Design and Implementation of a Bluetooth-Based Rover Prototype for Short Range Extraterrestrial Explorations. An Exploratory Study.

Byakatonda Denis, Willy Kamya*

Faculty of Education, University of Kisubi

Abstract

Background:

Extraterrestrial exploration is an integral part of scientific research, some unnavigable or hard-to-reach places such as active volcanoes, bottoms of water bodies, radioactive sites and experimental chambers, mountain caves, or even other planets may contain very valuable data about our universe or some scientific phenomena. This project attempted to solve some of these accessibility problems by designing and implementing a rover that could be used to explore such environments without putting human life at stake.

Methodology:

The project adopts a very cost-effective approach, firstly, Arduino boards and Atmega microcontrollers are used for the design of control systems, and Bluetooth is used for remote communication. Performance results showed that the Bluetooth technology is suitable for use in a clean environment with fewer obstacles, the HC-05 Bluetooth was able to receive and transmit data up to 8 meters in a clear environment and up to 2.5 meters through walls.

Results:

Furthermore, the rover was 86.7% accurate in detecting obstacles along its way using ultrasonic sound sensors. The testing results are in the range of agreement with those of similar projects such as the obstacle avoidance robotic car by Bilkis, Faiza, Susmita & Muhammad (2017).

Conclusion:

The results of the study showed that building exploration robots or rovers can be built using cost-effective contemporary technology that is accessible to most developers, implementation of an obstacle is possible with Ultrasonic sensors and short to midrange communication and control is possible via Bluetooth.

Recommendation:

However, future researchers may investigate the use of renewable energy in powering the rovers and improving the transmission quality of Bluetooth.

Keywords: Bluetooth-Based Rover Prototype, Short Range, University of Kisubi, Submitted: 11th/09/2022 Accepted: 15th/11/2022

1. Background

Bilkis (2017) Defines an autonomous robot as one which can operate on its own without any external interference in an environment that is unstructured and unknown to the robot or sys-

*Corresponding author.

Email address: kamyawilly2@gmail.com (Willy Kamya)

tem. According to Crisp (2017), this can be made possible by embedding a pre-programmed system that can receive information about the environment through sensors and make decisions accordingly, such as changing the path or moving around the obstacle.

Autonomous machines are one of the fastest and most rapidly evolving technologies in the modern world today. Almost every car manufacturer is racing to be the first to produce the first fully standalone self-driving car on the market, Tesla (Tesla, 2022) and Mercedes-Benz (2022) car makers have already rolled out several models with autopilot and driver assist functionality which enables the car to move autonomously. More to that, several industries are also turning to robotic self-controlled machines to do repetitive tasks, amazon, for example, automated most of the sorting processes in its warehouses with robots to increase efficiency (Li, et.al, 2016).

But it's not just the automobile and e-commerce industries, several other fields are implementing self-controlled machines that can work with less or even without any human assistance. The idea of autonomous machines gets even more useful when it's needed to perform things that put human life at stake such as exploring extraterrestrial environments, these could be very rough terrains, dangerous caves, mountain tops, volcanoes, sea bottoms, and even other planets! NASA, among others, has been at the forefront of space exploration. Because of the possible unknown circumstances in most of these expeditions, it is too risky to send humans on first-time missions, having an autonomous system to survey the area first is always an alternative. On July 4, 1997, NASA landed the first 'Pathfinder' rover on mars to collect data that would be used for future missions, according to an article by NASA, an unprecedented amount of data was collected and the rover outlived its primary estimated lifetime. Furthermore, the NASA Mars Science Laboratory (MSL) on August 6, 2012, landed the curiosity rover on mars, another autonomous vehicle to explore and collect data about the 'red planet' (Arturo, et.al, 2021).

To implement autonomous machines, they must detect and avoid obstacles. according to (Kirti, Sayalee, and Shradda, 2016), Obstacle avoidance is a combination of computational intelligence (software) and physical machines (hardware) such as motors and sensors. At the heart of autonomous systems lies the fundamental idea of object detection, in self-driving systems, this helps to avoid collisions and accidents. Obstacle avoidance in robotics can bring more flexibility in maneuvering in varying environments and would be much more efficient as continuous human monitoring is not required (Bilkis, et.al, 2016).

Some of the most valuable data about our universe lie in places that are so hard to reach by humans. Natural caves and volcanoes for instance contain fossils and geological data, bottoms of water bodies contain fossils that could tell us about early lifeforms, and space contains data about the nature of the universe and possibly its foundations, Williford (2018). Next-generation exploration research will need more ways to reach such places that would put human life in danger, thus enabling researchers to collect data and interact with such environments remotely.

From this background, it is clear that autonomous robotic systems will fuel future developments in exploration and discovery among others. Such systems will enable researchers to reach places that humans would not dare and collect valuable data that could be used for further developments. To get there though, there's still a need for continued research and development into how best these machines can be made more reliable and efficient.

2. METHODOLOGY

*2.1. **Research design***

The study adopts an Exploratory research design; An exploratory design is conducted about a research problem when there are few or no earlier studies to refer to or rely upon to predict an outcome (USC, 2022). This kind of approach is best for this project since fewer projects have been done in which Bluetooth and Arduino-based technologies have been used in controlling an exploration rover, it also allowed the researcher and probably other researchers to continue exploring the problem statement further.

2.2. Tools and materials

Arduino NANO

The project uses an Arduino NANO board with an embedded ATmega 328P microcontroller and programming circuit which contains 14 digital input and output pins some of which can act as PWM outputs, and another 9 act as analog inputs. It also includes a 16 MHz crystal oscillator, a Mini USB connection, an ICSP header, and a reset button, more information can be found in the official datasheet from the Arduino website at (https://www.arduino.cc/en/uploads/Main/ArduinoNanoManual23.pdf). The Nano board doesn't have a DC power jack like other Arduino boards but instead has a mini-USB port. This port is used for both programming and serial monitoring. The fascinating feature of Nano is that it will choose the strongest power source with its potential difference, and the power source selecting jumper is invalid.

This type was used because it has all the necessary specifications needed for the project in terms of I/O pins, power supply, memory, and RAM, and was easy to interface with all other peripherals used in the project. ATmega 328P microcontroller

The microcontroller is a compact Integrated Circuit (IC) designed to control a specific operation in an embedded system, it typically includes a microprocessor, memory, and Input/Output (I/O) peripherals on a single board.

(Adapted from: https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf)

Arduino IDE

The Arduino Integrated Development Environment (IDE) is an open-source software developed by Arduino used for programming Arduino-based boards. It provides features such as code highlighting and debugging which make the programming process rather easier.

Ultrasonic sensors

To implement object detection and distance measurement, ultrasonic sound sensors were used. These operate on the principle of reflection of sound. During operation, they send ultrasonic sound and when it meets an object, it bounces off as an echo, the echo is then detected by the sensors and this signal can be taken to the microcontroller for further processing and decision-making. The HCSR04 model of Ultrasonic sensors was used in the project, as described above, it works by converting sound waves into electrical signals and vice vasa (Blum, 2014).

