, 2012). The speed and angular direction of the motors determine the speed and motion of the robotic car. If the motors are turning at the same rate in the forward direction, the robot moves forward, but if the motors are moving at the same rate in the reverse direction, the robot moves backward. When one wheel is rotating slower than the other, the car will turn/curve in the direction of the slower wheel. This enables the robot to turn left or right. This method is suitable for our design since only two wheels are involved as mentioned earlier. The navigation of the robotic vehicle from one point to the other is made possible using a Bluetooth Module connected wirelessly to an Android mobile application developed for this project. The mobile application was designed to control the movement of the robot in forward and backward direction and to also display the result on an LCD screen.

The control of the robotic vehicle is implemented using a microcontroller and in this case, the Atmega 328p-pu was selected for this task. The chip is small and light weight; it operates at a frequency of 16MHz to 20MHz to provide timely feedback to the user. The microcontroller is a single chip that contains a processor (CPU), non-volatile memory for the program (ROM or Flash), volatile memory for the input and output (RAM), a clock and I/O control unit and time. It is designed for a set of specific functions to control a particular system. The reason for using the microcontroller is because it is extremely versatile.

The coding was done using C/C++ with the Arduino IDE and Arduino libraries. This programming language was chosen because of its simplicity and pre-existing functions. The language makes it easy to communicate with the motors and sensors since it contains most of the functions that are needed. Another benefit of this language is that it allows the user to easily change the setting on their device. The user benefits from a lot of open source code and easy manipulation of the default setting. The range that is covered by the sensor can be easily changed by the average person since lots of free tutorials can be harnessed from the internet.

2.1 Choice of Bluetooth module

In selecting a Bluetooth module certain factors are taken into account, some of these factors include;

i. Maximum power output of Bluetooth module

There are three classes of Bluetooth modules exist. Power output ranges of all three classes are given below:

(a) class 1 : 100 mW
(b) class 2 : 2.5 mW
(c) class 3 : 1 mW

ii. Distance between your two Bluetooth device's receiver and transmitter:

According to range of Bluetooth devices, there are also three classes of Bluetooth modules:

(a) class 1 : 100 meter
(b) class 2 : 10 meter
(c) class 3 : 10 centimetre

iii. Mode of communication you want to use

Bluetooth modules need communication protocols to interface with other devices. The microcontroller can communicate with the Bluetooth device through following wired communications to send or receive data from other Bluetooth devices:

(a) UART
(b) SPI
(c) USB

Bluetooth modules which have UART communication are easier to program.

2.2 Choice of power supply

The DC power source used for the design was a rechargeable Lithium Polymer (Li-Po) battery. Lithium polymer batteries are a newer type of battery now used in many consumer electronics devices. They are lighter in weight, offer much higher capacities and discharge rate. A LiPo cell has a nominal voltage of 3.7V. For this project, two of these cells were connected in series to achieve the total dc power rating of 7.4V.

2.3 Choice of microcontroller

The ***microcontroller*** is the brain of any robotic system. The coordination of the several sensors and actuators is impossible without a microcontroller. For this work, the Atmega 328P-PU was selected as a suitable microcontroller. The system requirements and control specifications clearly rule out the use of 16, 32 or 64 bit microcontrollers or microprocessors.

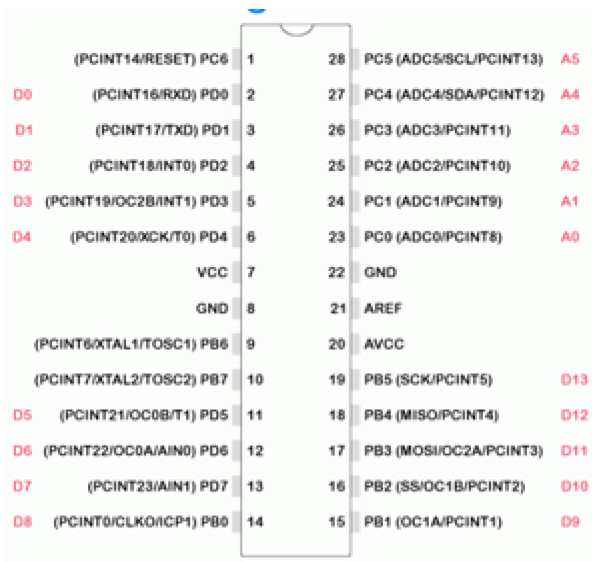

Figure 2. Atmega328P micro-controller

FEATURES OF ARDUINO UNO
ATmega328

i. Operating Voltage: 5v.
ii. Input Voltage: 7-12v.
iii. Digital I/O Pins: 14(of which 6 provide PMW output).
iv. Analog Input Pins: 6.
v. DC Current per I/O Pin: 40mA
vi. DC Current for 3.3V Pin: 50mA
vii. Flash Memory: 32KB
viii. SRAM: 2KB
ix. EEPROM: 1KB
x. Clock Speed: 16 MHz

