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A Multi-Threaded Real Time Operating System based Robotic Car

Chiang Liang Kok[1], Nadaison Saravanan S/O Selvaraj[1], Yit Yan Koh[1]
[1] *University of Newcastle, Australia*
Corresponding Author: chiangliang.kok@newcastle.edu.au

---***ABSTRACT***---
Robotics has been around for many years. The first modern robot was invented in 1950s. It was an inventor from Louisville, Kentucky by the name of George C. Devol. As technology advances, we have many robots available today. In today's world most places need robots to ease the workflow. However, most of the existing robots we need to constantly try and improve them in many ways. This paper proposes a Multi-Threaded Real-Time Operating System (RTOS) based Robotic Car controlled through an Android App. This robotic car facilitates users to wirelessly control the robotic car via their Android mobile phone. Three different modules are operating concurrently in the device – microcontroller, RTOS, and Android app. The first module is the microcontroller which processes various input/output data. The second module is RTOS which takes the user's input and prioritizes which task it will execute. Lastly, the Android app which is a user interface where the user can input the direction they want the robotic car to move.

KEYWORDS;- *Multi-Threaded Real Time Operating System, Robot, Android App*

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I. INTRODUCTION

A remote-controlled car has been around for more than a decade. Some of it has been used for teaching purposes, hobbies, and high-level competitions/race. They can be as simple as a toy you buy from a shop to being as complex as where individual parts are being sold for high level competition/race. These remote-controlled cars have been the basis of many advanced developments such as the Robotic Drug Delivery System. As technology advances there are many remote-controlled cars with advanced features. For example, anti-collision systems, rechargeable batteries etc. With the advancements of microcontrollers, it is now possible to be able to control a remote-controlled car via your mobile phone through an application. Real Time Operating Systems (RTOS) available online to develop a program that can achieve a mobile phone application-controlled car instead of a traditional remote-controlled car. The aim of the project is to design and develop an application controlled robotic car that is being controlled using a mobile phone application through Android and IOS application. There are 3 different sections in this project. Hardware design, software design and application design. These three sections must communicate with each other to achieve a successful project completion. This is where wiring schematic of all the components are. The microcontroller will be connected to the different modules, for example the motors, motor driver, chassis kit, sensors, Wi-Fi/Bluetooth module and power supply. Real-Time Operating Systems (RTOS) provides multi-threaded capability to enhance the responsiveness of any device or system. There are different RTOS in the market ranging from open source to licensed versions. Many of these RTOS have also been ported to a variety of microcontrollers to allow them to be readily available for embedded system applications. In this project, Arduino IDE is used. The RTOS will be deployed onto the microcontroller. Visual block base programming environment. MIT App Inventor is used for creating applications for user interface.

II. LITERATURE REVIEW

The first modern robot was invented in 1950s. It was an inventor from Louisville, Kentucky by the name of George C. Devol. As technology advances, we have many robots available today. In today's world most places need robots to ease the workflow. As we were just hit by COVID-19, it was very hard for those working in the medical field to attend to every patient in the hospital. Therefore, research was made to come up with a solution for easing manpower issues. Intelligent drug delivery vehicles were researched and published. The vehicle can automatically complete the drug delivery in a designated hospital area. This can then save human resources is particularly important. With this system, it is possible to save some medical resources [1]. Robotics has played an important part in infectious diseases in clinical care, disease prevention, diagnosis and screening, patient care and disease management. In such a difficult environment it is difficult for humans to deal with therefore, robots have been developed to combat infectious diseases [2], In the medical industry robots have to perform very complex tasks because human lives are at stake. Technology has advanced so much in the past few years that it is not surprising that robots are being deployed to play a very important role to help us ease challenges we face [3]. Even in surgeries, robots aid doctors to perform precise actions and reduce complications. In orthopedic surgery handheld surgical robot aids the surgeon in stabilizing the drilling position by eliminating unwanted tremors which also reduces force artefacts from motor actuator [4]. In the logistic industry, robots are crucial in delivering precise and accurate deliveries. There are many robots placed for different sections of industry. These robots solve manpower issues and also potentially fatal issues. Traditionally without robots, humans have to do heavy lifting and operate heavy machinery. With robots available these potential problems are being irradiated. This improves safety and efficiency [5]. These autonomous robots benefit human workers to help prevent injuries or extreme health effects due to working conditions [6]. Robotics has revolutionized the logistic industry with many smart options available. These solutions have made the world move faster in imports and exports. Companies have improved on traditional forklift and pallet jack methods by replacing them with automated guided vehicles (AGV). This is to move around heavy pallets and containers faster, precisely and reduce human accidents. This solution also reduces air pollution. The robot can maneuver precisely and effortlessly below the pallet's confined free access. A novel, compact drive unit is a crucial element in ensuring access to the pallet's restricted free entrance. The vastness of the mall and its omnidirectional movement are advantages [7]. Using robots to educate programming and learning different computer languages. This enables easy learning as there is a visual aid to see the robots move. In STEM educations, robots are widely used to teach coding [8]. Based on the robot, which is used in the practice of teaching English to primary school students and has had positive application effects, a collection of educational robot aided teaching curricular materials has been developed. Research demonstrates that the robot can perform the tasks of teaching English vocabulary, role playing, and open discourse and can further enhance students' focus and initiative in classroom practice [9]. An embedded system's microcontroller is a small integrated circuit that controls a single process. On a single chip, a typical microcontroller has a CPU, memory, and input/output (I/O) peripherals. Microcontrollers, also known as embedded controllers or microcontroller units (MCU), may be found in a variety of devices, including vending machines, robots, and medical devices. They are essentially straightforward mini-personal computers without a complicated front-end operating system that are used to operate minor aspects of bigger components.