The relationship between speed of the waves, distance and time is as follows;

$$Speed \;=\; distance\; x\; time$$

But the waves move twice the distance (i.e., to and from the object) before they are detected by the sensor, thus for application purposes of this sensor;

$$Speed \;=\; 2(distance)\; x\; time$$

If the speed of the waves in the environment is known (and usually it is), the time between sending sound and receiving the echo is measured by the sensor, thus the distance of the object can be calculated.

$$distance = \frac{Speed}{2\;\times time}$$

The specifications of the HC-SR04 Ultrasonic sensor are as follows;

Motors and motor driver

The project uses two kinds of motors, DC motors attached to wheels for the motion of the entire prototype and a servo motor onto which ultrasonic sensors are mounted for turning left and right to seek a clear path.

The DG01D-A130 geared motor was used for system motion, this king was strong and versatile enough to handle the entire weight provided it is supplied with enough power.

The SG90 servo motor was used to turn the ultrasonic sensors left and right to seek a clear path whenever an obstacle is detected.

Specifications of the SG90 servo motor are;

Project build process

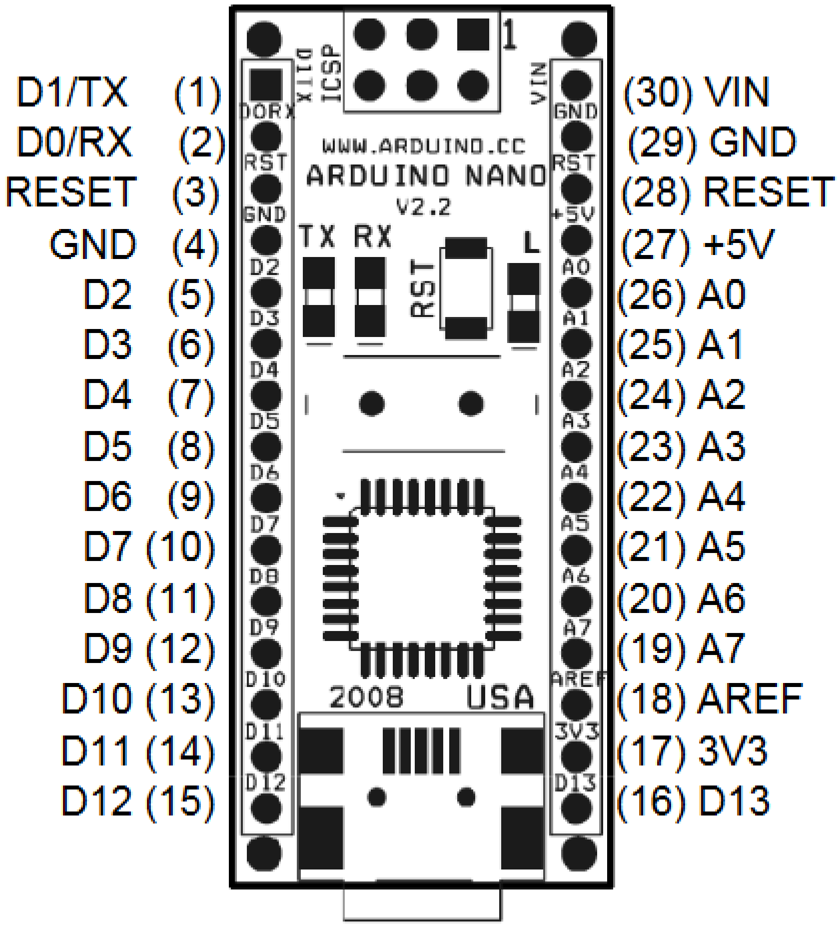


Figure 1: Pinout view (Source:Arduino.cc)

Table 1: The specifications of theHC-SR04 Ultrasonic sensor are as follows;

Working voltage	DC 5V
Current	15 mA
Frequency	40Hz
Max range	4m
Min range	2 cm
Measuring angle	15 degrees
Trigger input signal	10 μS TTL pulse
Echo input signal	TTL lever signal and the range in proportion

HC-SR04 Ultrasonic sensor specifications

Table 2: **Specifications of the SG90 servo**

Size	22.4x12.5x22.8 mm
Quiescent current	5mA
No load current	90mA
Pulse signal	PWM 50Hz / 0.5 – 2.5 ms
Operating voltage	4.8 – 6.0 V