2.4 Choice of voltage regulator

Fluctuation of voltages is a common phenomenon that plagues electronic circuits of all sorts, so the regulation of voltages is pivotal for the optimal performance of a circuit.

A voltage regulator is designed to automatically maintain a constant voltage level within a circuit. For this project, the 7805 IC voltage regulator is used. The 7805 integrated circuit (IC) is a member of 78xx series of fixed linear voltage regulator ICs used to maintain voltage fluctuations. 7805 IC provides +5 volts regulated power supply with provisions to add heat sink as well.

The 7805 IC voltage regulator ratings are:

i. Input voltage range 7V- 35V
ii. Current rating $I_c = 1A$

Output voltage range VMax = 5.2V,VMin = 4.8

2.5 Choice of controlling motors

Direct current (DC) motors work on the principle of Lorentz force which states that when a wire carrying current is placed in a region having magnetic field, the wire experiences a force. This Lorentz force provides a torque to the coil to enable it to rotate (Kramer, 2012). Geared DC motors can be regarded as an extension of a DC motor. A geared DC Motor has a gear assembly attached to the motor. The speed of motor is counted in terms of rotations of the shaft per minute and is termed as RPM .The gear assembly helps in increasing the torque and reducing the speed. Using the correct combination of gears in a gear motor, its speed can be reduced to a desirable level. This concept whereby gears reduce the speed of the vehicle but increase its torque is known as gear reduction according to (Jain, 2012).

The Micro DC Gear Motor with Shaft is ideal for this application because of its unique design to accommodate ease and to easily incorporate the controller and wheels. These motors are inexpensive, small, easy to install, and ideally suited for use in a mobile robot car.

2.5.1 Specification

i. Gear Ratio 1:48
ii. No-load speed (5V) : about 208RPM
iii. Rated Torque 0.8 Kg.cm @ 5V
iv. No-load current (6V) : ≦ 350mA
v. Size: 71mm x 27.4mm x 22.4mm
vi. Weight: 28gServo Motor

Servo motors are actuators that combine a motor, gearbox and encoder into a convenient and easy to use package. Servo motors are constructed from three basic parts; a motor and a potentiometer, these two components are connected to the output shaft and a control board. The output shaft can be positioned to specific angular positions by sending the servo a coded signal.

The servo motor is an excellent alternative to the stepper motor, since it offers greater torque and power characteristics (Lackey, 2017; Tukur, 2018; Papalias, & wong, 2005). Servo motors come in quite small sizes, and because they have built-in circuitry to control their movement, they can be connected directly to our microcontroller. Selecting the best motor for your application depends on a few key design criteria for your system including cost, positional accuracy requirements, torque requirements, drive power availability, and acceleration requirements. For applications where high speed and high torque is needed, servo motors shine. A servo motor can supply roughly twice their rated torque for short periods. At certain speeds, partially depending on the load dynamics, a stepper motor may enter resonance and be unable to drive the load. This results in skipped steps, stalled motors, excessive vibration and noise.

Overall, servo motors are best for high speed, high torque applications while stepper motors are better suited for lower acceleration, high holding torque applications.

2.5.2 Specifications

i. Weight: 55 g
ii. Dimension: 40.7 x 19.7 x 42.9 mm approx.
iii. Stall torque: 9.4 kgf·cm (4.8 V), 11 kgf·cm (6 V)
iv. Operating speed: 0.17 s/60º (4.8 V), 0.14 s/60º (6 V)
v. Operating voltage: 4.8 V a 7.2 V
vi. Running Current 500 mA – 900 mA (6V)
vii. Stall Current 2.5 A (6V)
viii. Dead band width: 5 μs
ix. Stable and shock proof double ball bearing design
x. Temperature range: 0 ºC – 55 ºC

2.6 Choice of Motor Drivers

2.6.1 Motor Driving With H-Bridge Circuit

In general an H-bridge is a rather simple circuit, containing four switching element, with the load at the center, in an H-like configuration:

In general an H-bridge is a rather simple circuit, containing four switching element, with the load at the center, in an H-like configuration:

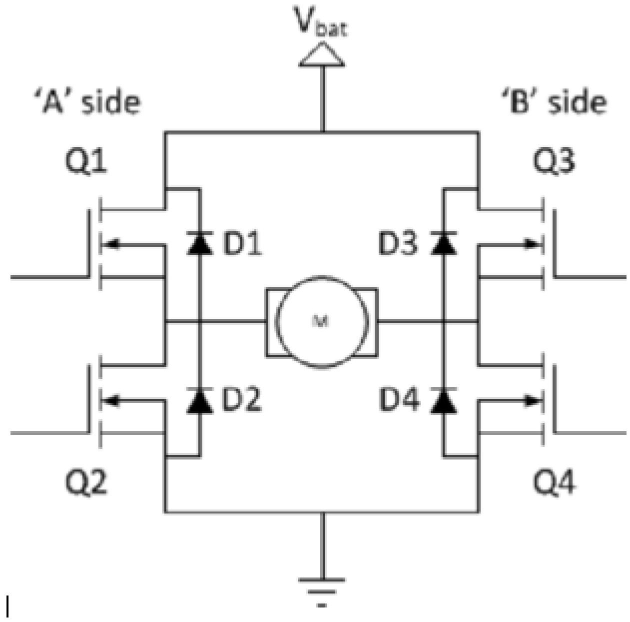

Figure 3 H-Bridge circuit diagram

The switching elements (Q1...Q4) are usually bi-polar or FET transistors, in some high-voltage applications IGBTs. Integrated solutions also exist but whether the switching elements are integrated with their control circuits or not is not relevant for the most part for this discussion. The diodes (D1...D4) are called catch diodes and are usually of a Schottky type. The top-end of the bridge is connected to a power supply (battery for example) and the bottom end is grounded. In general all four switching elements can be turned on and off independently.

The basic operating mode of an H-bridge is fairly simple: if Q1 and Q4 are turned on, the left lead of the motor will be connected to the power supply, while the right lead is connected to ground. Current starts flowing through the motor which energizes the motor in (let's say) the forward direction and the motor shaft starts spinning. If Q2 and Q3 are turned on, the reverse will happen, the motor gets energized in the reverse direction, and the shaft will start spinning backwards.

The H-bridge arrangement is generally used to reverse the polarity/direction of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motor's terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit. The following table summarizes operation, with Q1-Q4 corresponding to the diagram below.

Table 1 L293D Data sheet specifications

Q1	Q2	Q3	Q4	Result
1	0	0	1	clockwise
0	1	1	0	Anticlockwise
0	0	0	0	Motor coast
0	1	0	1	Motor brakes
1	0	1	0	Motor brakes
1	1	0	0	Short circuit
0	0	1	1	Short circuit
1	1	1	1	Short circuit

2.6.2 Motor Driver L293D

L293D is a quadruple high-current half-H driver. The device is designed to drive a wide array of inductive loads such as relays, solenoids, DC and bipolar stepping motors, as well as other high-current and high-voltage loads. All inputs are TTL compatible and tolerance up to 7 V.

Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. The driving gates are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled, and their outputs are active and in phase with their inputs. When the enable input is low, those drivers are disabled, and their outputs are off and in the high-impedance state. With the proper data inputs, each pair of drivers forms a full-H (or bridge) reversible drive suitable for solenoid or motor applications. In this project the L293D was used to implement the H-Bridge circuit principle.