The ESP32 is a dual-core system with a feature rich microcontroller that has inbuilt Wi-Fi and Bluetooth connectivity. ESP32 is internally integrated with 2.4Ghz Wi-Fi and communicates with upper computer through Wi-Fi [10]. ESP32microcontroller integrates antenna switch, power amplifier, receiving low-noise amplifier, filter and power management module and so on, which is easy to remotely control and monitor equipment through Wi-Fi or Bluetooth [11]. Overall specification and features the ESP32 microcontroller is rich in features and easy to connect to other modules. It is widely popular recently in robotics projects. STM32F4 microcontrollers are high performance microcontrollers. It is a dual-core system with up to 1 Mbyte of flash memory and sufficient I/O ports, the STM32F4 series MCU is suitable for more complex programs [12]. It has 15 communication interfaces including 6 USARTs, it is highly efficient to exchange data and control signal between the control core and sub-modules. This makes the STM32F4 microcontroller able to work at high-speed and low latency communication network within the system. Zhihao Gu [12] It is a kind of high performance and low power waste chip [13]. Although it lacks the feature rich of ESP32 it is still highly used in many robotics' projects. Commonly used in many projects. STM32F1 series microcontroller is classified as a mainstream MCU. This high performance 32-bit ARM Cortex MCU is low cost with a simple architecture. The chip could process information efficiently and has plenty of storage space. All the peripheral circuits relate to the master chip, the master chip for data processing and control [14]. As high as 72M frequency, data, instructions go different pipeline to ensure that the CPU speed to maximize. Support JTAG, SWD debugging. With the low-cost J-LINK, the functions such as high-speed and low-cost development and debugging schemes are realized. The service life is long, and the application occasions are wide [15]. Infrared sensors emit and pick up things using an infrared transmitter and receiver. Its benefits include easy operation, quick measurement times, and excellent accuracy. It is frequently utilized as a distance sensor in many aspects of daily life, particularly in robotics. This sensor is cost effective compared to other sensors for obstacle avoidance [16]. Infrared sensors have several restrictions, such as the inability to be used in sunlight owing to interference. Applications in the dark inside or outdoors may be challenging [17]. Ultrasonic sensors send and receive data over time using sound waves. Based on the speed of sound (340 m/s), the duration is then translated into a distance measurement. [16] Ultrasonic sensors are insensitive to light, dust, smoke, mist, vapour, lint & etc [17]. The ultrasonic wave covers a large area. As a result, it is quite challenging to determine the object's sudden point with accuracy [18]. However, it offers wonderful non-contact detection with high accuracy associated stable readings [19]. Real-time embedded systems are often created for a variety of functions, such as data processing or data control. Real-time systems could meet deadlines in a timely manner. Real-time operating system (RTOS) is frequently utilized to accomplish this goal. Additionally, RTOS needs to be able to handle several events at once and react reliably to unpredictable occurrences [20]. There is a scheduling algorithm in RTOS which assigns processes to run on microcontroller or central processor unit (CPU). It is a time-bound system that has set time restrictions. Processing in this kind of system must adhere to the established limitations. Otherwise, the system will not work. RTOS takes up less memory, consume fewer resources, response times are quite consistent, environmental uncertainty, the Kernel decides which job it should perform next after saving the state of the interrupted task and the Kernel transfers CPU control to the task and restores the task's state [21]. RTOS is only applied to the embedded application. MIT App Inventor is a visual block-based programming environment that allows anybody to design mobile apps for Android devices that is open-source and free. The blocks may be used to build a variety of features, including buttons, text fields, sensors, and more. MIT App Inventor also has a live testing tool that allows users to test their app in real time on their own Android smartphone. The platform can download the app as an actual app directly to your Android smartphone. In conclusion, MIT App Inventor is a good tool for people looking to learn app development with no prior knowledge of app development.