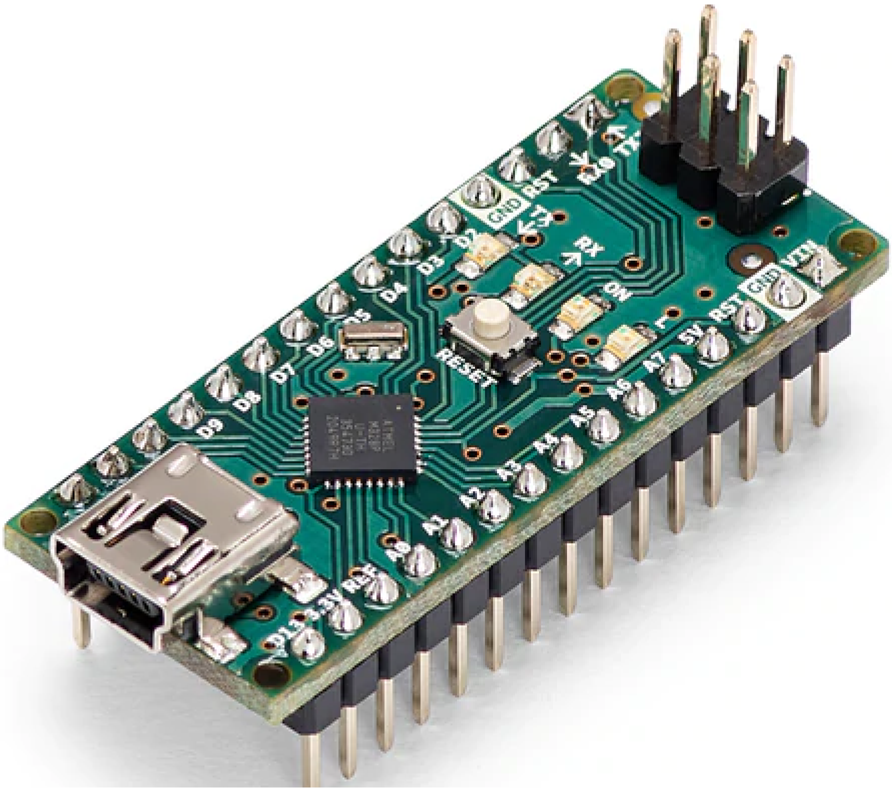


Figure 2: Arduino NANO board

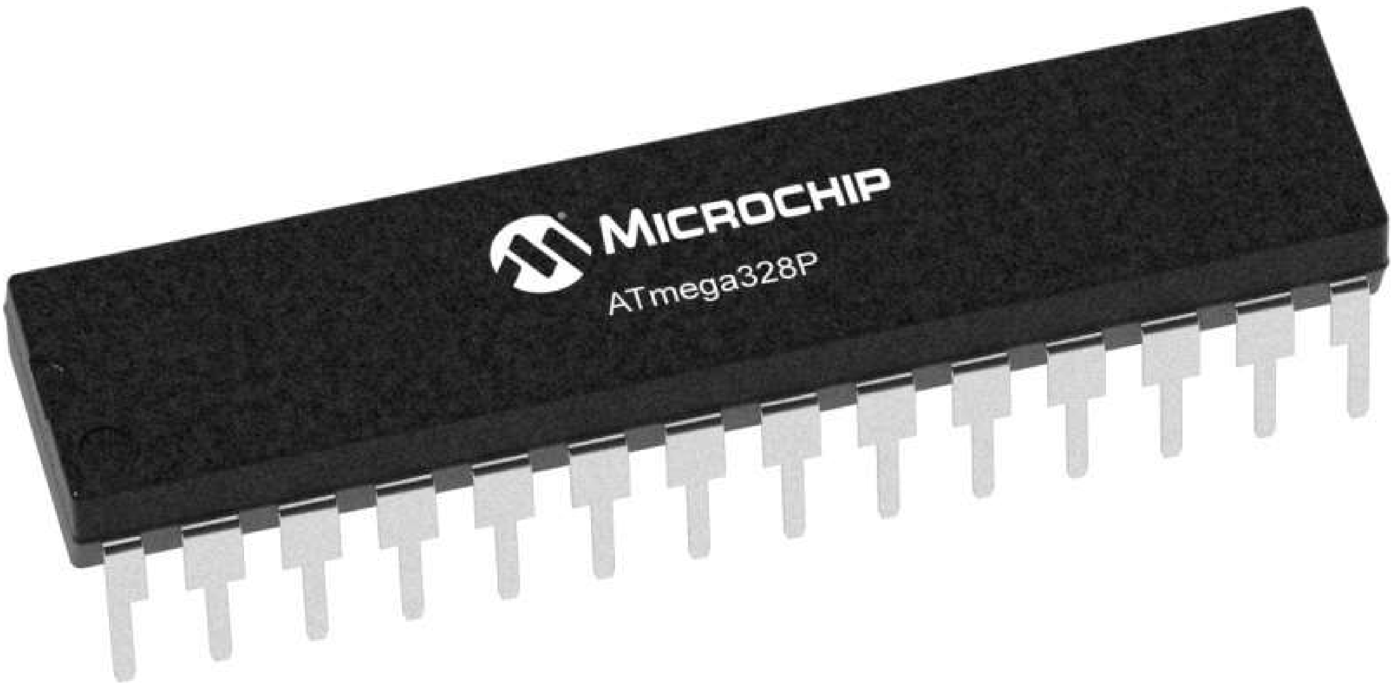


Figure 3: ATmega 328P microcontroller

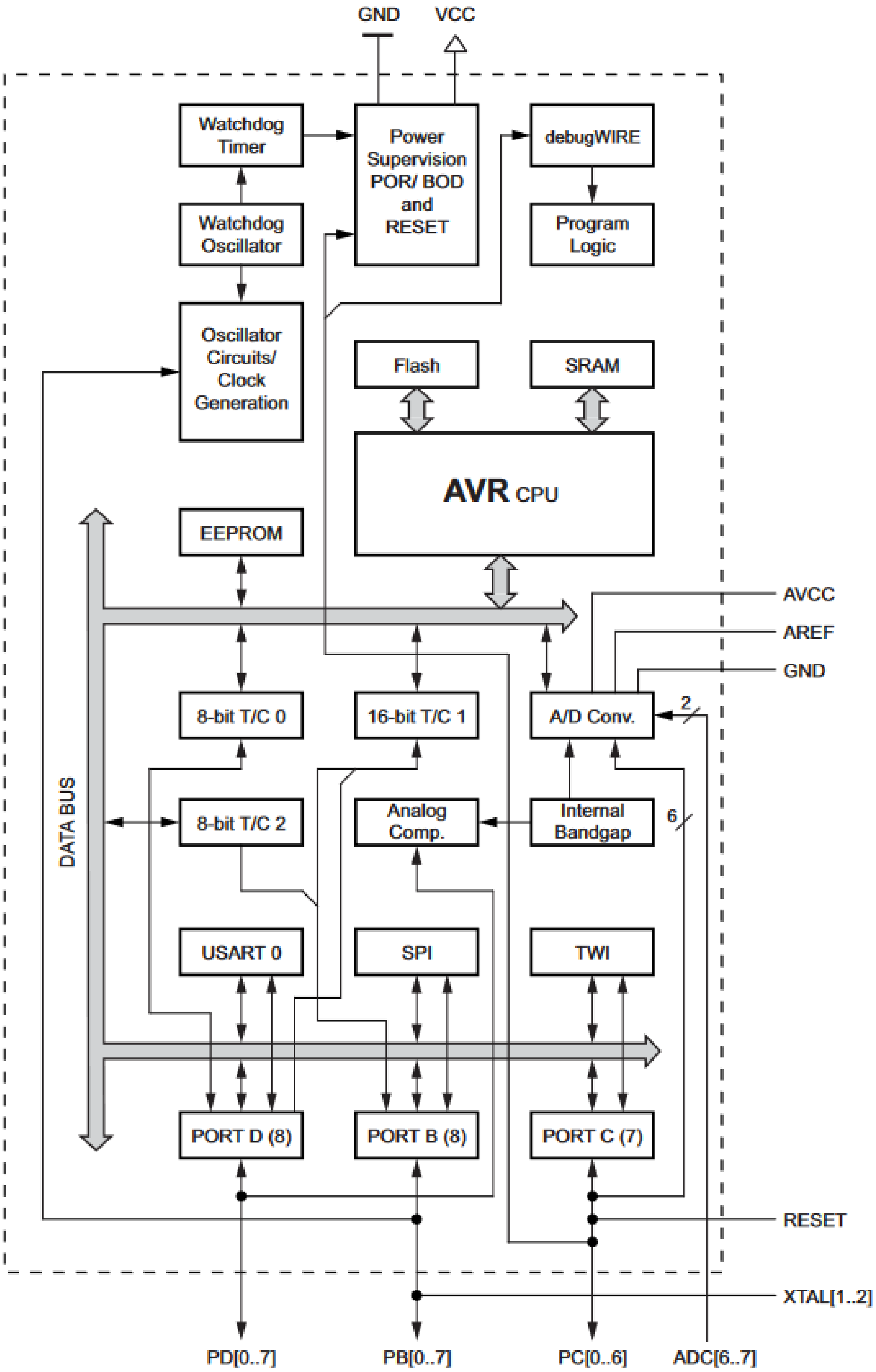