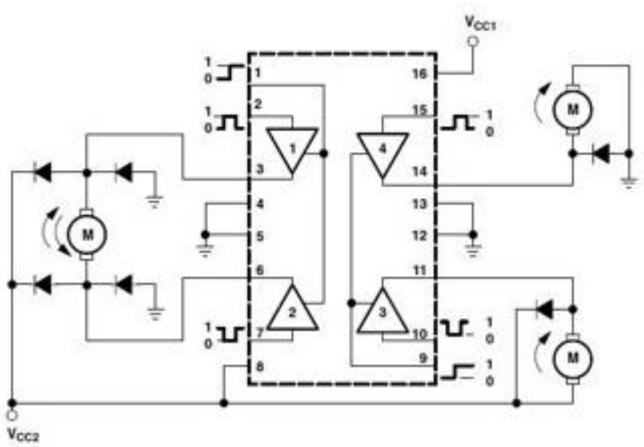

Figure 4 Functional Block Diagram of the L293D

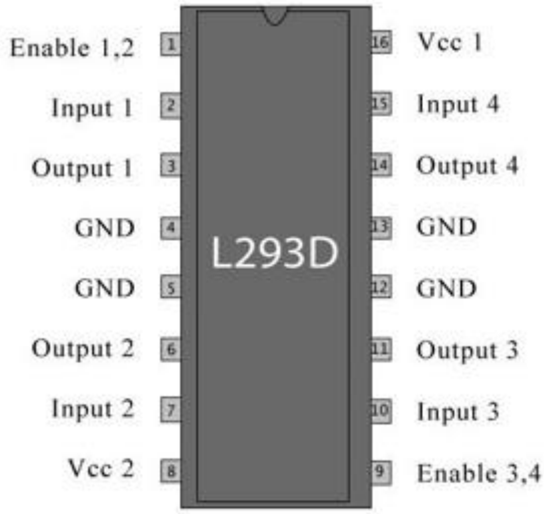

Figure 5 IC L293D Pin-out Diagram

Table 2 Data Sheet Specification L293D

EN	3A	M1	4A	M2
H	H	Fast motor stop	H	Run
H	L	Run	L	Fast motor stop
L	X	Free running motor stop	X	Free running motor stop

Table 3 Unidirectional Control of the L293D

EN	1A	2A	FUNCTION
H	L	H	Turn right
H	H	L	Turn left
H	L	L	Fast stop
H	H	H	Fast motor stop
L	X	X	Fast motor stop

The most commonly used motor driver IC's are from the L293 series such as L293D, L293NE, etc. These ICs are designed to control 2 DC motors simultaneously. For this work the L293D is used and it interfaces between the Arduino and the DC Motors. It consists of two H-bridge. It is worthy of note that the H-bridge is the simplest circuit for controlling a low current rated motor.

2.7 Choice of resistors

Using just two series resistors and an input voltage, we can create an output voltage that is a fraction of the input. It was used to step down the voltage that is being fed in to the microcontroller. Four resistors R_1, R2, R_3 and R_4 were used and their values were 10kΩ.

2.8 Choice of capacitors

Capacitors can be used in many different applications and circuits such as blocking DC current while passing audio signals, pulses, or alternating current, or other time varying wave forms. This ability to block DC currents enables capacitors to be used to smooth the output voltages of power supplies, to remove unwanted spikes from signals that would otherwise tend to cause damage or false triggering of semiconductors or digital components. Two capacitors C1 and C2 were used and their values were 22µF.

2.9 Software design

The programs implemented are written in embedded C language using Arduino IDE(an open-source platform used for building electronics project which consist of both a physical programmable circuit board and a piece of software) . An algorithm is generated on how the system should operate and a program is written with respect to this algorithm. The circuit as constructed, is designed on proteus workbench, a program is installed on it and simulated to analyze the program operation on the circuit. Basically the software used in the software design analysis are;

i. Arduino IDE
ii. Proteus 8 professional

3.0 Implementation

3.1 Hardware implementation

After the design was done, it was simulated using Proteus 7 software and implemented on a Vero board with the component units interconnected.

3.1.1 Drive unit

The chassis uses two powered wheels with two dc motors. The microcontroller which is at the heart of the drive unit, is powered with 5v power supply, and the two speed motors was interfaced with the motor drivers, and the motor drivers were powered by 5v which powers the motor driver IC, and 9v which powers the speed motors directly through the motor driver.

In order to hold the microcontroller on the board or in the circuit, a 28 pin IC socket was soldered directly on the Vero board as shown in figure 6. This is to ensure that the microcontroller was not soldered directly on the board to give leverage for changes in case of insurgence. Soldering on the ICs directly can easily destroy the ICs due to static charges and overheating. So, a 28 pin IC socket was mounted on the board for this purpose.