III. COMPONENT SELECTION

The ESP32-WROOM-32 module includes 4MB of flash memory and can accept up to 16MB of external flash memory. It also features 520KB of SRAM for data and program storage, as well as a variety of peripherals for interacting with sensors and other devices, including GPIO, I2C, SPI, UART, ADC, and DAC. The system has a dual-core CPU, Wi-Fi and Bluetooth capabilities, as well as other features to provide a versatile and powerful platform for Internet of Things (IoT) applications. The module is built on the ESP32 processor, a low-power system-on-chip (SoC) with built-in Wi-Fi and Bluetooth connectivity. To conduct multi-threaded activities and satisfy real-time requirements, the chosen microcontroller must have a high clock speed. The project's task management comprises sensor monitoring, networking protocols, device driver, and inter-task communication. For operating DC and Stepper Motors, the L298N Motor Driver Module is a high-power motor driver module. An L298 motor driver IC and a 78M05 5V regulator make up this module. Up to 4 DC motors or 2 DC motors with speed and direction control can be controlled by the L298N Module. The internal circuitry will be powered by the voltage regulator when the power source is less than or equal to 12V, and the 5V pin can be utilized as an output pin to power the microcontroller. Only after the jumper is inserted will the 78M05 voltage regulator be activated. When the power supply is more than 12V, the jumper should not be installed; instead, a separate 5V supply should be provided through the 5V connector to power the internal circuitry. An electrical circuit known as a H-bridge enables the application of a voltage across a load in either direction. To enable DC motors to operate forward and backward, H-bridge circuits are commonly employed in robotics and many other applications. Most of these motor control circuits are utilized in power electronic converters, including DC-DC, DC-AC, and AC-AC converters. A motor controller with two H-bridges is always used to drive a DC motor. S1, S2, S3, and S4 are the four switches used to construct an H-bridge. A positive voltage is provided across the motor when the S1 and S4 switches are closed. The motor may be operated in the reverse direction by opening the switches S1 and S4 and shutting the switches S2 and S3. The H-bridge motor driver circuit is often used to stop and start a motor, as well as to reverse its direction. When the motor abruptly stops because its terminals have become shorted.

Ultrasonic sensor is more suitable more this project has the robotic car should be used both indoors and outdoors with minimal disruptions from the surrounding environment. The detection distance is between 2 – 400cm while the effective angle is 15º. A 5V pulse lasting 10us is delivered to the module's Trig pin to initiate the range operation. After detecting the pulse, the module activates the transmitter sensor, which sends an ultrasonic burst of 8 echo pulses at a frequency of 40 kHz while waiting for the echo pulses to bounce back. The echo pin of the module will be set to 5V with a width equivalent to the distance from the item as shown in the timing diagram if an obstacle is met, reflecting the echo burst in the direction of the ultrasonic receiver. The robot will be instantly halted if the measured distance is less than 20cm. This signal pulse width will be recorded by the MCU, which will use it to tell motors to stop before hitting an obstacle.

A rechargeable battery system is typically made up of three fundamental parts. Rechargeable batteries Lithium Ion (Li-ion) or Lithium Polymer (Li-Po), a DC-to-DC converter module, and a battery charger module. In this project, Li-ion batteries are being used. Li-ion batteries have high power density, no memory effect and low cost to produce. The battery used is 18650 battery which produces 3.7V with a capacity of 3400mAH. By using a rechargeable battery system, it would mean less carbon footprint. The project is aiding the cause of going green. The LM2596 is a widely used voltage regulator integrated circuit (IC) that can step down voltage from a higher input value to a lower output voltage. It's widely utilized in electrical circuits, power supply, and battery charging. This is a switching regulator, which means it maintains the desired output voltage by rapidly switching the input voltage on and off. Because of this, it is more efficient than linear regulators, which waste excess voltage as heat. It has a wide input voltage range (up to 40V) and can deliver a controlled output voltage in the 1.2V to 37V range, with a maximum output current of 3A. It also has features such as thermal shutdown, overcurrent prevention, and short-circuit protection for safe operation. The battery produces a combined voltage of 7.4V therefore, a DC-DC step down converter is needed to deliver a controlled and stable output of 5V.

IV. PROPOSED WORK

The hardware architecture is the representation of overview of the interconnecting systems. The rechargeable battery powers up the entire circuit with the aid of DC-DC Step Down Converter. A switch is placed to toggle between turning on and off the robotic car. The Ultrasonic sensors and Motor driver IC takes its power from the ESP32 microcontroller. Therefore, it is directly connected to the MCU. Figure 1 shows the overall hardware architecture.

