Queen Mary University of London
School of Electronic Engineering and Computer Science

Microcontroller-Based Survey Vehicle

Final Report

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Programme of Study: BEng Electrical and Electronic Engineering

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Declaration

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Abstract

The theme of this report is to develop a working prototype of a vehicle that can survey an area of terrain. The research, design, implementation, and testing phases have been outlined in detail. The motive behind this project was to design and develop a small, cost-effective survey vehicle, of which the features can be manipulated and applied in a wide variety of fields.

A small car was built to roam the land and was controlled by a microcontroller. The vehicle had Bluetooth communication capabilities and could store a pre-programmed path from the user. Object detection was implemented using infrared technology and a location mapping algorithm was developed.

The project was mostly successful, with some minor flaws that were discussed. Areas of upgradeability and improvement were talked about in detail. The design methodology and algorithms implemented can be applied to similar projects, where another form of vehicle is to be designed to survey different features of the terrain, using a variety of sensors.

Abbreviations

Abbreviation	**Unit of Measure**
AC	Alternating Current
ADC	Analogue-to-Digital Converter
CPU	Central Processing Unit
DC	Direct Current
EEPROM	Electrically-Erasable Programmable Read-Only Memory
GPS	Global Positioning System
IC	Integrated Chip
IDE	Integrated Development Environment
IO	Input / Output
IR	Infrared
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MCU	Microcontroller Unit
OLED	Organic Light Emitting Diode
PMOLED	Passive-matrix Organic Light Emitting Diode
RAM	Random Access Memory
Wi-Fi	Wireless Fidelity

Units of Measure

Quantity	**Unit**	**Symbol**
Angle	Degree	°
Capacity	Milliampere hour	mAh
Clock Speed	Megahertz	MHz
Current	Ampere	A
Data Storage	Byte, Kilobyte	B, kB
Data Transfer	Bits per Second	bps
Length	Nanometre, Millimetre, Centimetre, Metre	nm, mm, cm, m
Mass	Gram, Kilogram	g, kg
Power	Watts	W
Time	Microsecond, Millisecond, Second	µs, ms, s
Voltage	Volts	V

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Contents

1 Introduction

Terrain surveying or land surveying is a method of determining the layout of the land, by accurately recording the distance and angle between three-dimensional points (Civil Simplified, 2017). There exists a small variety of vehicles that are used to survey various types of terrain and features. One example is unmanned aerial vehicles, such as drones, which are used to survey large properties, inaccessible buildings, etc. The use of drones requires a qualified pilot and permission to fly a drone in the area (Survey Operations, 2018). The drones may be efficient at scanning the area, but they are large and very expensive.

Another example is coastal surveying using three-dimensional laser scanning on manned vehicles. Coastal terrain, such as cliffs and dunes, are monitored accurately using advanced technologies (Survey Operations, 2018). Although this method of surveying is very accurate and promising, it is also very expensive and requires trained personnel to operate the equipment.

The range of options currently in operation makes use of advanced technologies, which are expensive and require trained or qualified personnel to operate. The size of the vehicles is large as the surveying equipment is also large and requires high maintenance. From these observations, this project was proposed to provide an alternative to terrain surveying. The main motive behind this project is to design and build a small, cost-effective survey vehicle, of which the features can be manipulated and applied in a wide variety of fields.

1.1 Aim

The aim of this project is to design and implement a cost-effective roaming vehicle that can be used to survey an area of terrain. The features which are surveyed will mainly include object detection and possibly others. The vehicle will move such that there is no overlap in scanning and return to the original starting position. The location of features will be mapped relative to the initial starting point rather than to a global positioning system reference.

1.2 Objectives

The survey vehicle system should be able to follow a pre-programmed path with a precision of about ±20cm. A mechanism for location awareness (and optionally orientation) needs to be included as well. The vehicle should be capable of 45, 90, and 180 degree turns. These objectives define the autonomous and roaming components of the survey vehicle. The survey vehicle needs to be able to autonomously scan an area and have some form of sensors to detect objects (optional). These objectives define the terrain surveying components of the survey vehicle.

1.3 Specification of Requirements

The survey vehicle needs to be low cost and efficient, meaning the system can be mass manufactured quickly and inexpensively. It should also be efficient in surveying and mapping by not overlapping an already covered area. The survey vehicle should also have efficient power management to allow for longer usage on battery power and reduce running costs.

The vehicle needs to be able to scan an area efficiently, without overlapping a previously traversed region, and map the specified area for specific features. It also needs to be aware of its location; feature mapping is relative to the initial starting position and the vehicle should return to the starting position.

The system will receive movement instructions from another device via Bluetooth serial communication. It will also transmit mapped data over Bluetooth. The device will run a simple application to communicate with the vehicle.

2 Technical Background

2.1 Microcontrollers

Microcontroller units (MCUs) are small devices designed for embedded systems, meaning they are incorporated into appliances and equipment to carry out a set of tasks repeatedly. MCUs have a central processing unit (CPU), memory, interfacing capabilities, and other functional circuits in a single chip. Microcontrollers usually belong to a ‘family’ or set of MCUs that have similar architecture and share the same instruction set.

2.2 EEPROM

Electrically-erasable programmable read-only memory (EEPROM) is a form of non-volatile memory for data storage (Techopedia, n.d.). When the EEPROM loses power, it remains its memory, making it useful for storing long-term data. Small portions of data in an EEPROM can be modified without affecting other stored data (Vahid, 2007). Writing data to an EEPROM takes quite some time (up to a few milliseconds depending on the device), whereas read times are much shorter (Lee & Seshia, 2017).

2.3 Motors

A motor is an electrical machine used to convert electrical energy to mechanical energy (Daware, 2012). The basic principle of a motor is described by the interaction between the electrical current flowing through a winding (coil of wire) inside a magnetic field. This interaction generates a force that causes the shaft of the motor to rotate (BBC, n.d.). Motors fall under two power classifications: DC and AC. For this project, DC motors were used.

DC motors can be either brushed or brushless, where brushless motors were developed be perform better in a compact space than brushed motors. Brushless motors can be further classified as stepper motors and servo motors. Servo motors have feedback to provide control of the position of the motor shaft. The movement of a stepper motor is determined by the internal gears and electromagnets (Motion Control Online Marketing Team, 2016).

For the movement of the vehicle, stepper motors will be used. The rotation of a stepper motor is divided into a specific number of steps. Stepper motors do not need feedback, as the rotational distance can be calculated from the number of steps the motor turns.

This makes stepper motors more accurate and allows for high control (Oriental Motor, 2016).

Stepper motors have two different types of winding arrangements, namely unipolar and bipolar. Unipolar stepper motors have a winding with a centre tap per phase, where each section of the winding is energised in a sequence for each direction of the motor rotation (Circuit Specialists, 2012). Bipolar stepper motors have only one winding per phase and require a complex circuit to energise the phases correctly. The current in the winding must be reversed for the direction of the motor rotation direction (Circuit Specialists, 2012). Unipolar stepper motors are used for this project as they are easier to operate and simpler to drive than bipolar stepper motors.

2.4 Motor Drivers

Motors require electrical energy to convert to mechanical energy in the form of the motor shaft rotating. Some motors can be powered with a small amount of energy, which can be supplied by MCUs without a problem. However, larger and more powerful motors require more energy to operate and most MCUs cannot supply this large amount of power. Motor drivers are used to provide an external source of power to the motors and some drivers also provide a means of control for the motor.

Stepper motors require a driver or controller to power the phases so that the motor can turn properly. Unipolar stepper motors can be simply driven using transistors, which are pulsed on and off in a specific sequence to energise the phases and step the motor (Earl, 2015).

2.5 Bluetooth

For wireless communication, Bluetooth will be used instead of other technologies, such as Wi-Fi, Radio Frequency, etc. Bluetooth is low cost, has a small form factor, and easy to work, making it desirable for many applications. Most modern devices are embedded with Bluetooth transceivers, which means additional hardware is not required to enable wireless communication. Bluetooth uses serial communication for data transfer, allowing for simple interfacing with the microcontroller (Components101, 2018).

2.6 OLED Display

An OLED (Organic Light Emitting Diode) display will be used to display status messages of the system. OLED displays are generally cheaper than LCDs (Liquid Crystal Displays) and consume less power. There are various types of OLED technologies available, each with their own purpose. Passive-matrix OLEDs (PMOLEDs) are easy to manufacture but consume more power than other types of OLED (Freudenrich Ph.D., 2005). This type of OLED is used where small screens are needed, as they are the most efficient for displaying textual content and icons. The OLED device that will be used in this project is a PMOLED type and uses IIC (a synchronous, serial communication protocol) to display data (Hord, 2013).