Figure 4: ATmega 328P microcontroller block diagram

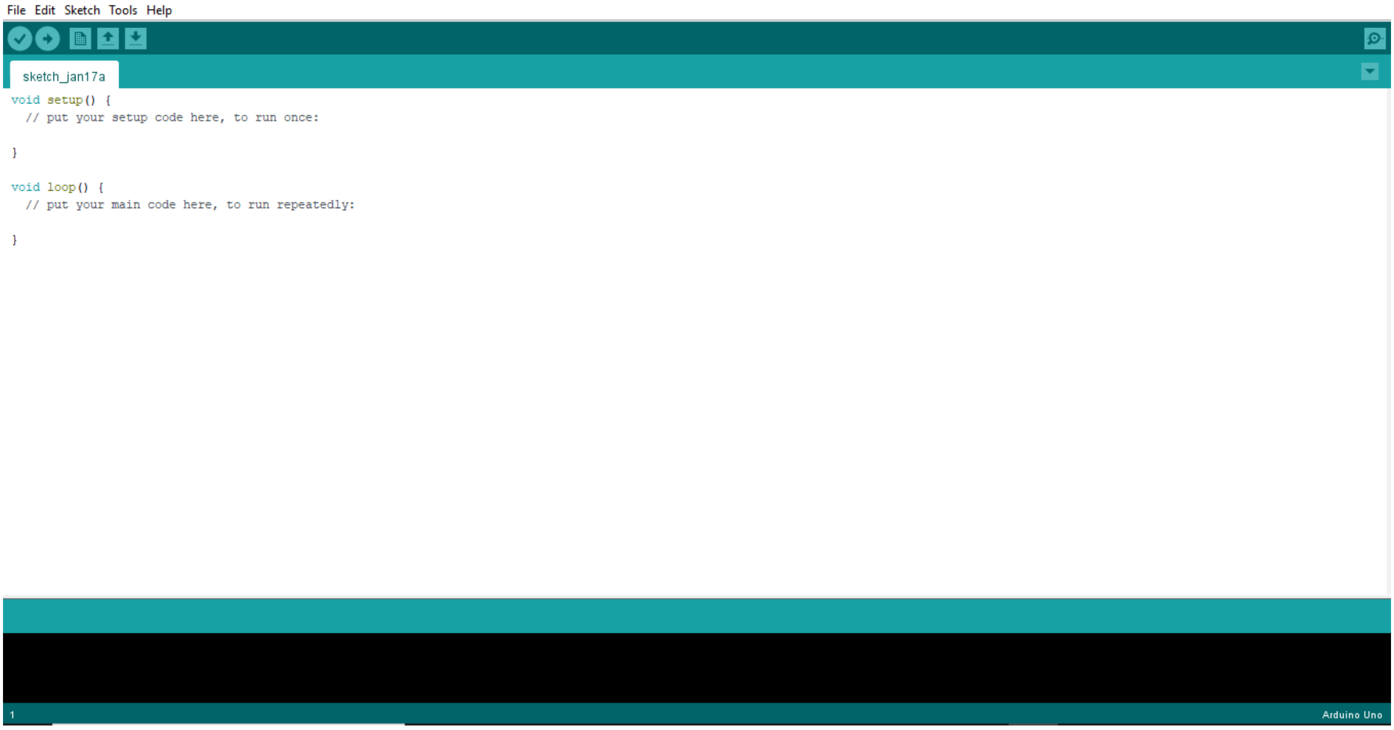


Figure 5: Arduino IDE interface

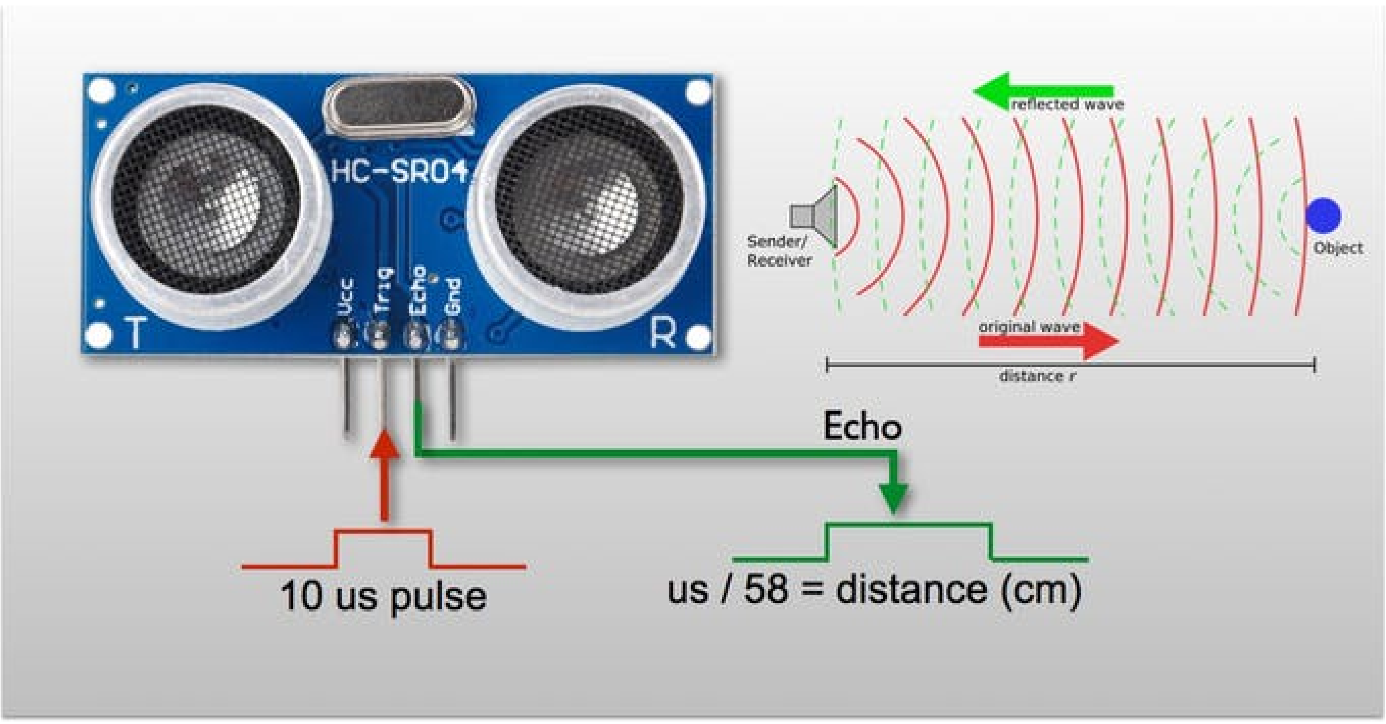
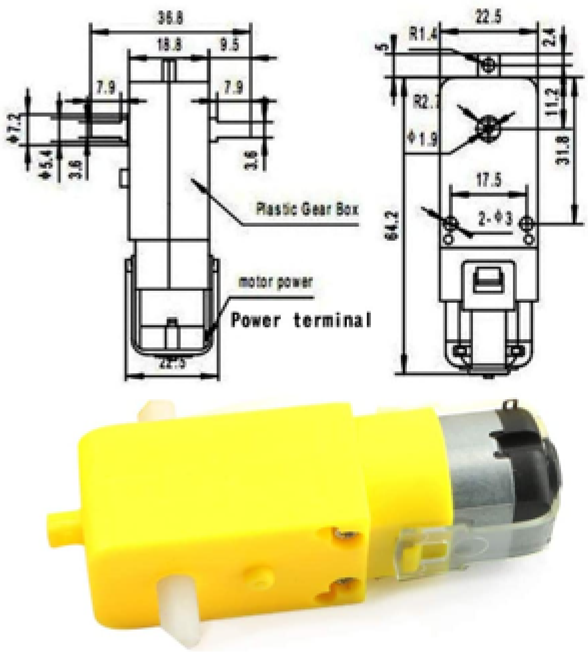