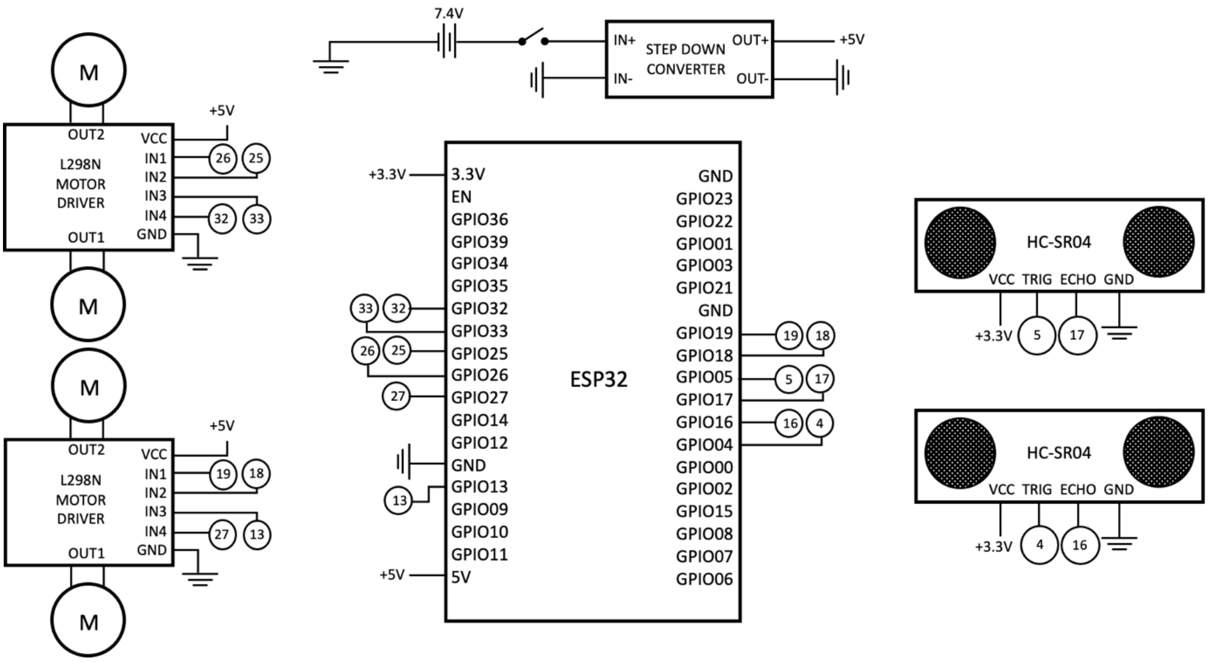

Figure 1 Overall Hardware Architecture

The ESP32 Microcontroller is powered up by two rechargeable Li-Ion batteries. The voltage(V) produced by the batteries is 7.2V which is higher than what is needed to power up the ESP32 Microcontroller. Therefore, a DC-DC step down converter is used to produce a steady 5V. The DC-DC step down switching regulator is used to regulate the voltage at 5V. It can step down the voltage from input voltage 4.5V - 40V to output voltage 5V. It has an efficiency of 92%. The circuit diagram of the connection is shown in Figure 2. Ultrasonic sensor HC-SR04 has a GPIO interface. It can be directly interfaced with the ESP32 MCU I/O pin. The connection overview is shown in Figure 3.