2.7 Analogue-to-Digital Converter

An analogue-to-digital converter (ADC) converts an analogue electrical signal to a digital representation. The input voltage is represented in discrete steps with a finite resolution as a digital number. The resolution of the ADC is determined by the number of bits that represent the digital number (mccdaq.com, 2010). An analogue signal is continuous, so it needs to be sampled to produce discrete data, which can then be processed. The discrete data is quantised to divide the continuous input into non-overlapping sub-ranges, where each sub-range has a discrete value. This value is then processed by a microprocessor.

There are two main groups of ADCs; the first group includes counter types, flash converter types, and successive-approximation, and the second group includes integrators and voltage to frequency converters (Kani, 2016). Flash ADCs are the fastest converters, consisting of comparators, but tend to be costly when a higher resolution is required (Ball, 2005). Successive-approximation samples the analogue data and holds it, for comparing with the next set of data (Smith, 2015). For this project, a flash type ADC will be used as it easy simple to implement and provides fast conversion times.

2.8 Infrared Emitter and Sensor

An infrared (IR) LED (Light Emitting Diode) or emitter “emits light in the infrared range of the electromagnetic spectrum” (Rouse & Haughn, 2015). IR light is not visible to the human eye and is also emitted off bodies that transfer heat. IR LEDs are used in many devices, ranging from night vision for cameras to remote controls for various appliances (Elemental LED, 2015).

Infrared light can be detected using an infrared sensor, which is available in many types. There are photodiodes, phototransistors, and photoresistors (light-dependent resistors). All these devices can be used to detect light but only the phototransistor and photoresistor can sense the light intensity. The phototransistor and photoresistor alter the amount of current flowing through them depending on the light level, making them ideal to detect the distance to objects.

2.9 Localisation

To determine the location of the vehicle, without the use of a GPS, a form of localization will have to be used. This can be achieved in various ways, such as triangulation, edge/wall detection, distance tracking, bearings, etc. Triangulation involves measuring the angle and distance to a set of markers and calculating the location using geometry. Edge/wall detection involves using sensors to determine if an edge/wall has been reached, from which the location can be determined. Distance tracking involves keeping track of the distance travelled, which can be achieved by counting the number of wheel rotations, then determine the location.

2.10 Compass

A compass module is used to detect low-field magnetic fields and output digital data. The compass module outputs data in three axes, which can then be used to calculate the headings (Parallax, 2018). In this project, a compass can be used to keep track of the bearing of the vehicle. The bearing of the vehicle can be compared against a reference bearing to ensure the vehicle is moving in a straight line or has turned the correct angle.

3 Design

3.1 Microcontroller

Intel introduced the MCS-51 (more commonly known as the 8051) family of MCUs, to which the AT89S8253 chip belongs to (Mazidi, et al., 2005). The AT89S8253 will be used in this project as it a high performance and low-power MCU, with enough memory and interfacing ports. The chosen microcontroller provides 12kB of flash memory for storing programs, 256 Bytes of internal RAM, and 2kB of EEPROM memory for data storage. The flash memory has a durability of 10,000 write/erase cycles and the EEPROM has a durability of 100,000 write/erase. The MCU has 32 general purpose IO pins, which are fully programmable and divided as 4 ports (Atmel Corporation, 2010).

3.2 8051 Programming

The 8051 microcontrollers need to be programmed with software in order to function. The CPU works only with binary data (ones and zeros) but at a very high speed. The 8051 microcontrollers work with machine code, which is a program consisting of binary data. Writing machine code is a very laborious process for programmers, so assembly languages were developed, which provided mnemonics for the machine code instructions. An assembler must be used to convert the assembly language program into machine code (Mazidi, et al., 2005).

For this project, assembly language was used to write the program for the MCU. As the assembly language is a low-level, it communicates directly with the internal structure of the CPU (Mazidi, et al., 2005). This allows for programs to be written more efficiently than high-level programming languages, such as C, C++, Java, etc.

3.3 Stepper Motors

The stepper motors that will be used in this project is the 28BYJ-48 as they are small, inexpensive, low-weight motors, and provide adequate torque for the required application. The 28BYJ-48 is a unipolar stepper motor with five wires, which can be easily and precisely controlled (Components101, 2018). The chosen stepper motors require 64 steps for one revolution of the internal shaft and have a step angle of 5.625° ($360° \div 64 = 5.625°$). The motors have a gear reduction ratio of 64:1, meaning 4096 ($64 \times 64 = 4096$) steps are required for one full revolution of the external shaft.

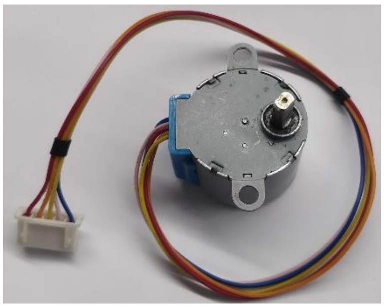

Figure 1: 28BYJ-48 Stepper Motor

The 28BYJ-48 stepper motor can be driven using various techniques; full 4-step sequence, wave drive 4-step sequence, and half step 8-step sequences. Figure 2, Figure 3, and Figure 4 show the stepping sequences for the mention stepper motor stepping sequences, where a ‘1’ indicates that the indicated phase (“winding”) is energised. Full stepping provides the most torque but uses more power, as two coil windings are energised at any given time. Wave driving uses less power, as only one winding is energised at a time, but provides slightly less torque than wave driving (Jayant, 2015). When the stepper motor is being wave driven, only 2048 steps are required for one full revolution of the external shaft.

Clockwise	Step #	Winding A	Winding B	Winding C	Winding D	Counter-clockwise
	1	1	0	0	1	
	2	1	1	0	0	
	3	0	1	1	0	
	4	0	0	1	1	

Figure 2: Stepper Motor Full 4-Step Sequence (What-When-How, 2011)

Clockwise	Step #	Winding A	Winding B	Winding C	Winding D	Counter-clockwise
	1	1	0	0	0	
	2	0	1	0	0	
	3	0	0	1	0	
	4	0	0	0	1	

Figure 3: Stepper Motor Wave Drive 4-Step Sequence (What-When-How, 2011)

Clockwise ↓ / Counter-clockwise ↑

Step #	Winding A	Winding B	Winding C	Winding D
1	1	0	0	1
2	1	0	0	0
3	1	1	0	0
4	0	1	0	0
5	0	1	1	0
6	0	0	1	0
7	0	0	1	1
8	0	0	0	1

Figure 4: Stepper Motor Half Step 8-Step Sequence (What-When-How, 2011)

3.4 Motor Drivers

The stepper motors require a motor driver to power and control it appropriately. An integrated chip (IC), consisting of an array of Darlington transistors, will be used; specifically, the ULN2003APG IC will be used. The chip has 7 sets of input and output pins, where each output can provide up to 500mA of current, a maximum output of 50V, and a maximum power dissipation of 1.47W (Toshiba, 2010).

Figure 5: ULN2003APG Motor Driver Module for 28BYJ-48 Stepper Motor (HiLetgo, 2018)

A driver module board with the ULN2003APG IC will be used for the prototype build, as it was provided with the 28BYJ-48 stepper motors. The driver module provides easy interfacing with the stepper motors and has four LEDs to show which windings of the motor are energised, allowing for easy debugging. Each driver module is configured with four input and output pins, so each motor will require its own driver module.

3.5 Bluetooth

The HC-05 Bluetooth module will be used in this project as it provides two-way serial communication and is a low-power device (Components101, 2018). The HC-05 can be configured to be a master or slave device to be used in a variety of applications. The HC-05 has a working supply voltage of 3.6V to 6V. The Bluetooth device has a default baud rate of 9600bps but can be configured to operate between 4800bps and 1382400bps (DSD TECH, 2016).

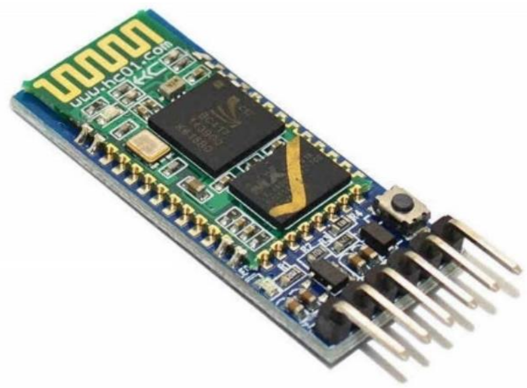

Figure 6: HC-05 Bluetooth Module (HiLetgo, 2017)

The Bluetooth module has one pin to receive data and another to transmit data. The receive pin (Rx) of the Bluetooth module is connected to the transmit pin (Tx) of the MCU. The transmit pin of the Bluetooth module is connected to the receive pin of the MCU. Figure 7 shows how the Bluetooth module is interfaced with the microcontroller.