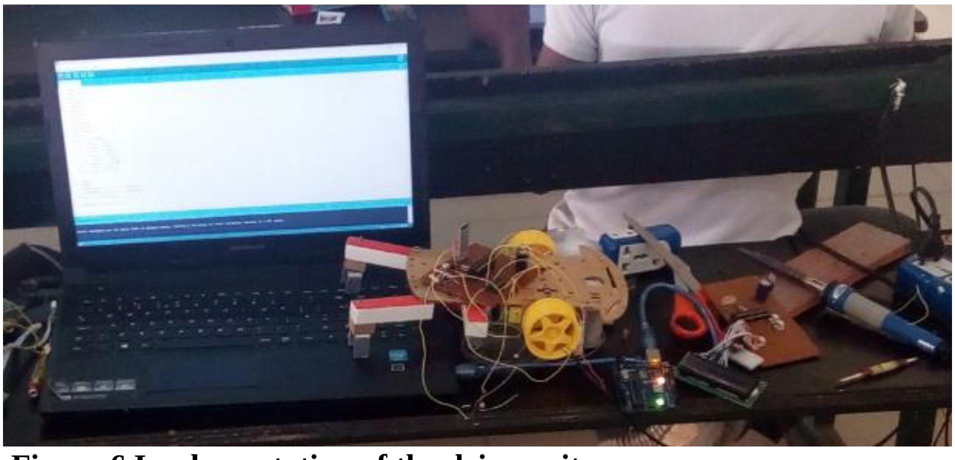

Figure 6 Implementation of the drive unit

3.1.2 Communication unit

After the circuit diagram was drawn, the respective IC socket of each IC required were carefully mounted on the vero board and then soldered alongside the capacitors and crystal oscillator. The circiut was checked for possible bridging and whether the stipulated voltage and current will be found on each pin of the IC socket.

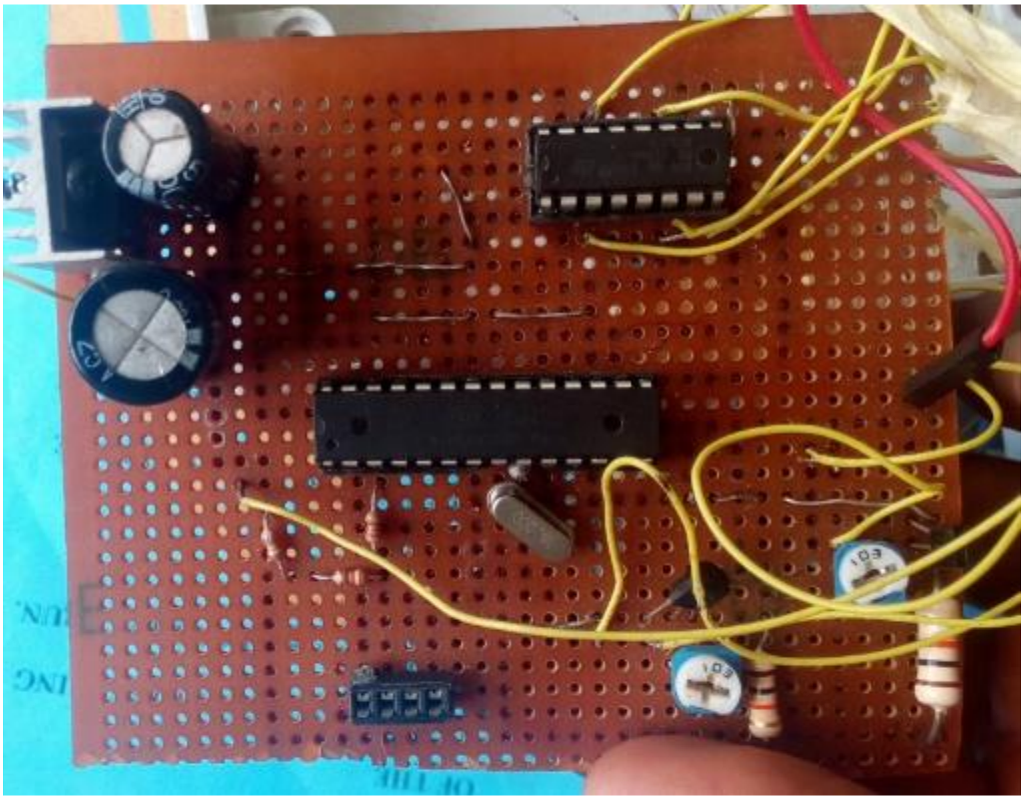

Figure 7 Implementation of the communication unit

3.1.3 Control unit

The control unit was built using necessary components (bluetooth module and microcontroller ATmega 328). The implemented control unit is shown on below