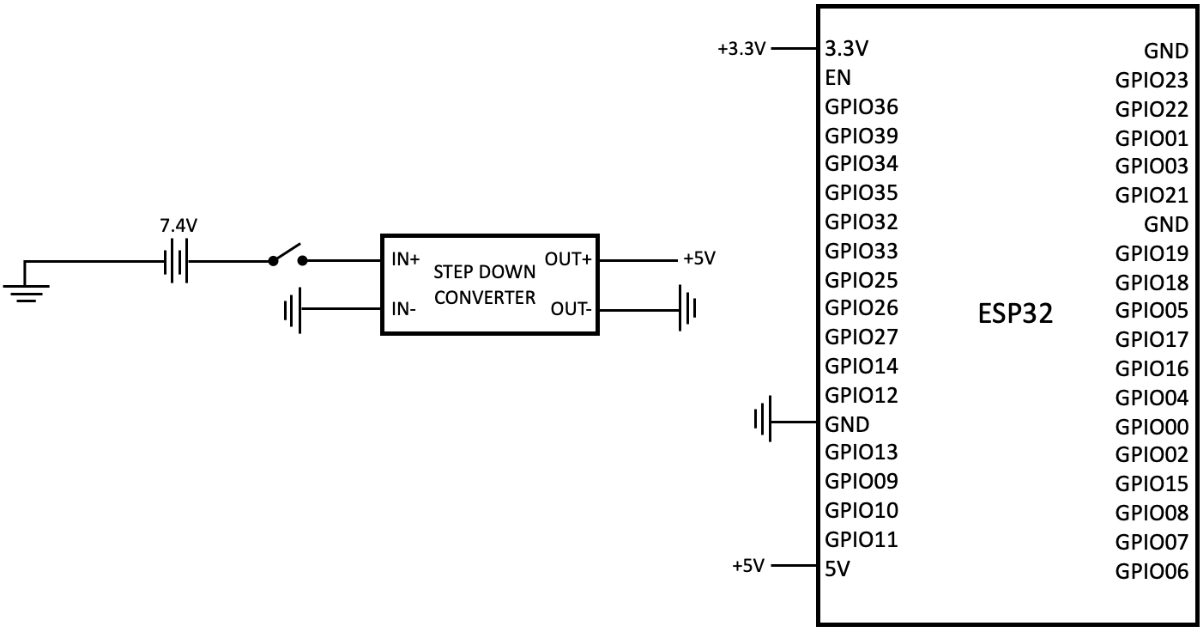

Figure 2 Circuit Connections

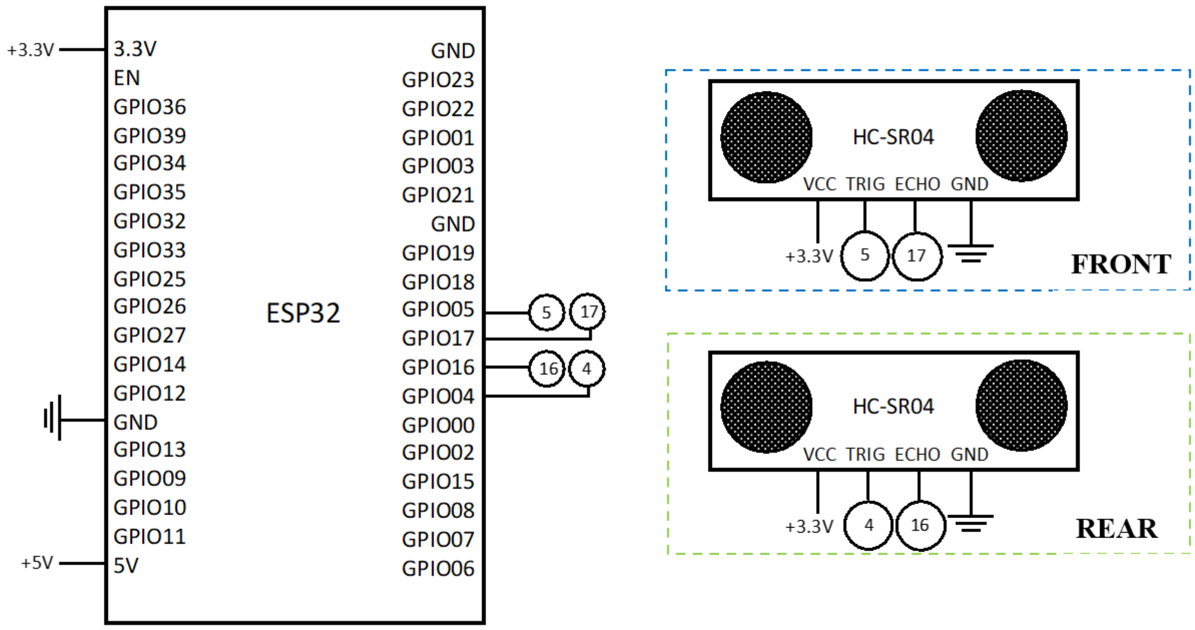

Figure 3 Connection of Ultrasonic Sensor to ESP32

L298N Motor Driver module consists of an L298N Motor Driver IC, 78M05 Voltage Regulator, resistors, capacitor, Power LED, 5V jumper in an integrated circuit. Motor driver connection to ESP32 is shown in Figure 4.

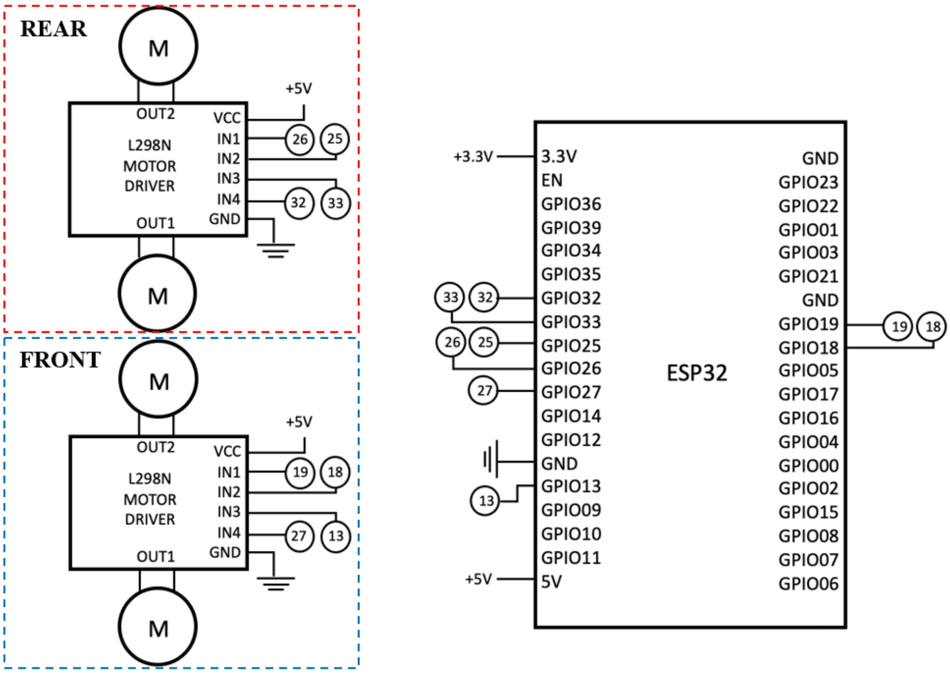

Figure 4 Motor Driver Connection to ESP32

The hardware architecture is done to place the different systems mounted on the chassis. Size of component and ease of connection with each other is considered before placing the different systems on the chassis of the car. Figures 5 and 6 below show the top view and under carriage view of the chassis respectively.