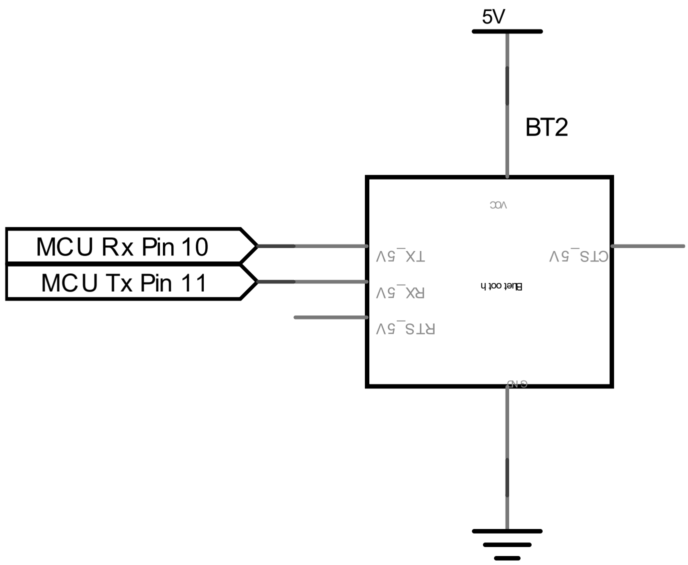

Figure 7: HC-05 Bluetooth Module Interfacing with Microcontroller

3.6 Object Detection

The survey vehicle’s object detection circuit consists of infrared LEDs, infrared sensors, and a one-bit flash ADC circuit. The infrared LEDs used are the L-7113F3BT 5mm blue lens infrared diode. The infrared LED can operate at a maximum supply voltage of 1.6V and a maximum current of 50mA. It has a blue lens, a view angle of 20° and emits light with a wavelength of 940nm (Kingbright, 2007). The infrared sensors used are the L-7113P3C 5mm phototransistors. The sensors are spectrally matched to the emitters and operate at the same voltage and current (Kingbright, 2003).

The ADC used is a 1-bit flash type and uses the LM311 differential comparator. The LM311 can operate with a supply voltage of 5V and output at the same voltage level. The comparator is configured to compare two voltages and output either high or low signal depending on the result. The input voltage, which is taken from the infrared sensor, is compared against a reference voltage, which is set by a potentiometer.

If the infrared sensor receives infrared light, then the input voltage into the ADC will be greater than the reference voltage. The output of the ADC will then be a high voltage level of 5V. If the sensor receives little or no light, then the input voltage into the ADC will be less than the reference voltage. The output of the ADC will then be a low voltage level of about 0.2V.

Figure 8 shows the schematic for the circuit that is used for object detection. An array of four IR LEDs and sensors are used to cover a wide area underneath the survey vehicle. The object detection circuit is replicated four times to accommodate for the infrared array.

The outputs of the ADC are to be combined using a logic NAND gate to reduce the number of pins required by the MCU for the object detection circuit. The outputs of two ADCs are combined into one NAND gate. The outputs of the remaining two ADCs are into another NAND gate. The outputs of the two NAND gates, with the ADC inputs, are combined into a third NAND gate, of which the output is interfaced with the MCU.

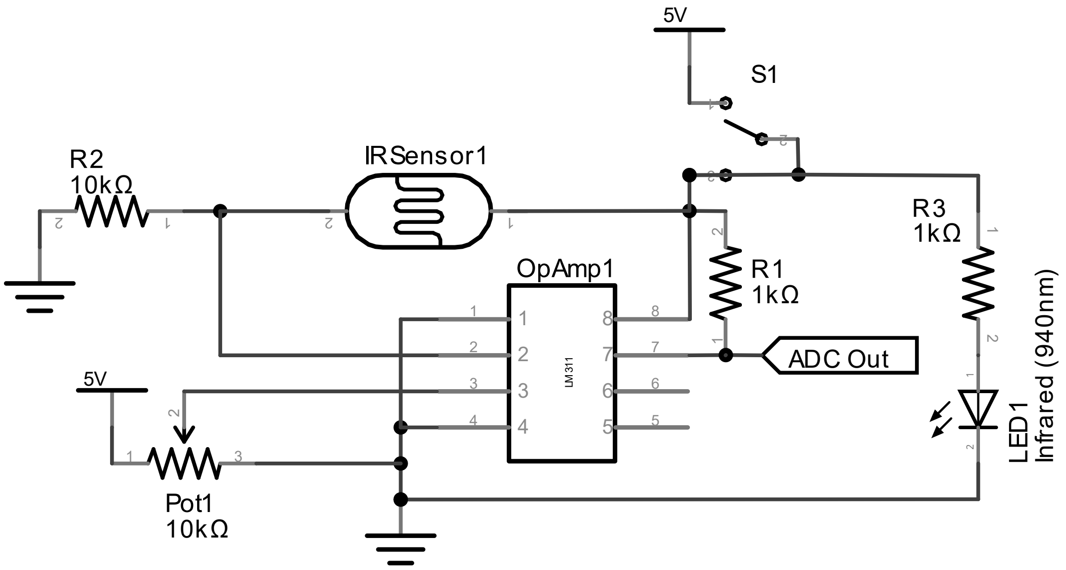

Figure 8: Object Detection Circuit using Infrared

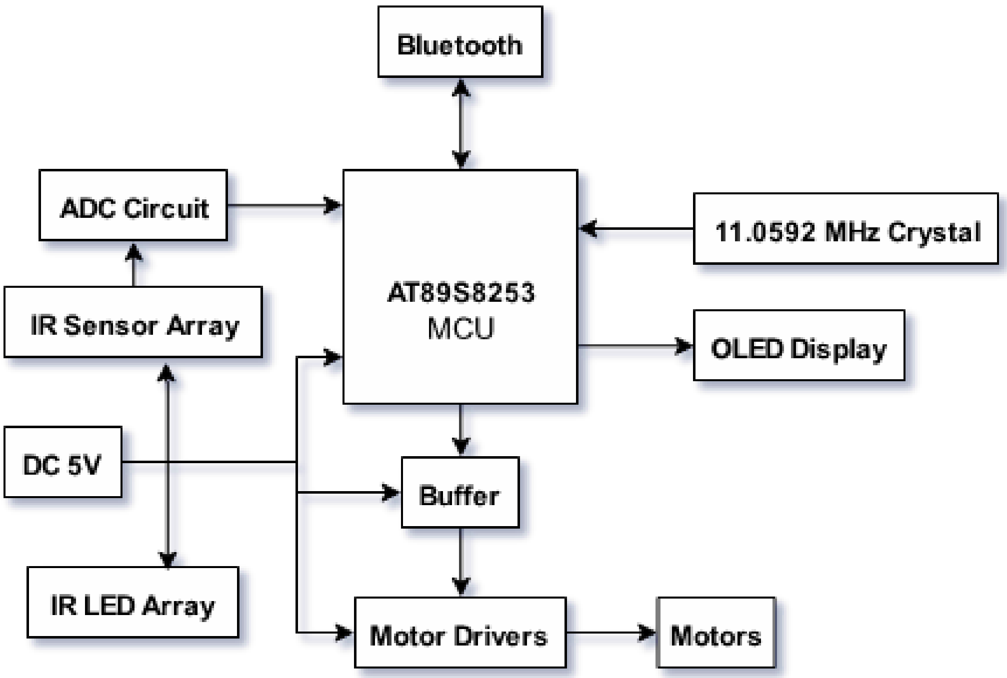

Figure 9: Survey Vehicle Functional Block Diagram

4 Implementation

4.1 Overview

The survey vehicle uses the AT89S8253 MCU to communicate with all the peripherals and process all the data received. The movement of the vehicle is controlled by four 28BYJ-48 stepper motors, which are each driven by a driver module consisting of a ULN2003APG Darlington transistor array. The MCU interfaces with the driver modules through an M74HC244 octal bus buffer. The vehicle communicates with external devices via Bluetooth using the HC-05 module.

An array of four infrared LEDs and sensors is used to detect objects in the terrain. The sensors each pass through a 1-bit flash ADC, which is made of an LM311 differential comparator. If an object is detected by any of the sensors, the program will transmit a status message notifying the user an object was detected and its location relative to the initial start point. The program maps the vehicle’s location by keeping track of the path followed.

4.2 Program

The program for the MCU was written using assembly code. The program for the MCU consists of four main sections: Bluetooth communication, path programming and movement, location mapping, and object detection.

The Bluetooth communication portion of the program waits for the user to send a command, then display a message and execute a section of code (if necessary). The command consists of one character, which is a capital letter of the alphabet. There are four main commands: “S” to enter ‘Path Programming Mode’, “M” to display the programmed path, “G” to start the movement of the vehicle (following the programmed path), and “H” to display the list of all available commands.

The program enters ‘Path Programming Mode’ when the program receives the “S” command. In ‘Path Programming Mode’, the four previous commands are no longer valid, but a new set of six commands are used to define the path for the vehicle to follow. The commands available in ‘Path Programming Mode’ are: “F” to move the vehicle forwards, “L” to perform a 90° left turn, “R” to perform a 90° right turn, “E” to perform a 45° right turn, “W” to perform a 45° left turn, “X” to exit ‘Path Programming Mode’.