Figure 6: HC-SR04 Ultrasonic sensor and operation principle



No load speed	80-100 rpm
No load current	190-250 mA
Maximum torque	800gf.cm min

Figure 7: Geared motor for moving the wheels

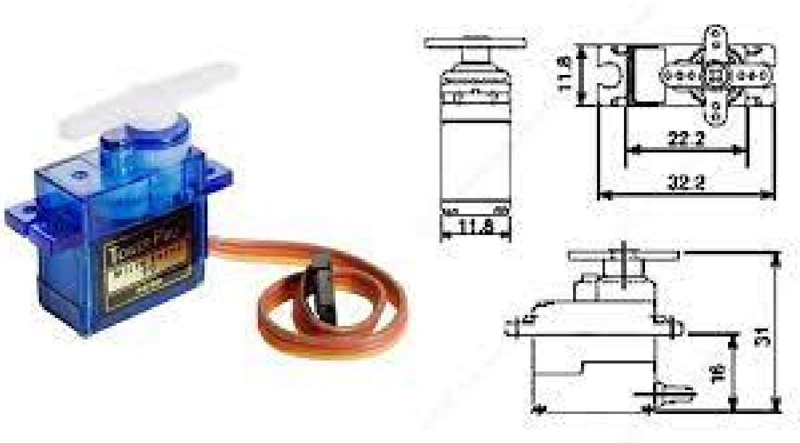


Figure 8: **SG90 servo motor**

This subsection describes how the different parts mentioned above are connected together to design and build the project. It contains details about the project block diagram and electronic circuitry. In order for the prototype to fully function with the prescribed autonomous capabilities, a software program will be coded and uploaded to the microcontroller unit, the subsection concludes with the algorithm and software design process and description.

Block diagram

Figure 9, above is a block diagram showing the connection and interaction of the different hardware parts. The central part of the system is a micro controller which acts like the 'brain' of the entire system, it receives, processes, and executes instructions based on data from sensors or data from the controller.

Ultrasonic sensors continuously send out ultrasonic waves, when an echo is detected, the signal is sent to the microcontroller for further processing and decision-making, based on the outcome of the processed signal, the microcontroller sends instructions to the motor driver which further con-

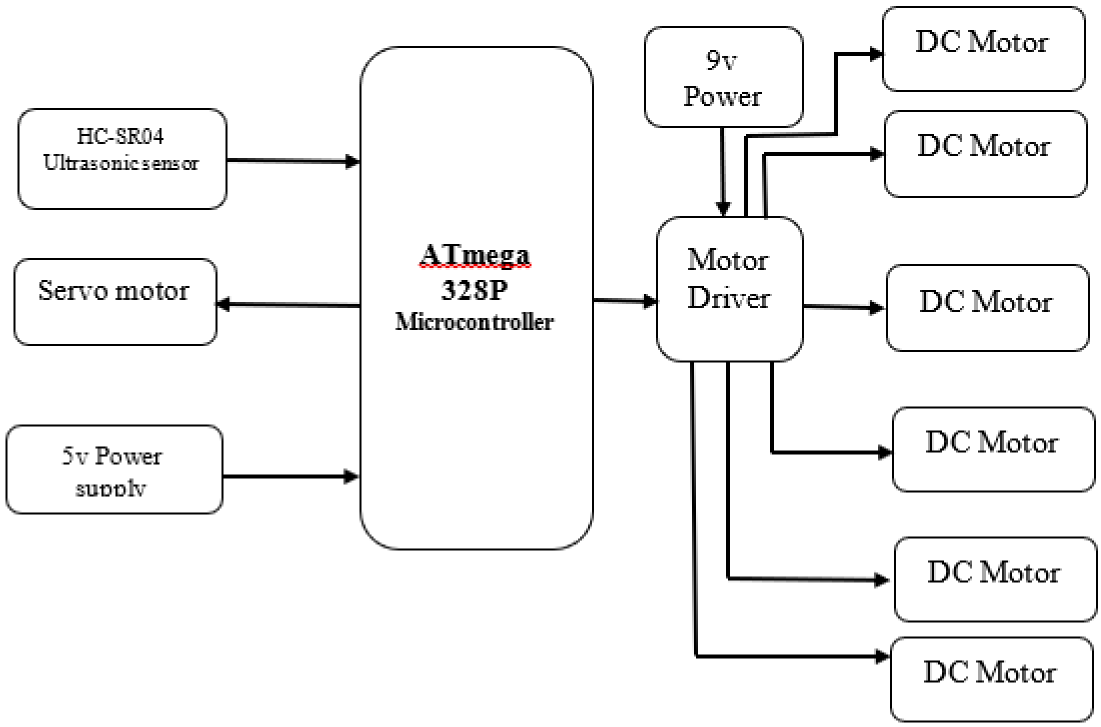


Figure 9: **Block diagram showing connection of the hardware components**

trols the voltage and current distribution to the motors.

The microcontroller unit is powered by 5 volts DC, to provide extra power to the motors however, another source of 9-12 VDC is connected to the motor driver to supply the motors.

Circuit Diagram

The figure 10 shows the electric circuit diagram for the project. It shows how all the components described above are put together to make the electronics system of the proposed prototype.

Flow chart and software

The code or software for this project is written following the above flow chart or algorithm and the Arduino Integrated Development Environment (IDE). Following the flowchart above, when the microcontroller unit is powered on, the peripherals connected to it are initialized to standby mode, ready to take instructions from the control unit. The software code for running the entire device has been attached in the appendix, comments are inserted where due to explain the functionality of the code.

Testing parameters

To ensure the prototype is working well and efficiently, the following test parameters are used in chapter 4 for testing, analysis, and establishment of efficiency and accuracy limits.

Obstacle detection

The researcher measured how efficient the prototype is in detecting obstacles through the attached HCSR04 ultrasonic sensors and avoiding these obstacles by stopping before the collision. The researcher will place objects of different natures in the rover's path and calculate the percentage of successful detections and avoided collisions. Here, efficiency will be defined as;

Wireless communication via Bluetooth

Interaction between the rover and the human controller for this prototype is via Bluetooth technology, here, the researcher measured the time taken for the signals to be transmitted from the control device (android phone) to the rover and vice vasa. The time measurements were taken with a stopped clock with an accuracy of up to a millisecond.