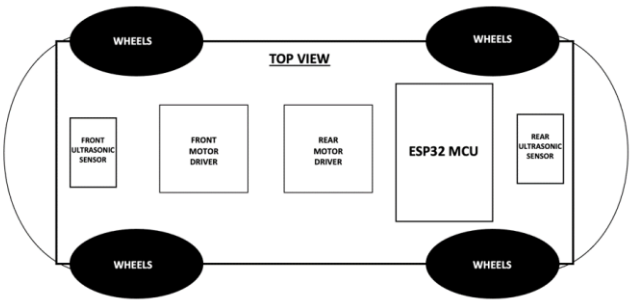

Figure 5 Top View of Chassis

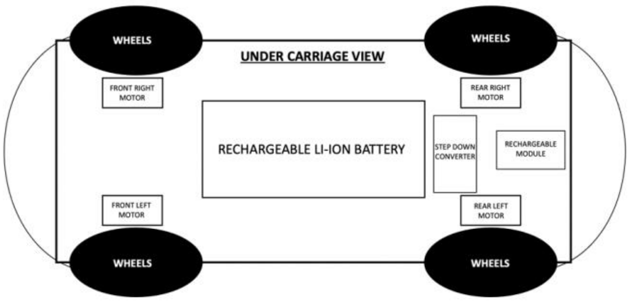

Figure 6 Under Carriage View of the Chassis

Software architecture represents the design decisions related to overall system structure and behavior. Figure 7 below illustrates the overall software architecture.

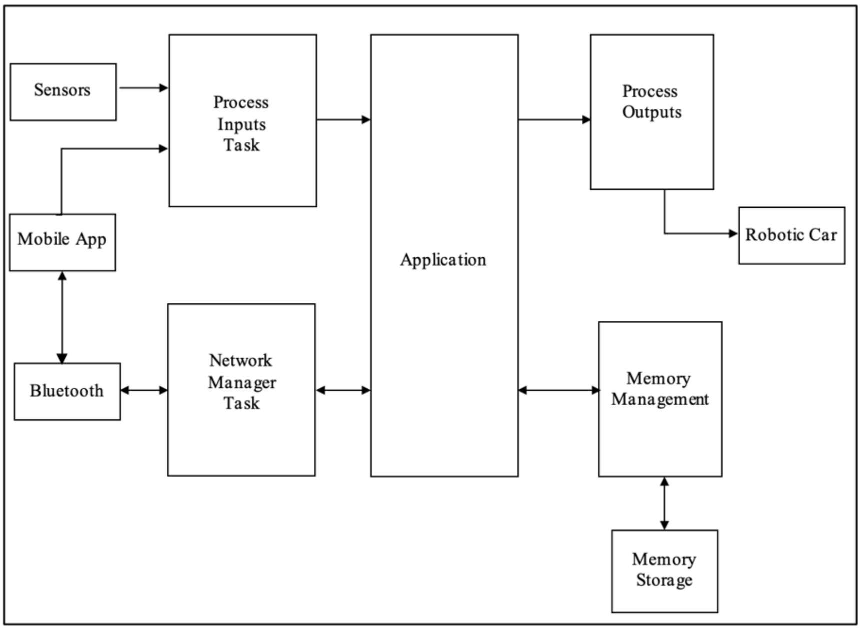

Figure 7 Overall Software Architecture

This app design application is for user to control the car around. It has buttons to turn left and right, move forwards and backwards and stop. It is connected via Bluetooth to ESP32 MCU. This application can only be downloaded on user's smart android phone. The app best functions when the phone is in a horizontal position. Figure 8 shows the application outlook and Figure 9 shows the code block programming that is done to create the application.