In ‘Path Programming Mode’, when movement commands are entered, the program stores the commands in the internal EEPROM of the MCU. Writing to the internal EEPROM is a slow process: the MCU takes up to ten milliseconds to store one byte. To the user, this delay is not noticeable if they enter commands at a slow pace (e.g. one command every few seconds). The internal EEPROM has a size of 2kB, which allows up to 2048 commands to be stored; a character of the alphabet is one byte.

After the user has programmed the path for the vehicle, they can then view the programmed path by sending the command “M”. Alternatively, the movement of the vehicle can be started by sending the command “G”. Once the vehicle has started the movement, it does not stop until it reaches the end of the programmed path. Whilst the vehicle is moving forward, the program checks the infrared sensors about every 1cm. When an object is detected, a status message is displayed with the location of the object. The vehicle’s location is mapped and displayed as a set of x-axis and y-axis coordinates. The initial starting position of the vehicle is defined as the origin (0,0).

4.3 Object Detection

The vehicle uses an array of infrared LEDs and sensors for object detection. An array of four infrared LEDs is used to emit infrared light and an array of four sensors is used to detect the infrared light. Each sensor is connected to a one-bit flash ADC circuit that outputs a low signal when no infrared light is received. Each ADC output is connected to its own pin on the MCU.

For the prototype testing, the survey vehicle moves about a plain white surface. Black pieces of tape or paper are considered as objects. The infrared light emitted is reflected by white surfaces and absorbed by black surfaces. The ADCs output a high signal when the infrared sensors detect infrared light. A low signal is outputted when little or no infrared light is received by the sensors. Therefore, when the ADC output is low, the program will respond to an object being detected.

The arrays of infrared LEDs and sensors are mounted to the bottom of the vehicle’s body. This allows for a shorter distance between the infrared arrays and the ground so that amplifiers are not required. The infrared arrays are placed towards the front of the vehicle so that object detection is almost immediate. The infrared LEDs and sensors are spaced out across the width of the vehicle to ensure maximum coverage possible.

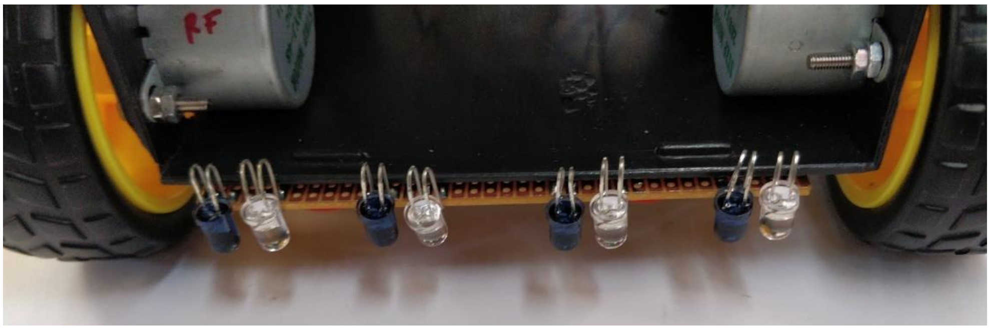

Figure 10: Mounting of IR LEDs and Sensors

4.4 Vehicle Design

The body of the vehicle is made of a plastic, hollow, rectangular box, with two open sides. The box was small, lightweight, and easy to work with. Four plastic wheels, with rubber tires, with a diameter of 65mm were used. The motors are mounted on the inside of the body and fixed with nuts and bolts. The motors drivers and MCU circuit are mounted to the top of the vehicle's body and the object detection circuit is mounted to the bottom side of the body.

The total length (front to back) of the vehicle is about 14cm. The total width (between the outer ends of the wheels) is about 17cm. The height of the vehicle is about 24cm, including the jumper wires. The vehicle has a measured mass of 548g ± 1g, without the power supply.

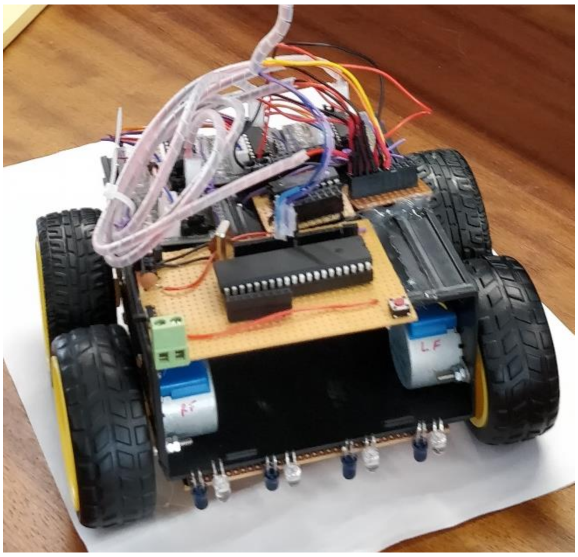

Figure 11: Final Build of the Survey Vehicle

4.5 Movement

The movement of the vehicle is controlled by four small stepper motors with wheels attached to each one. This four-wheel drive system provides the vehicle with a higher combined torque and the ability to change direction by being able to pivot on the spot. The large wheels allow the vehicle to traverse a greater distance in a short time. The wheels can travel 20.4cm ($65mm \times \pi \cong 204.2mm$) in one full revolution.

The stepper motors require 2048 steps for one full revolution of the motor shaft. The motors take about 8 seconds to complete one full revolution with a step delay of 4ms ($4ms \times 2048 = 8192ms = 8.192s$). This means the vehicle can move 20.4cm in 8.192s with one full revolution of the motors. Therefore, the vehicle can move about $2.5cm$ per second ($20.4cm \div 8.192s \cong 2.49cms^{-1}$).

4.6 Power Consumption

The survey vehicle requires a 5V power supply that can supply at least 0.5A of current. The total power drawn is less than 2.5W. A mobile power bank will be used to power the vehicle. The mobile power bank has a battery capacity of 2000mAh, which means, for example, that it can power a device drawing 2A for 1 hour. This time limit is an estimation as the battery capacity is not exact and numerous factors can affect the usage time. Therefore, the survey vehicle should be able to operate for about 4 hours from a fully charged battery, with a capacity rated at 2000mAh.

The motors each have a leakage current of about 1mA in an idle state (not rotating). When the motors are rotating, each motor draws a current of about 100mA, in wave-drive mode (one phase active at a time). All four motors require a combined current of 400mA when being driven using the wave drive 4-step sequence, as described in Section 2.3.

The stepper motor driver modules have a leakage current of up to 100µA with a supply voltage of 50V. The driver modules are supplied with 5V and will output about 100mA at any given time to each stepper motor. The M74HC744 octal bus buffer was used to control the driver modules as the MCU pins were not able to output enough current to control 4 driver modules simultaneously. The M74HC244 has a leakage current of up to about 10µA and can supply up to 35mA per pin.

The HC-05 Bluetooth module is supplied with 5V. When the Bluetooth module is searching for a device (in pairing mode), it draws about 30mA. When the Bluetooth module is paired, it draws a continuous current of about 10mA, regardless of transmitting data or when idle.

The infrared LED draws about 17mA ($(5V - 1.2V) \div 220\Omega \cong 17.27mA$) when a current limiting resistor of 220Ω is connected in series with it. An array of 4 infrared LEDs draws a total current of about 69mA. The maximum current that any of the infrared sensors can draw is about 3.8mA ($(5V - 1.2V) \div 1000\Omega = 3.8mA$). An array of 4 infrared sensors draws a total current of about 15.2mA. The LM311 differential comparator draws up to 7.5mA, so four comparators draw a total of up to 30mA. Therefore, the complete object detection circuit draws a total of up to 118mA.

The total calculated vehicle power consumption, when in full operation, is about 563mA. With a battery rated at 2000mAh, the estimated time of usage is about 3.5 hours.

5 Testing

Throughout the development of the survey vehicle, each component was tested individually. This was to ensure that they worked as intended before implementing it into the final system. After testing each component individually, they were tested with other components, one at a time. Eventually, all components were tested together.

Before programming the microcontroller, the program code was run through a simulator. The simulator used was the MCU8051 IDE, which is freely available as open-source software. The MCU8051 IDE was used extensively throughout the project to write, compile, and simulate the program code.

The first component tested was the microcontroller unit itself. A small program was written to flash an LED that was connected to one of the port pins of the MCU. This was to determine if the base circuit was working as intended with the 11.0592MHz crystal. After confirming the correct operation of the basic MCU circuit and LED flash code, the motors were tested next.