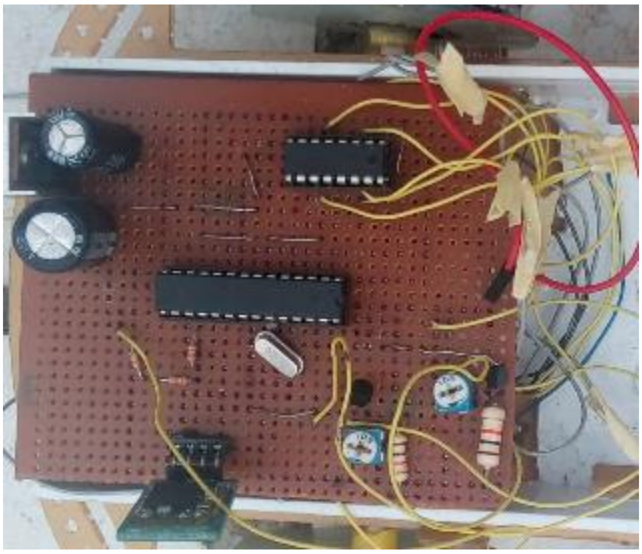

Figure 8 Implementation of the control unit

3.1.4 Data acqusition unit
The data acqusition unit was also built using components such as photoresistor, laser diode, bluetooth module and micro controller ATmega 328. The implemented data acqusition unit below.

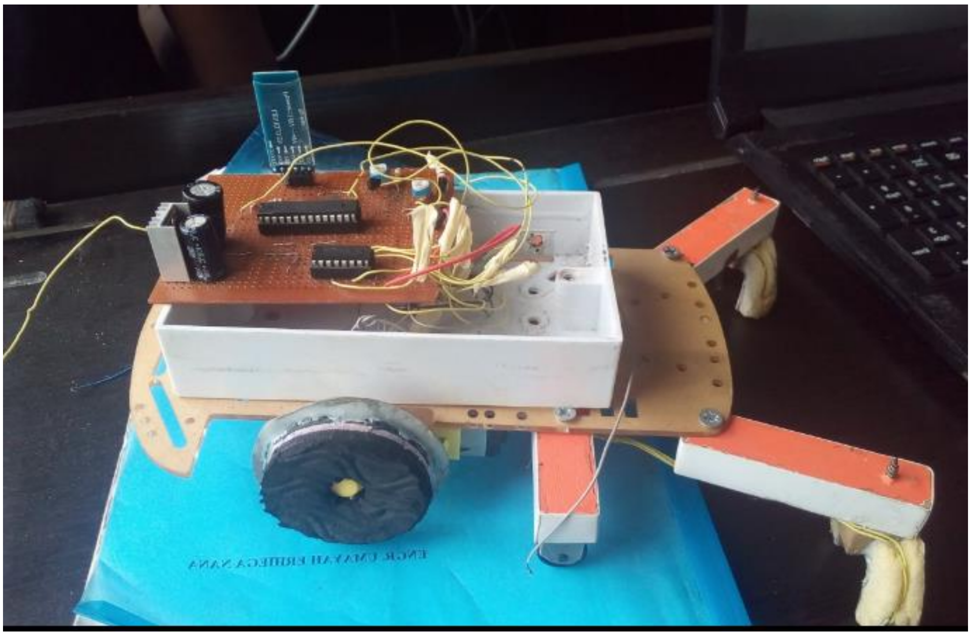

Figure 9: Vero board implementation of node

3.2 Software implementation
The Arduino UNO programmer was used to program the ATmega 328 microcontroller and the codes were written in the C complier and a mobile app was also developed for this project in order to remotely control the robotic vehicle as shown in figures 9 and 10.

Figure 9: Mobile app status indicating crack detected

3.3 Mode of operation

The mode of operation of the robotic rail track crack detection system is explained by figures 11 and 12. .

When the vehicle is powered on, it moves along the model track. The principle of operation is such that, during normal operation when there are no cracks, the LED light does not fall on the LDR and hence the LDR resistance is high. However, when the LED light falls on the LDR, the resistance of the LDR gets reduced and the drop in resistance will be approximately proportional to the intensity of the incident light. This change in resistance indicates the presence of a crack or some other similar structural defect on the rail track and the robotic car stops immediately and communicates this information via the blue tooth module installed on it to the mobile app developed. The position of the crack is noted and the car continues its movement forward after a command to do so have been initiated from the mobile app.