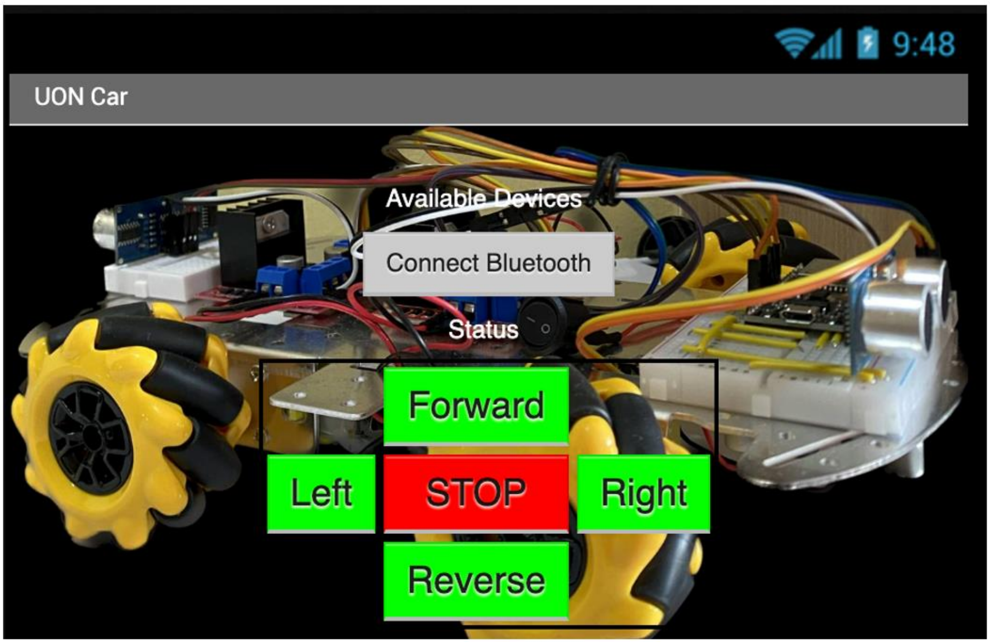

Figure 8 Application Outlook

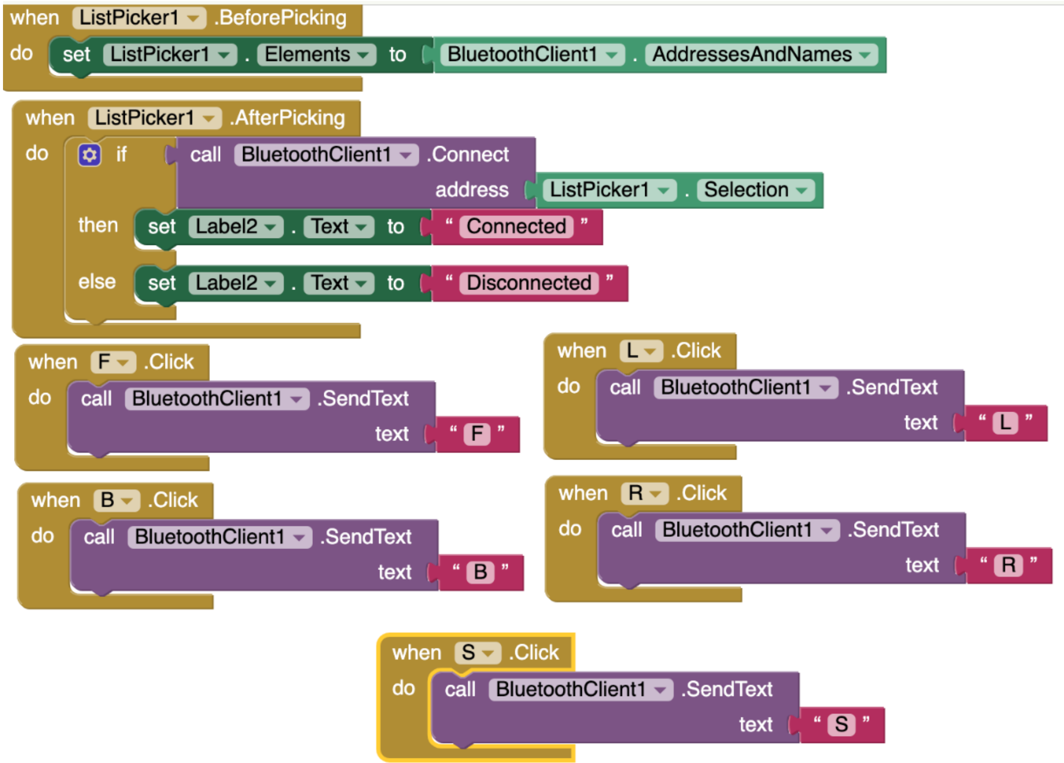

Figure 9 Visual Block Code for Application

User will launch the robotic car application and connect it to the Bluetooth module via Bluetooth. ESP32 MCU will then establish the connection and transfer the signal back to the app. The user can then start controlling the car by pressing the various buttons on the app. However, if the ultrasonic sensor detects that an object is 20cm away it will immediately stop the robotic car. Users will then have to move the car in a different direction. User cannot override the ultrasonic sensor. Figure 10 shows the overall program flow for the entire system.