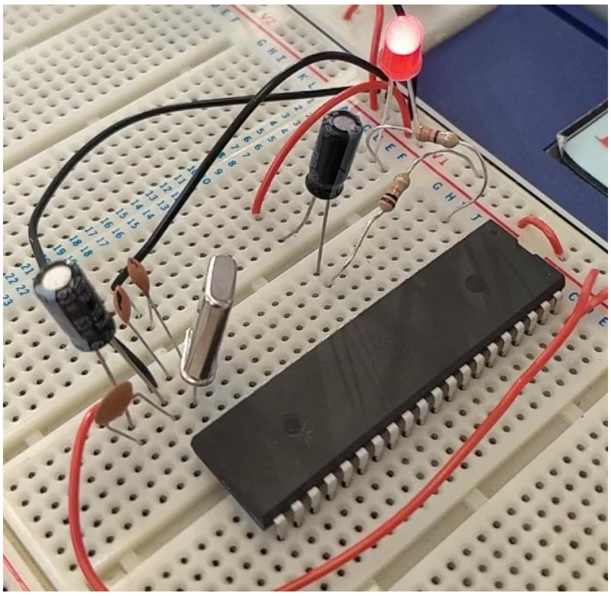

Figure 12: Testing of the Microcontroller Basic Circuit with LED

Initially, one stepper motor was interfaced with the microcontroller, with a motor driver. A small program was written to test if the motor was working. The basic motor program was written to rotate the motor in one direction indefinitely. Initially, there were some issues with the stepping of the motor, due to the step delay being too fast and too slow. After determining the correct step delay, the motor was as expected. The program for the motor control was developed further to include rotation in both directions. A second motor was then interfaced with the microcontroller and both motors operated with the same behaviour.

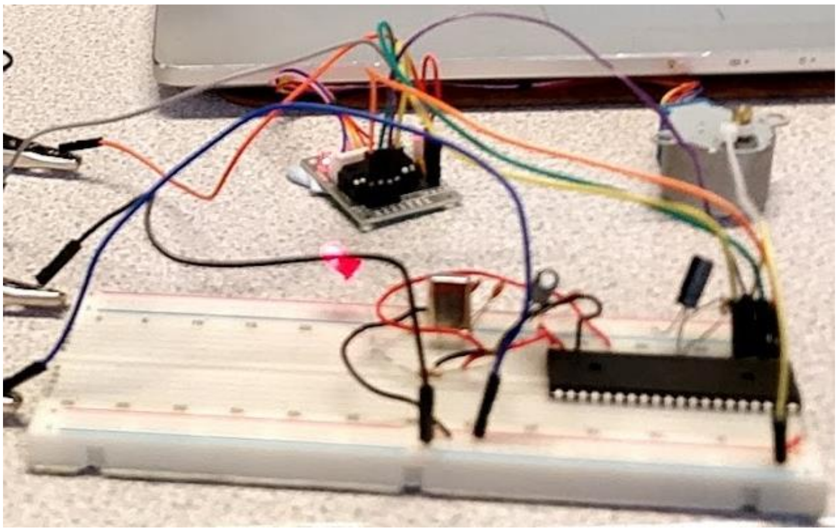

Figure 13: Testing of Stepper Motor with Microcontroller

The OLED display was the next component to be tested. Example program code provided by the project supervisor was used to test the display. The display operated as expected from the program outline. The OLED code was not further developed as this component was not used in the prototype build of the survey vehicle.

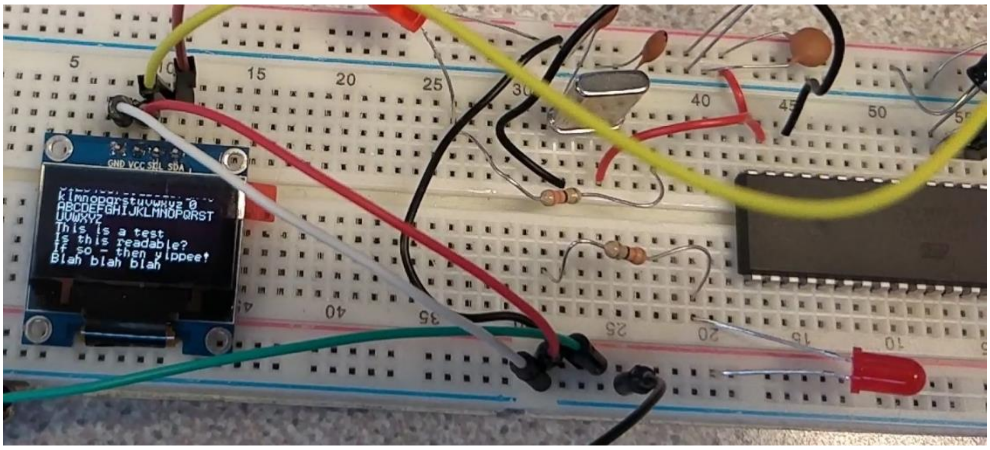

Figure 14: Testing of OLED Display with Microcontroller

The next component to be tested was the Bluetooth module, which again was tested with an example program code provided by the project supervisor. After confirming that the Bluetooth module was working with the example code, a small program was written to simply toggle the state of an LED. The Bluetooth module was tested with multiple devices and serial communication software to confirm the correct operation of the program code and the Bluetooth module itself.

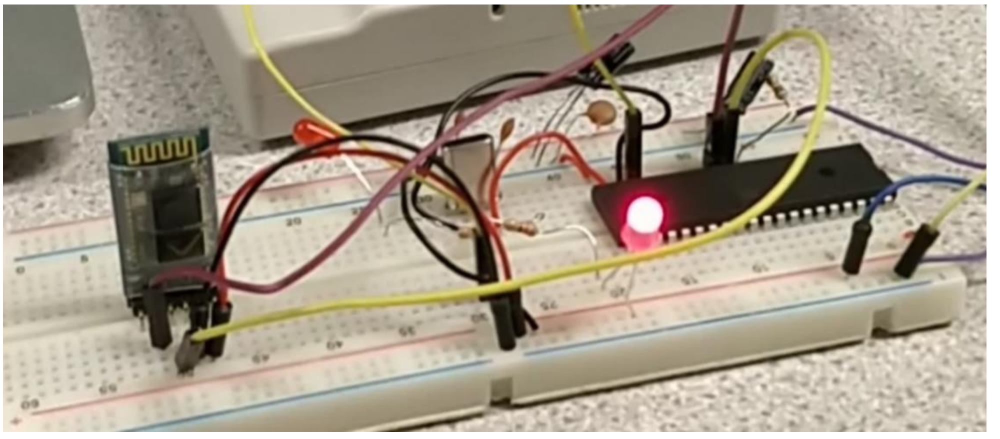

Figure 15: Testing of the Bluetooth Module with the Microcontroller

The infrared LED, infrared sensor, and LM311 were tested after the Bluetooth module, with a simple circuit. The infrared diodes were placed side-by-side, pointing in diagonally towards each other. A sheet of white paper with a piece of black tape was used to test the infrared LED and sensor. A digital multimeter was used to check the output of the sensor and ADC to ensure the correct output.

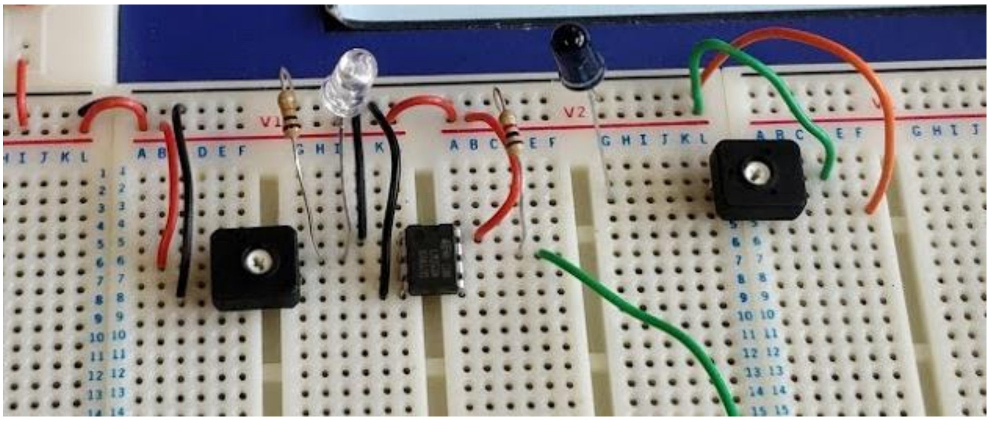

Figure 16: Testing of Infrared LED, Infrared Sensor, and LM311 Circuit

After each component was tested and verified to be working correctly, a development board was built to test the motors. The development board was a piece of wood with the motors mounted next to each other, in the layout that they would be implemented in, in the final build. The stepper motors were then tested with two buttons and another program. The new program accepted the buttons as inputs and made the motors rotate either clockwise or counter-clockwise. The motors would only rotate for the duration the buttons were held down for.