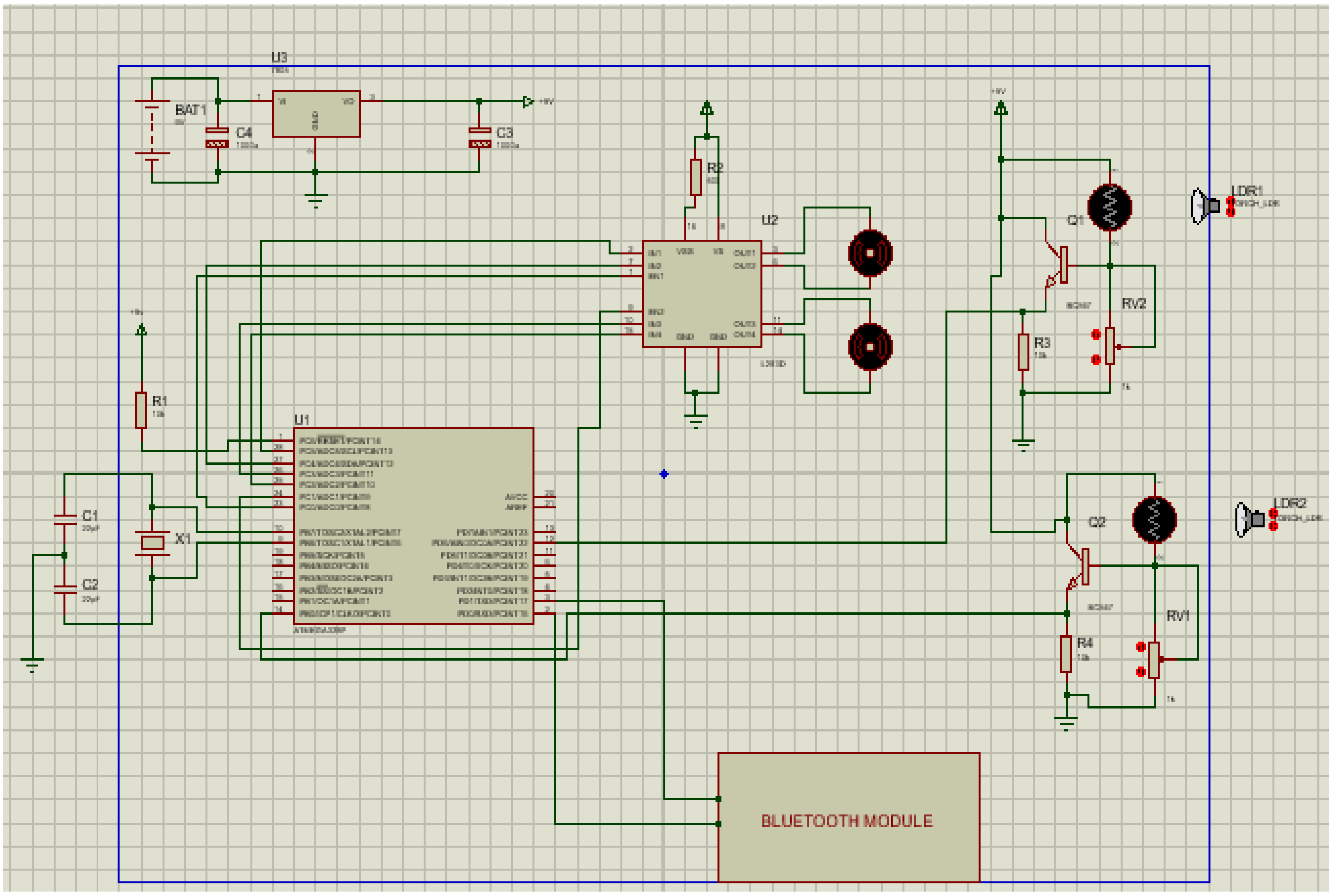

Figure 10 Complete Circuit Diagram

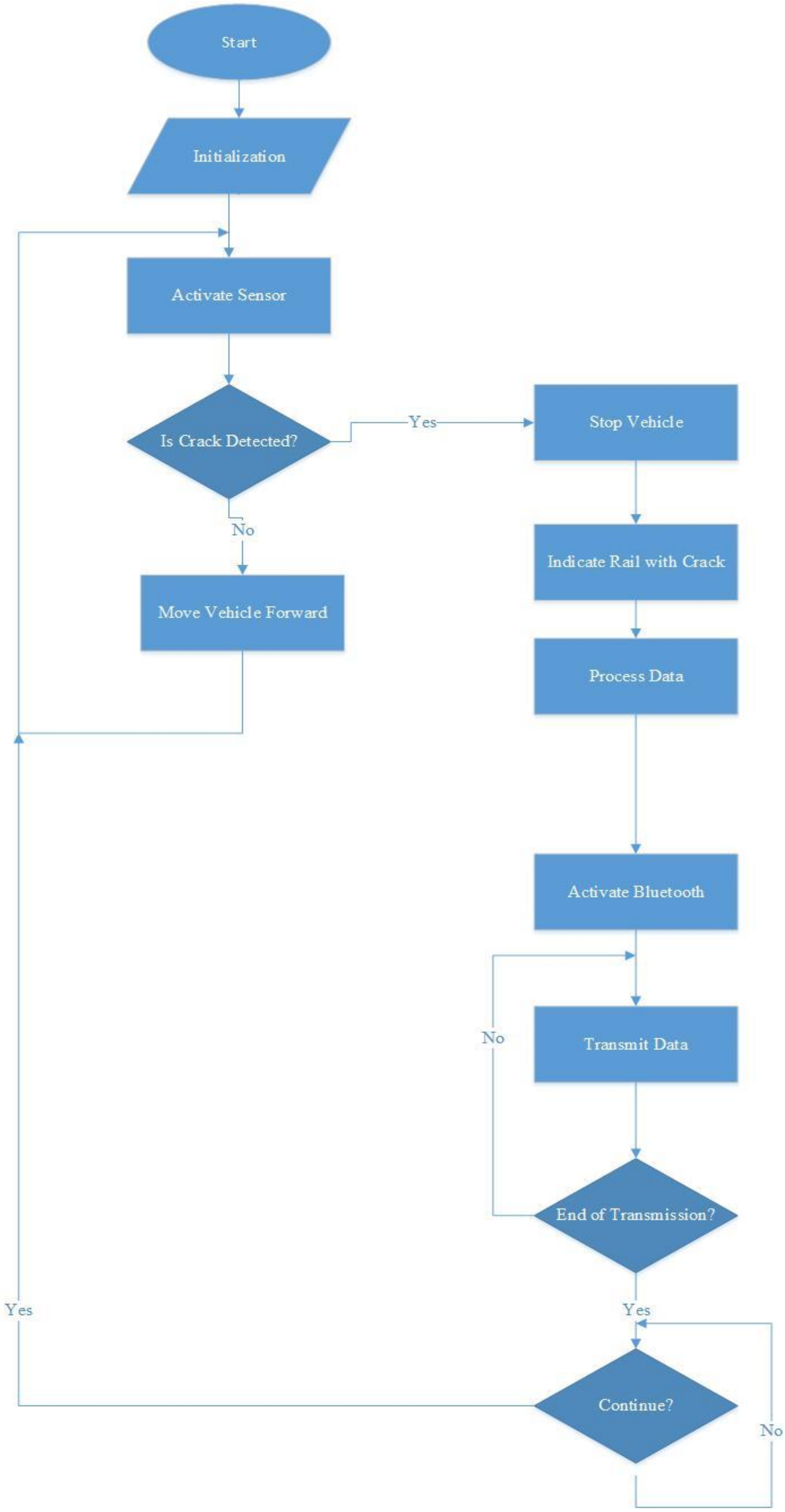

Figure 11 Program flow chart

4.0 Conclusion

Due to the importance of railway transportation as one of the most economical means of transport passengers and goods from one place to another and with the increasing investment in this sector by the Nigerian government [10], there is every need to ensure that this transport sector is made safer and returns are made on these investments. However, unless the Nigerian Railway Corporation (NRC) refines its methods and adopts modern methods such as the system proposed in this research these expectations may remain to a large extent elusive. This proposed method has many advantages as to why it's most suitable for the Nigerian environment. Some of these include less cost, low power consumption, accuracy, lesser manpower and lesser time. Also, the vehicle developed in this project is capable of working effectively in extreme environments such as heat, cold, or rough environments where manual inspection may not be feasible.

However in the future, the research can be expanded further to include new features such as:

1. An internet of things (IoT) functionality to enable monitoring and control of the robotic vehicle from any part of the country.
2. Features such as metal detectors, GPS tracking, pothole detection sensors and proximity sensors to guide and improve the navigation and control of robot on field.
3. Incorporating a self-charging system using solar energy could provide a constant power supply to the system keeping it in operation for a long time.

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