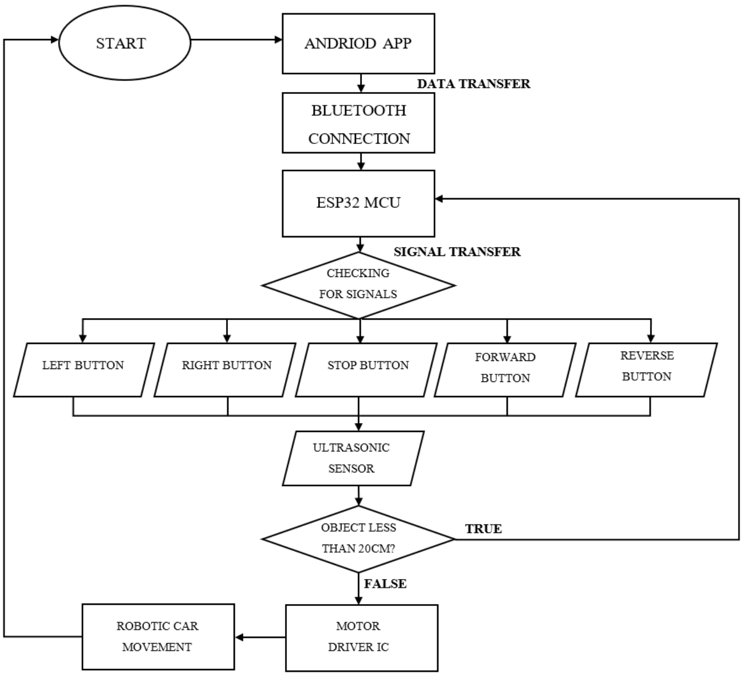

Figure 10 Overall proposed program flow for the entire system

The robotic car can be controlled by the android application. It can move left, right, forward, reverse and stop. There are 2 ultrasonic sensors, one in the front and one at the back for object detection. These ultrasonic sensors detect objects at 20cm. Once the ultrasonic sensors detect an object it will make the robot stop. During this sequence the user is unable to overwrite the robot by moving in the direction of the obstacle. The user must move in another direction to avoid the obstacle. The hardware is designed in this way for ease of connections between the different components. This is to ensure there is neat wiring in the event of any faults. it can be identified easily. The components chosen are as such due to the budget of S$200-S$300. Working within the budget has taught me how we must research for the ideal components such that it is not too expensive that is too good for the project nor too cheap that it will spoil easily. Overall, this project is a success with the given scope and time frame. Figure 11 shows that this proposed work has implemented a robotic car controlled by android app.

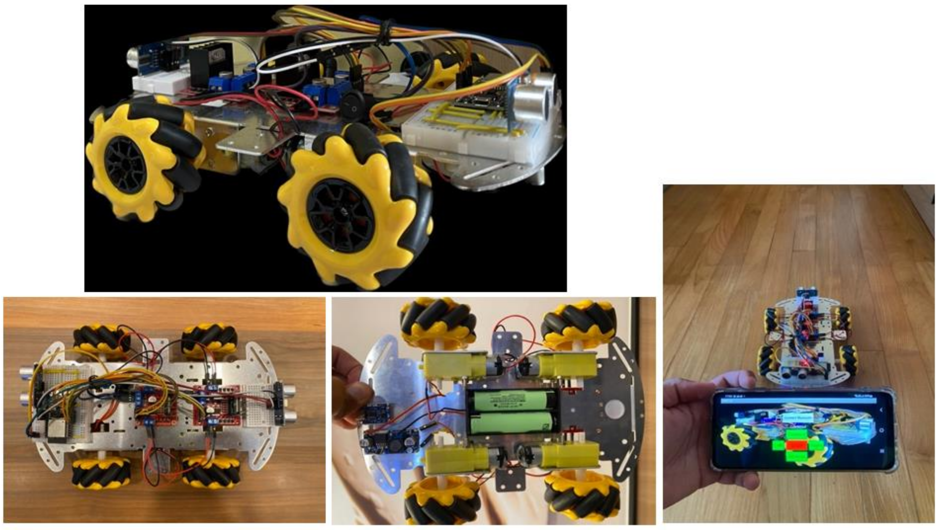

Figure 11 Implemented a Robotic Car Controlled by Android App

V. CONCLUSION

Robotics has changed our lives in many ways. It has made our lives easier and is always improving our lives in a certain way. Doing this project has made me think that a simple robot could improve our lives is a win for us. The proposed robotic car can move via user interface such as android application. It enables the user to control the car in any direction they want the car to move. The speed of the prototype is approximately 5km/h and the torque is 0.45Nm. A real-time operating system is implemented as the firmware design to create threads for each of the different tasks to make sure that all the tasks can meet their deadline. The prototype has a battery life of up to 10 hours. The cost of production for this prototype is S$96.36. During the 1st phase of my project, I researched many robotic articles which were for education, medical needs and logistics needs. Now during my 2nd phase of the project, I realize my robot could be implemented for pipeline works in the oil and gas industry. A few improvements like adding lasers to scan structural integrity, cameras to feedback to the user interface for fault findings and powerful sensors like Li-Dar for mapping would revolutionize the industry. For this to work in the oil and gas industry we would need very good heat resistant and waterproof materials. In summary, the real-time operating system robotic car controlled through an android app is project with a lot of potential depending on the nature of its work. It is easily modifiable and integrated with more sensors and components. As a result, it is a successful completion of the project.

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