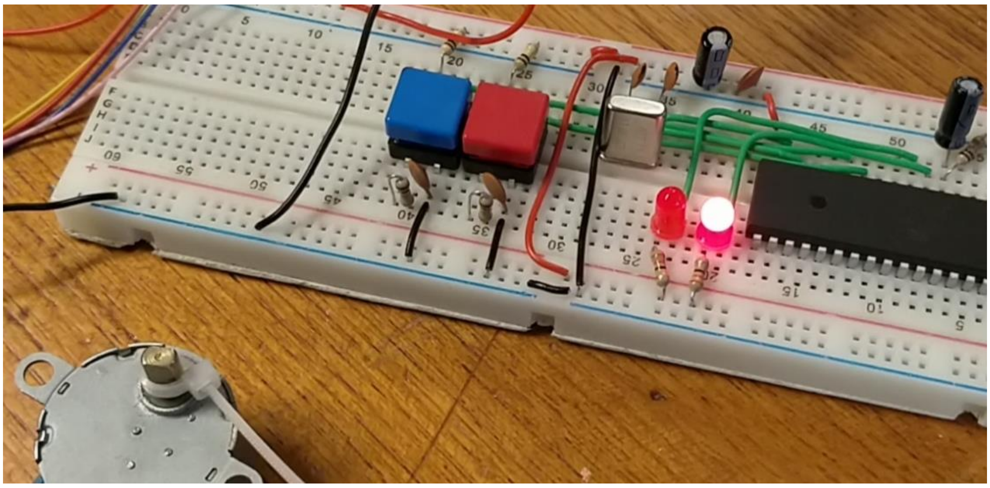

Figure 17: Stepper Motor Interfacing with MCU and Direction Control Using Two Buttons

When testing two motors with the microcontroller, they were interfaced with one port (Port 2) of the microcontroller. The MCU ports have eight pins and each motor driver requires four of these for interfacing, so two motors would require eight pins. Another two motors and drivers were added in parallel with the already connected motors and drivers. This meant that only eight port pins (one MCU port) were required to interface four stepper motors and drivers.

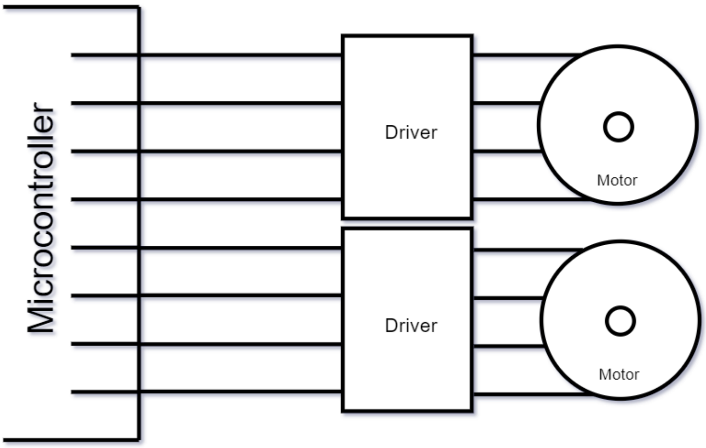

Figure 18: Interfacing Two Stepper Motors and Drivers with the Microcontroller Using One Port

However, during testing, the motors were discovered to not be working correctly. During initial testing of four motors, the problem was not apparent. Each motor was tested individually to check that they were each working and to ensure that the code did not have any issues. Each motor driver was also checked individually to make sure that each one was working. It was finally discovered that the MCU port pins could not control two drivers connected in parallel using four port pins.

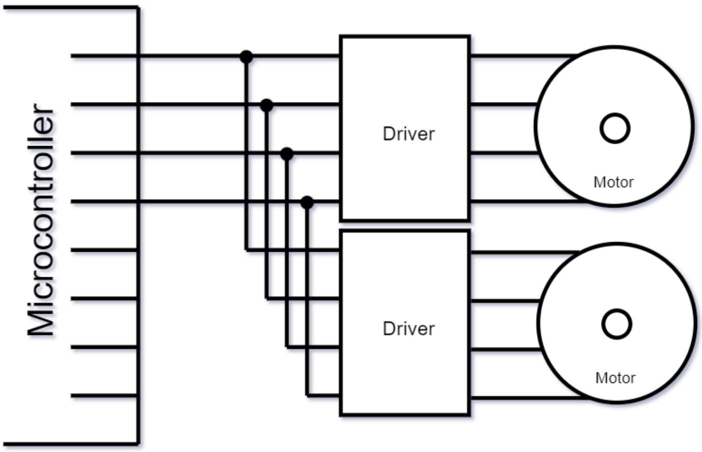

Figure 19: Interfacing Two Stepper Motors and Drivers with the Microcontroller in a Parallel Arrangement

In order to control two motor drivers connected in parallel on four port pins, an external line driver of buffer was required. An octal bus buffer was chosen to interface between the microcontroller and the motor drivers. After interfacing the bus buffer with the MCU and four motor drivers, all four motors were confirmed to be functioning as intended.

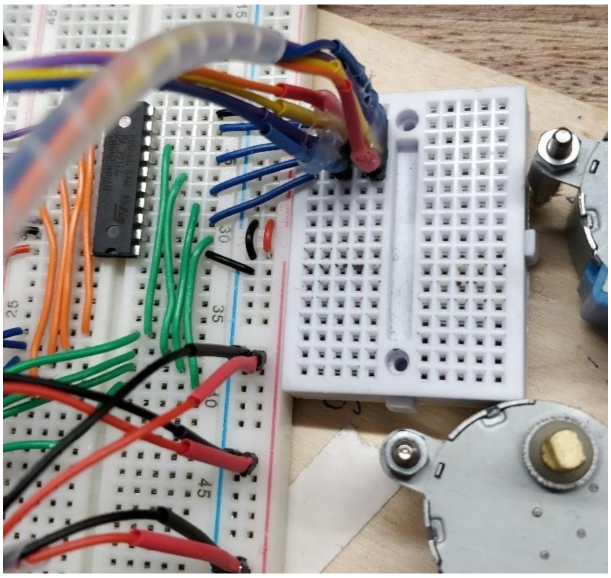

Figure 20: Bus Buffer Interfacing with Two Motor Drivers in Parallel

The next test was interfacing both the Bluetooth module and motors with the microcontroller. The program with the button control for the motors was modified to incorporate the code for receiving Bluetooth commands. Two commands were first used to make the motors turn either clockwise or counter-clockwise. After the program and components were confirmed to be working, the program was developed further to include more commands and functions. The additional commands and functions were to make the motors rotate in opposite directions. This was the basis for basic movement control of the vehicle.

The next component to test was the internal EEPROM of the microcontroller. A simple program was written to test the EEPROM, but this program could not be simulated using the MCU8051 IDE, due to software limitations. Therefore, the code had to be compiled and programmed onto the microcontroller. The microcontroller was then powered on briefly to test writing to the EEPROM. The MCU chip data was then downloaded onto a computer to check if the EEPROM write had been successful, which it was.

When testing multiple writes one after another, there were issues arising. The MCU would only write the first byte of data to the EEPROM and the following bytes would be not be written. This was found to be due to incorrect timing of the EEPROM write cycle. The AT89S8253 datasheet states “EEPROM write cycles in the serial programming mode are self-timed and typically take 4ms” (Atmel Corporation, 2010). Another document states that the EEPROM write cycle takes up to 10ms, “which is guaranteed to last no longer than 10 milliseconds” (Atmel Corporation, 2007). The two documents contain conflicting information, so further testing had to be conducted to determine which time duration was correct.

The EEPROM program was modified to have a longer write cycle duration. The EEPROM write cycle was set to be 12ms long to ensure that the EEPROM write was successful. The new program code with a 12ms write cycle delay had desirable outcomes. Multiple bytes of data were able to be written to the internal EEPROM of the microcontroller.

The program for the Bluetooth module was developed further to enable sending characters to the paired device. After testing the program, the code was developed further to enable the program to send strings of characters (words, phrases, sentences, etc.) to the paired device. The transmission of single characters and strings of characters was confirmed to be working correctly.

Next, the Bluetooth module was tested with the internal EEPROM of the microcontroller. The programs of each component were combined and resulted in a program that would wait for a character to be received via Bluetooth, then it would be stored in the EEPROM. Following this test, the path programming algorithm was implemented in the program code.

The path programming algorithm was combined with the Bluetooth and EEPROM program, as it made use of functions available to both components. The program code was tested on the MCU and the MCU data was downloaded to the computer to ensure that the programming code worked. One issue that was found was that the EEPROM would only store the last byte received and this was found to be caused by not incrementing the data pointer register.

The motors were then combined with the Bluetooth module, EEPROM, and path programming implementation. An initial issue was found where the motors would not stop rotating after they had completed the set number of steps. The issue was found to be a case of sharing registers and overwriting the data stored. After resolving the issue, the program worked as intended.