The maximum communication distance was also tested and measured using a tape measure,

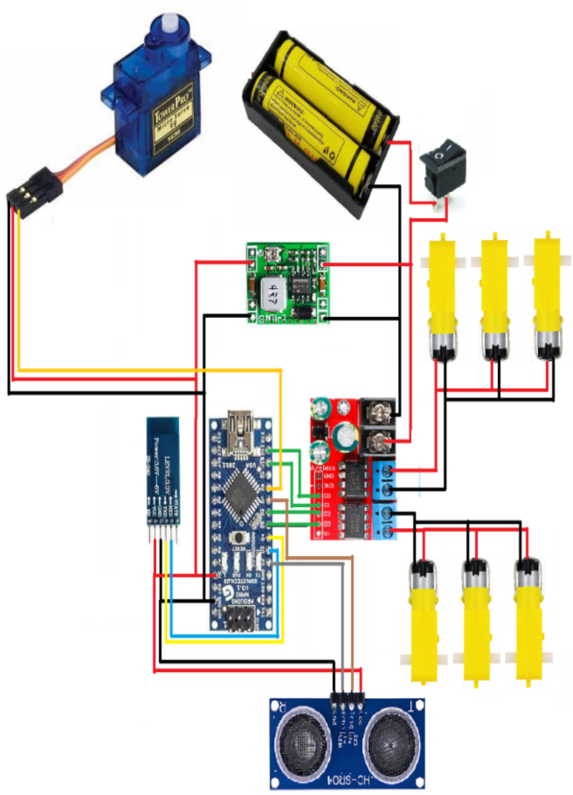


Figure 10: Electricalcircuit diagram showing connections between the components

allowing the researcher to know and establish limits within which the prototype can be controlled remotely.

Ethical considerations

Research ethics were considered during the project, and all external sources of information and literature used in any form were carefully cited and referenced thus the original authors were acknowledged for their work on the subject. All computer systems and software used in the project were used in a way that does not undermine the integrity of the systems involved. Recyclable materials will be used as much as possible in the design implementation to protect the environment.

3. PRESENTATION AND ANALYSIS OF RESULTS:

Obstacle detection and avoidance

Objects of different kinds were placed along the rover's path to act as obstacles, the researcher counted the number of obstacles that were successfully detected. The results were recorded below and used to establish obstacle detection accuracy or efficiency.

above shows results of detection of obstacles of different kinds. Out of the thirty obstacles tested, twenty-six of them were successfully detected.

From; $Accuracy = \frac{Number\ of\ successful\ detections}{Total\ number\ of\ obstacle\ tested} \times 100\%$

$$Accuracy = \frac{26}{30} \times 100\% = 86.7\%$$

The ultrasonic sensors on the rover were thus 86.7% accurate. Of the materials used, the wire mesh had large spaces which likely couldn't reflect the sound waves; thus, such an obstacle couldn't be detected by this principle. It is worth noting that all these objects were placed somewhat directly Infront of the rover in a range within which

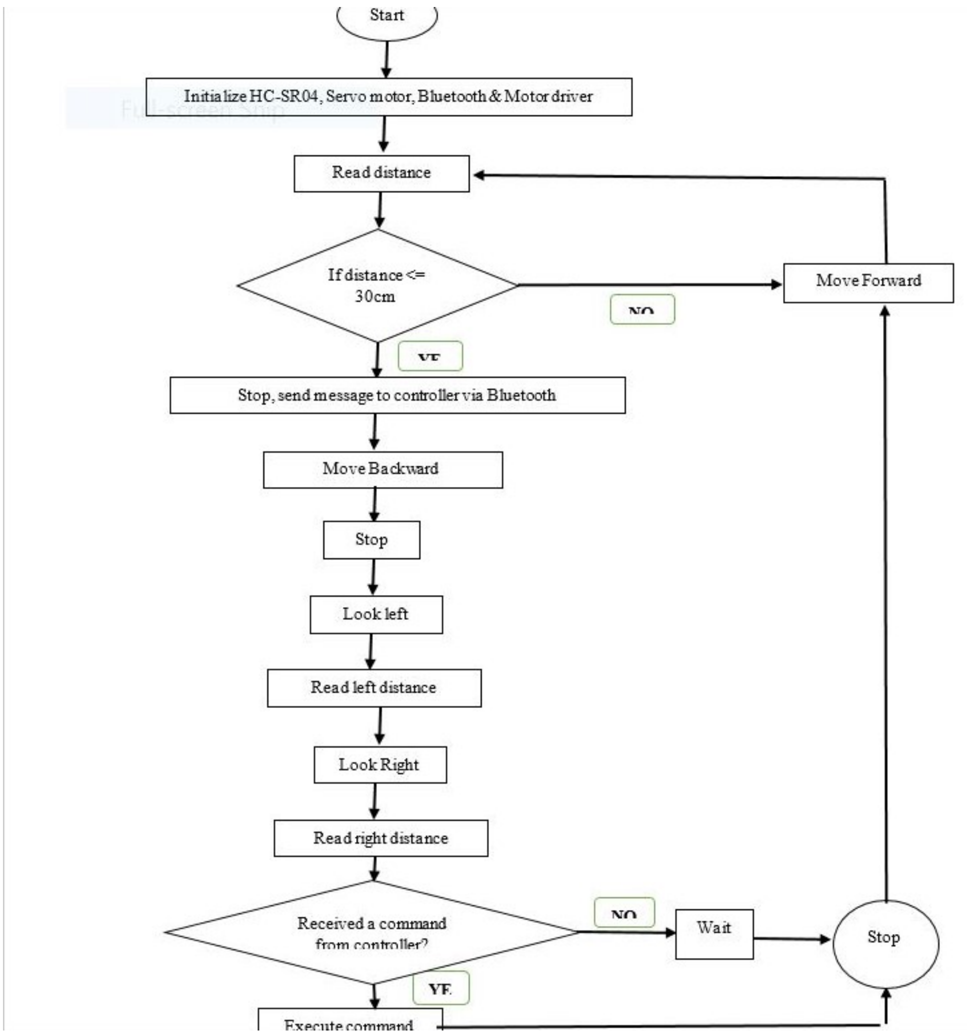


Figure 11: **Project software flowchart**

waves sent by the ultrasonic sensors would reach them.

Bluetooth sensitivity

The prototype uses Bluetooth for remote communication and control. Since Bluetooth runs on short-range radio frequency, it was necessary to test the range within which the controller could still efficiently communicate with the rover. The figure below is a graph of the time taken to transmit or receive a message from the rover versus distance for two different environments.

From the graph 12, it can be seen that the used Bluetooth module is more sensitive in a clean environment without obstacles, under such conditions, the maximum range of sensitivity was 8 meters. When tested in an environment with walls, the sensitivity quickly drops, as seen in the graph, the response time increased rapidly with an increase in distance and transmission ceased at about 2.5 meters. Furthermore, for both environments, the response time increased with distance from the rover. The results indicate that Bluetooth transmission technology is highly affected by the environment in which it is being used.

Power consumption

There was a lot of stress on the battery coming from the inductive components, especially the driving motors and servo motors. The motors need a lot of energy for their operation, especially since they are geared motors. The motor driver shield is powered from the same source as the Arduino board. The Arduino requires a 5V supply and it was supplied power using double lithium-ion batteries, each of 3.7V while the motor driver

Table 3: **Detection results for different obstacles**

Serial Number	Status
Object 1	Detected
Object 2	Detected
Object 3	Detected
Object 4	Detected
Object 5	Detected
Object 6	Detected
Object 7	Detected
Object 8	Not Detected
Object 9	Detected
Object 10	Detected
Object 11	Detected
Object 12	Detected
Object 13	Detected
Object 14	Not Detected
Object 15	Detected
Object 16	Detected
Object 17	Detected
Object 18	Detected
Object 19	Detected
Object 20	Not Detected
Object 21	Detected
Object 22	Detected
Object 23	Detected
Object 24	Detected
Object 25	Detected
Object 26	Detected
Object 27	Detected
Object 28	Detected
Object 29	Not Detected
Object 30	Detected

shield requires 5-28V and was supplied power with two 3.7V Li-on batteries connected in series. The motors, servo motor, and sensor all required 3-6V each. With fully charged batteries for the motor driver shield, it took about 3 hours of operation before the power supplied was insufficient to rotate the motors.

4. CONCLUSION AND RECOMMENDATIONS

5. Conclusions

The goal of the project was to describe and build a prototype of a rover robotic car based on Arduino and Bluetooth technologies. Finally, the prototype was designed and made and its performance was tested and reported. The following key design and performance issues are worth noting.

The accuracy of the rover in detecting and avoiding objects depends on the nature of the

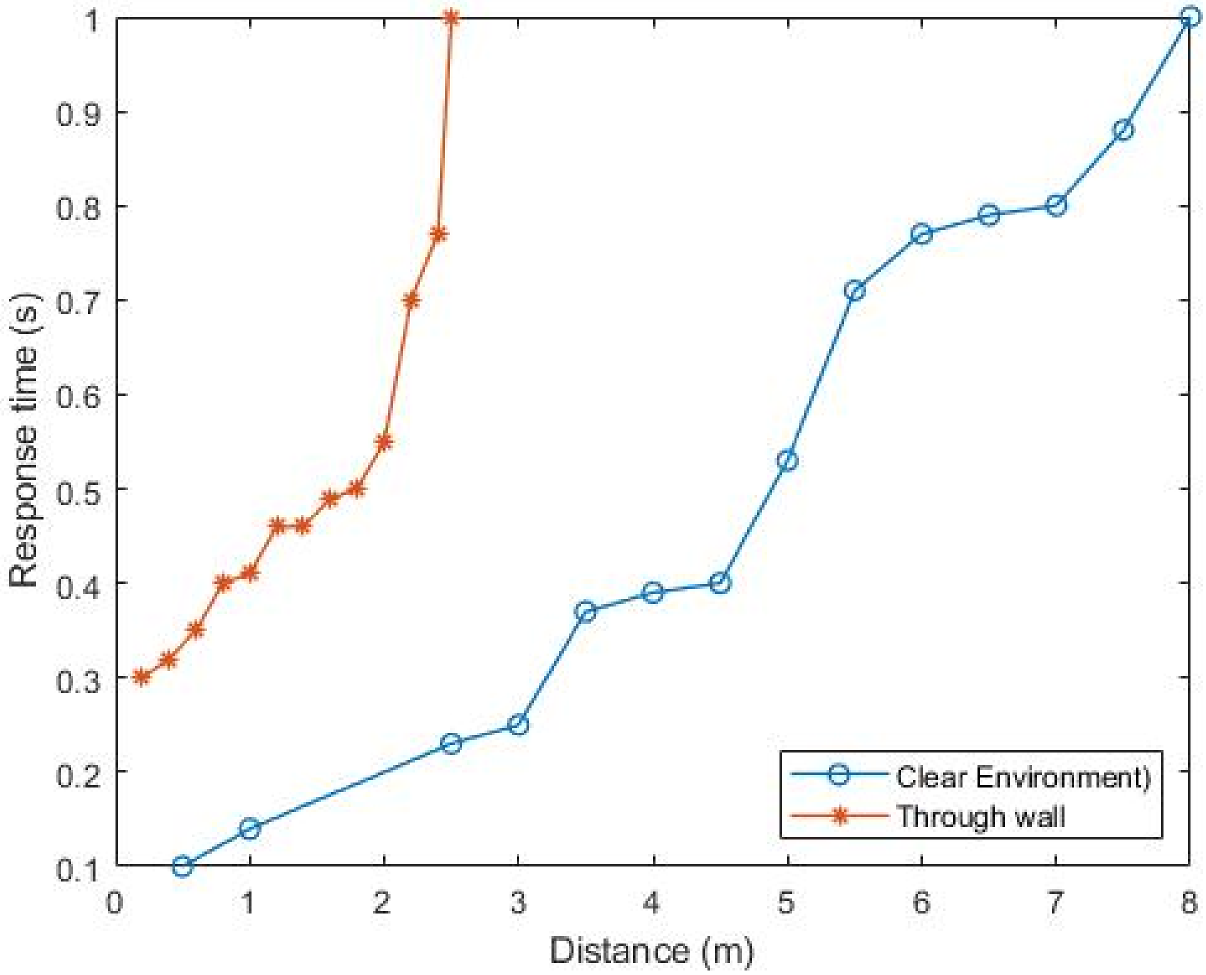


Figure 12: **A graph of reaction time versus distance from the rover**

obstacle, its location relative to the sensors, and the rover's speed. Firstly, the obstacle should be dense enough to reflect sound, it should also lie within the detection range of the sensors, if an obstacle say approaches the rover from the sides, it won't be detected. The speed of the rover was also adjusted (by reducing the power in the driving motors) so that the rover can easily brake when an obstacle is detected, this was also enhanced by using rubber wheels to increase friction.

Regarding the performance of Bluetooth for communication and control, results for different environments showed that it is more efficient in a 'clear' environment without obstacles such as walls and metallic barriers. Further, the response time was dependent on the distance from the control device (phone) to the rover.

The software to control the rover was written in C++ using the Arduino IDE, the code or program execution and data processing on the ATmega 328P microcontroller unit was efficient, and no runtime errors were experienced.

Some undesirable performance issues included abrupt disconnection of the Bluetooth module, requiring a reconnection during operation, which could at times lead to delays or even unseen eventualities due to loss of communication and control. Also, as the rover moved away from the controller, given that the Bluetooth signal strength decreased, there was a time lag between transmissions which to a smaller extent deters real-time communication.

6. Recommendations:

The use of multiple sensors would improve obstacle detection and avoidance accuracy, some of these sensors could be placed on the sides and at the back of the rover to detect side and behind obstacles in case of reverse motion. The sensors could also be placed at different angles and heights and optimized to cover as much range as possible.

The addition of a Camera into this project could help the controller to direct the rover even beyond line of sight. Also, the camera could be used for image processing purposes and capturing data from the test environment.

For this project, though the rover has some automated capabilities such as detecting obstacles and stopping to avoid a collision, and checking its left and right paths to find out if there's a clear path, it still needs a human controller to be able to execute some functions, for example, what to do next after detecting an obstacle and stopping. Though this was suitable for this project, writing software that would make it fully autonomous would be a good idea, though it should allow human intervention at some point.

Lastly, using long-range industrial-grade Bluetooth modules could improve the operating distance of the rover, and the addition of antennae could also add to the sensitivity.