After all the main components were confirmed to be working and the program behaving appropriately, plastic wheels were added onto the stepper motors. The wheels in possession did not fit the stepper motor exactly, as the stepper motor shaft was slightly smaller than standard. The correct fitting wheels for the stepper motor were not available so they would have to be designed and produced manually, which would result to be more costly and time-consuming. Instead, a workaround solution was devised, where a wood splint would be inserted into the wheel. This splint would cause the hole to be smaller and provide a tighter fit onto the stepper motor shaft.

Figure 21: Vehicle Wheel Modification to Fit onto Stepper Motors

Next, the vehicle was built, using a hollow plastic box, with two open sides. The motors were attached, then tested before adding the wheels to ensure they still functioned. The wheels were then attached to the stepper motors and, once again, tested to see if they behaved correctly. The vehicle could not be tested properly as all the circuitry was built onto a breadboard, which was large and heavy. The motors would not be able to function as intended with a large and heavy object on top of the vehicle. Despite these issues, the vehicle was tested to see if it was able to move, and it was able to.

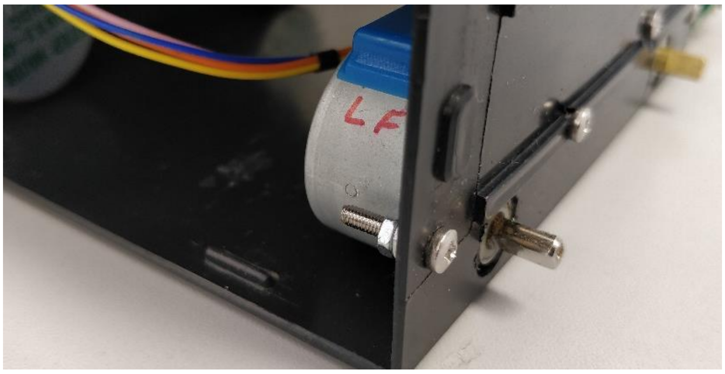

Figure 22: Stepper Motor Mounting onto the Vehicle Chassis

Figure 23: Wheels Mounted onto Stepper Motors and onto Vehicle Chassis

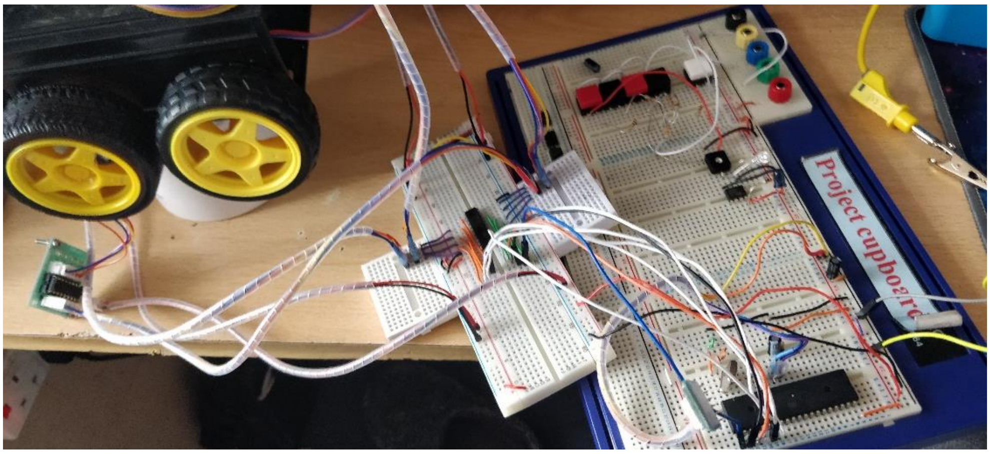

Figure 24: Component Testing with Constructed Vehicle

Each component of the survey vehicle was soldered onto a stripboard. The bus buffer was soldered onto a small piece of stripboard with female pin sockets. The microcontroller circuit was also soldered onto its own piece of stripboard with female pin sockets. Using female pin sockets allowed for easy interfacing between components. The object detection circuit was also soldered onto a separate piece of stripboard with female pin sockets. The standalone stripboard circuits provided better wire management than if all the circuitry was soldered onto one stripboard.

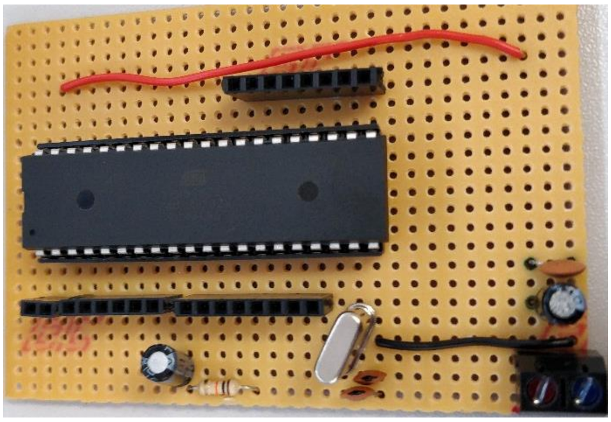

Figure 25: Microcontroller Circuit Soldered onto a Stripboard

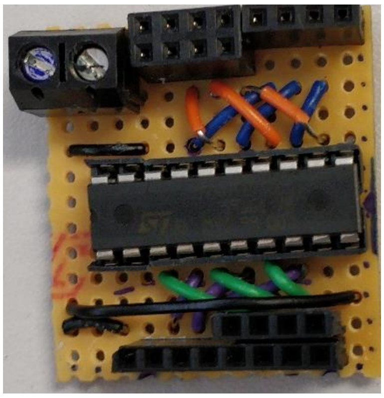

Figure 26: Bus Buffer Circuit Soldered onto a Stripboard

Each individual circuit was connected and interfaced with the microcontroller, then tested to ensure each component and circuit still worked correctly. The motor drivers, bus buffer circuit, and microcontroller circuit were fixed to the top of the vehicle. This provided easy access to the modules for debugging and for removing the MCU chip from the IC chip socket, for programming purposes. The object detection circuit was built and soldered onto a stripboard and fixed to the bottom of the vehicle, as the infrared arrays were located on the stripboard.

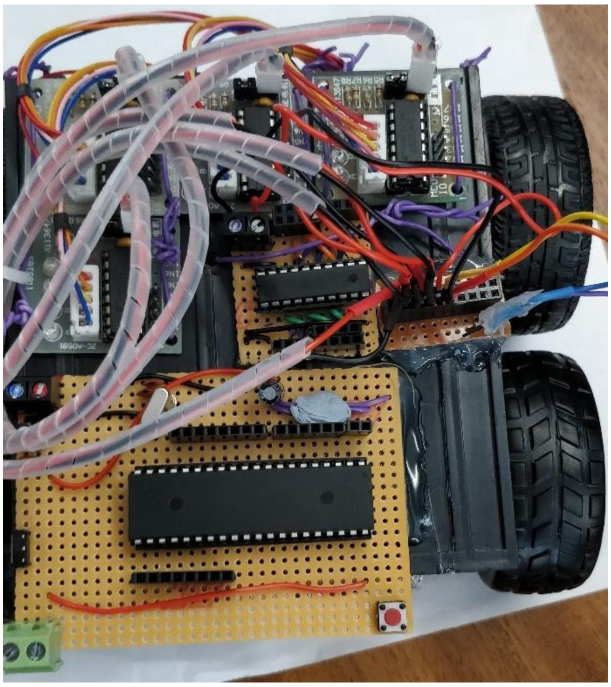

Figure 27: Stripboard Mounting to Top of Vehicle

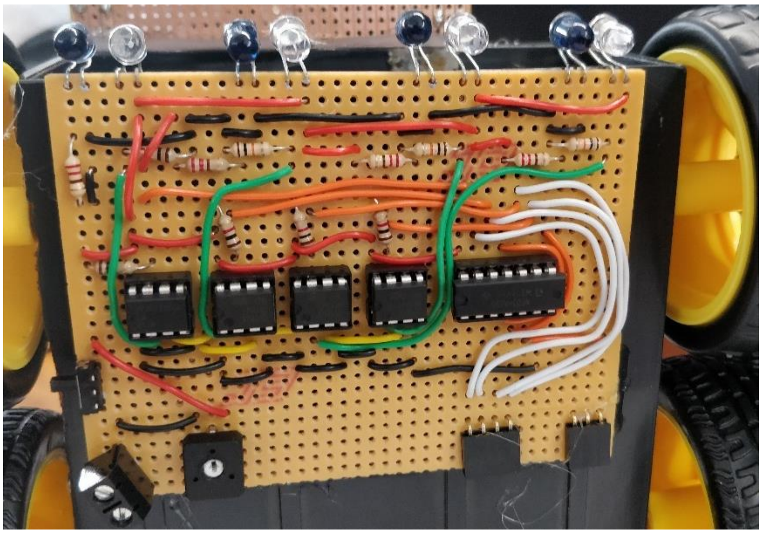

Figure 28: Object Detection Circuit Soldered onto Stripboard and Mounted to Bottom of Vehicle

After the vehicle and all core components were assembled together, the system was tested to ensure they all work. The next program code involved the algorithm for location mapping. The program for location mapping was simulated using the MCU8051 IDE before being combined with the main code with all the components. After the new program code was confirmed to be working correctly, a program was written for the object detection circuit.