7. ACKNOWLEDGEMENT:

Lord, I can't thank you enough for enabling me to work on this project, I surely couldn't have accomplished it was not for your grace. Am also to indebted several men and women who have been of great help during the project.

I acknowledge the good work done by my supervisor Mr. willy Kamya, thank you for the restless efforts you put in to help me accomplish this work, your comments have surely been useful in shaping the project in the right direction, may you live to be a blessing to more. A big thanks to my lecturers Mr. Joseph Owalu, Dr. Kasumba Henry, and Mr. Amutuheire Peter, it is because of the knowledge acquired from your lectures that I've been able to do this.

More thanks to my brother and friend Eng. Ssekandi William whose input on the electronics part of the project was very helpful, I couldn't have pulled this off this way without you. Shout out to all those who were inspired to do this project, Eng. Twesiime Julius, Eng. Charles Ssewagude, and Mr. Ssozi Patrick. I could go on and on mentioning names but the list wouldn't fit here, I only pray that God blesses each soul that has had a hand in this.

8. References:

1) Arduino (September, 15, 2021). About Arduino. https://www.arduino.cc/en/about

2) Arturo Rankin, Mark Maimone, Jeffrey Biesiadecki, Nikunj Patel, Dan Levine, Olivier Toupet, "Mars Curiosity Rover Mobility Trends During the First 7 Years," Journal of Field Robotics, 09 January 2021.https://doi.org/10.1002/rob.22011

3) Banzi, M. (2008). Getting Started with Arduino, Make: Books, CA: USA.

4) Bares, J. E., & Wettergreen, D. S. (1999). Dante II: Technical description, results, and lessons learned. The International Journal of robotics research, 18(7), 621-649.https://doi.org/10.1177/02783649922066475

5) Bilkis. J, Faiza. T, Susmita. L, Muhammad. M, (2017). Obstacle Avoiding Robot. Global Journal of Researches in Engineering: Robotics & Nano-Tech. Volume17 Issue 1 Version 1.0 Year 2017. International Research Journal. Publisher: Global Journals Inc. (USA).

6) Blum, R. (2014). Arduino Programming in 24 Hours. Indianapolis: Sams Publishing

7) Crisp, J. (2004). Introduction to Microprocessors and Microcontrollers. Oxford: Newnes.

8) E. Daniel Wang. Obstacle Avoidance Algorithms and Sensors for Autonomous Robots. www2.ece.gatech.edu/academic/courses/ece4007/10fall/I

9) E. Karabegovic and E. Husak. 2012. Trend of Industrial Robot Share in Different Branches of Industry in America. International Journal of Engineering Research and Applications (IJERA). 2(2): 479-485.

10) E. Prassler, J. Scholz and P. Fiorini. 1999. Maid: A robotic wheelchair roaming in a railway station. Proceedings of the International Conference on Field and Service Robotics. pp. 31-36.

11) Faiza Tabassum, Susmita Lopa, Muhammad Masud Tarek, Dr. Bilkis Jamal Ferdosi (2017). Obstacle Avoiding Robot. Global Journal of Researches in Engineering: Robotics & Nano-Tech. Volume17 Issue 1 Version 1.0 Year 2017. International Research Journal. Publisher: Global Journals Inc. (USA).

12) Juang, H., & Lum, K. (2013). Design and Control of a Two-Wheel Self-Balancing Robot using the Arduino Microcontroller Board. 10th IEEE International Conference on Control and Automation (ICCA) (pp.634-639), Hangzhou, China, June 12-14, 2013.https://doi.org/10.1109/ICCA.2013.6565146

13) Kirti Bhagat, Sayalee Deshmukh, Shraddha Dhonde, Sneha Ghag (2016) Obstacle Avoidance Robot. International Journal of Science, Engineering and Technology Research (IJSETR), Volume 5, Issue 2.

14) Kolapo Sulaimon Alli, Moses Oluwafemi Onibonoje, Akinola S. Oluwole, Michael Adegoke Ogunlade, Anthony C. Mmonyi, Oladimeji Ayamolowo and Samuel Olushola Dada (2018). Development of an Arduino-Based Obstacle Avoidance Robotic System for an Unmanned Vehicle. ARPN Journal of Engineering and Applied Sciences, Vol. 13, No. 3.

15) Li, J. T., & Liu, H. J. (2016). Design optimization of amazon robotics. Automation, Control and Intelligent Systems, 4(2), 48-52.https://doi.org/10.11648/j.acis.20160402.17

16) Mercedes-Benz (2022). Driving assistance systems in S-class: Intelligent drive next level. https://www.mercedes-benz.com/en/innovation/autonomous/the-new-s-class-intelligent-drive-next-level/MIT News (July 7, 2021). Designing exploratory robots that collect data for marine scientists. https://news.mit.edu/2021/victoria-preston-exploratory-robots-0707

17) NASA(July, 29, 2021): Human Exploration Rover Challenge https://www.nasa.gov/marshall/news/releases/2021/nasa-issues-human-exploration-rover-challenge-handbook-for-2021-22-competition.html

18) Squyres, S. W., Knoll, A. H., Arvidson, R. E., Ashley, J. W., Bell, J. F., Calvin, W. M., ... & Yingst, R. A. (2009). Exploration of Victoria crater by the Mars rover Opportunity. Science, 324(5930), 1058-1061.https://doi.org/10.1126/science.1170355PMid:19461001

19) Tesla (2022). Autopilot and full self-driving capacity. https://www.tesla.com/support/autopilotUniversity of southern California, USC (Feb, 18, 2022). Research Designs. https://libguides.usc.edu/writingguide/researchdesigns

20) Ulrich and J. Borenstein. 1998. VFH+: Reliable obstacle avoidance for fast mobile robots. Proceedings of the 1998 IEEE Conference on Robotics and Automation. pp. 1572-1577.

21) Volpe, R., Balaram, J., Ohm, T., & Ivlev, R. (1996). Rocky 7: A next generation mars rover prototype. Advanced Robotics, 11(4), 341-358.https://doi.org/10.1163/156855397X00362

22) Williford, Kenneth H., Kenneth A. Farley, Kathryn M. Stack, Abigail C. Allwood, David Beaty, Luther W. Beegle, Rohit Bhartia et al. "The NASA Mars 2020 Rover Mission and the Search for Extraterrestrial Life." In From Habitability to Life on Mars, pp. 275-308. Elsevier, 2018.https://doi.org/10.1016/B978-0-12-809935-3.00010-4

9. Publisher details:

Publisher: Student's Journal of Health Research (SJHR)
(ISSN 2709-9997) Online
Category: Non-Governmental & Non-profit Organization
Email: studentsjournal2020@gmail.com
WhatsApp: +256775434261
Location: Wisdom Centre, P.O.BOX. 148, Uganda, East Africa.

Author biography

Willy Kamya born 2/07/1987 in Lwengo district, he holds an MSc. In physics from Kyambogo university, BSc. Education from Gulu university, completed UACE from Masaka SSS, UCE from Nakyenyi SSS, and PLE from Nakyenyi P/S, currently is a lecturer of physics and a researcher at university of Kisubi in the faculty of education.