The program code for the object detection behaved as expected during simulations. After programming the MCU with the new program, the behaviour was not as expected. This was due to the logic NAND gate circuit, which combined the outputs of the four ADCs to one output. The output of the NAND gate circuit was not behaving as expected and the issue could not be detected. Therefore, the output of the NAND gate was disregarded and instead the ADC outputs were directly interfaced with the microcontroller. The program code was then modified to reflect the new changes and tested once again. The object detection circuit and program now worked as expected. The object detection code was then combined with the main program code and tested once again to ensure the system behaved as expected.

6 Discussion

The survey vehicle built as part of this project is a prototype design with numerous areas that can be improved. Overall, the prototype build of the survey vehicle has met most of the objectives and requirements. The vehicle was built using low-cost components that can perform the task required.

The power usage of the vehicle is low, allowing it to be able to operate for extended periods of time with low capacity batteries. The battery is easily replaceable as it is already mass produced for other available technologies.

The survey vehicle can follow a pre-programmed path with high precision. The user determines the path to follow and programs it onto the microcontroller by sending commands to it. Bluetooth communication has been implemented on the vehicle, allowing it to receive instructions from an external device. The vehicle can precisely follow the programmed path due to being driven by stepper motors. When the user programs the path, they should be aware of the amount of area to be traversed with each move to prevent overlapping of an already covered area.

A mechanism for location awareness is written as part of the program. The vehicle can keep track of its location relative to the initial starting point. The program used in the prototype build does not include a mechanism for the vehicle to return to the start point, but this can be added in the next program update. Alternatively, the user can program the path such that the vehicle returns to the initial start position.

The vehicle is capable of 45° and 90° turns in both directions. If the user wishes to make a 180° turn, they can program two 90° turns, which is equivalent to 180°. The program can be modified to include a command to make the vehicle rotate 180°.

The survey vehicle has an array of infrared LEDs and sensors, which are used to detect objects. The prototype build of the vehicle can differentiate a simple contrast in colours of black and white, where a black item is detected as an object. When the vehicle is programmed with a path, it can move on its own and scan the area, which it moves about. Additional sensors can be added on to the vehicle, for improved terrain surveying.

7 Future Improvements

The survey vehicle can be improved in many areas, some of which have been highlighted below.

The prototype build of the vehicle uses stripboards for the circuitry of the system. Printed circuit boards can be designed and produced to reduce to the footprint of the circuitry, reduce the weight of the vehicle, and provide a cleaner finish.

The chassis of the vehicle can be modelled used computer-aided design software. It can then be produced with a higher quality of finish by either 3D printing it or having the parts laser cut.

The circuitry of the vehicle can be further improved by reducing the number of motor drivers used. Currently, four driver modules are used, of which four pins of each one are used and three are unused. If all IO pins were used on the driver modules, then only three drivers would be required.

The speed of the vehicle can be increased by replacing the stepper motors with a lower gear ratio variety or another model completely. The size of the wheels can be increased to increase the speed of the vehicle. Though, larger wheels could result in a potentially heavier and vehicle.

The program of the vehicle can be improved in many ways. Firstly, it can be made more efficient by reducing the amount of repeated code. The program lacks a few features, such as 180° turning, storing the location of where an object was detected, ability to return to start position by itself, and efficient area scanning.

To provide a simpler interface between the survey vehicle and the user, a desktop or mobile application can be developed. This could provide a graphical user interface and seamless experience with the survey vehicle. The application can be used to store journey logs of the vehicle or a real-time map of the vehicle when it's moving.

8 Conclusion

This report details the research, design procedure, and development stages required to produce a vehicle that is capable of surveying terrain. A program was developed using assembly language that can control stepper motors, detect objects, communicate with an external device via Bluetooth, and provide a method of location tracking. Throughout the development of the survey vehicle, extensive testing was carried out on each component and program code created, to ensure that the whole system would behave as expected.

The project details the successes, flaws, the ability of upgradeability and areas of improvement. The design ideas and algorithms implemented can be applied to similar projects, where another form of vehicle is to be designed to survey different features of the terrain, using a variety of sensors.

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Appendix A - Program Code

The program code can be found by visiting the following web link:

https://github.research.its.qmul.ac.uk/ec16121/Survey_Vehicle

The files listed in "Final_Version" are the latest copy of the program code uploaded to the microcontroller. The file of type “asm” is the program code written in assembly language and can be viewed using a text editor. The file of type “hex” is the program code in machine code as a result of the assembly code being assembled by the assembler provided by the ‘MCU8051 IDE’ software. Sub-programs that were used in the testing phase of the project can also be found at the above link.

Appendix B - System Block Diagram

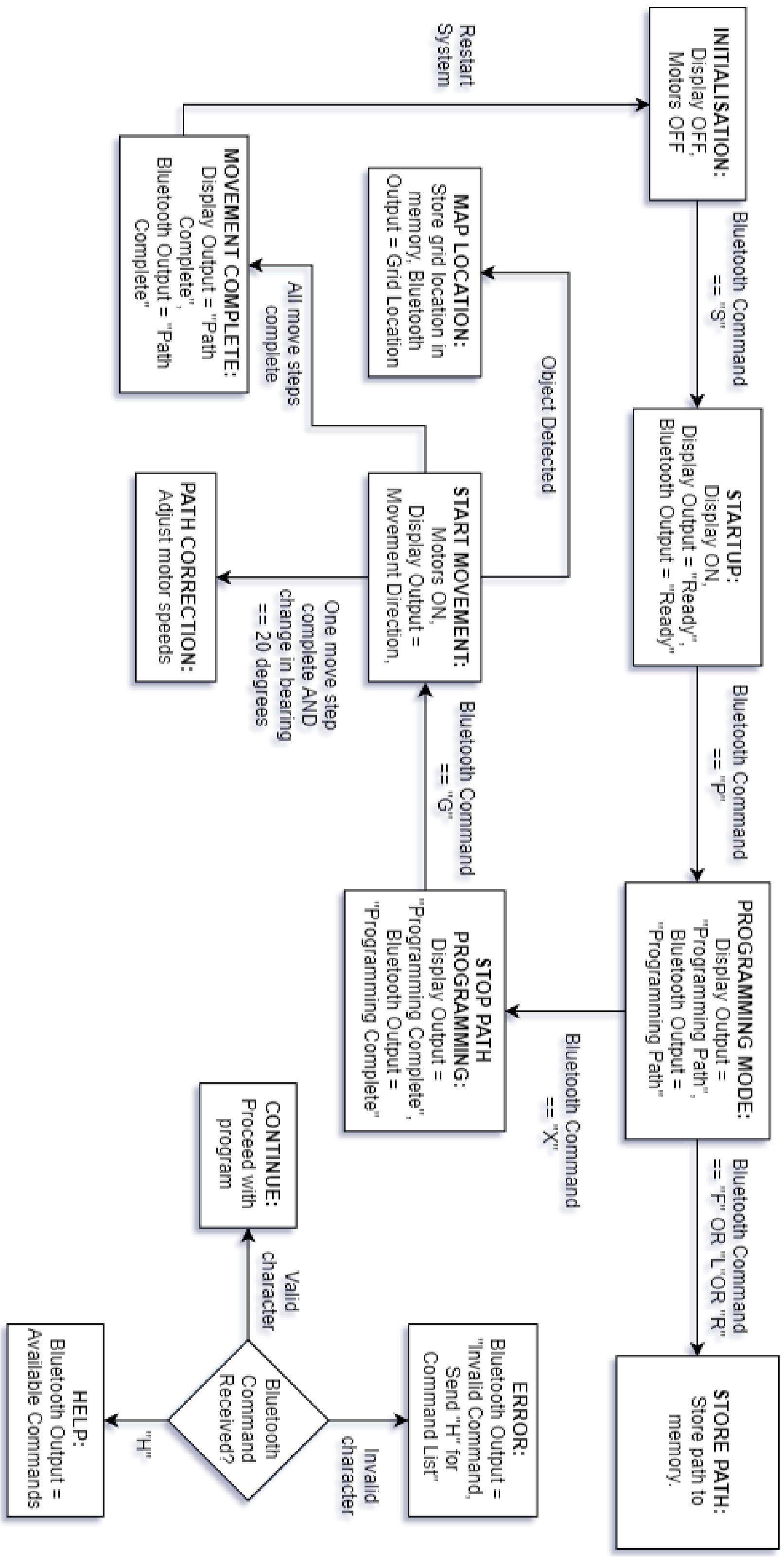

Figure 29: Survey Vehicle System Block Diagram Describing System Behaviour

Appendix C - Schematics

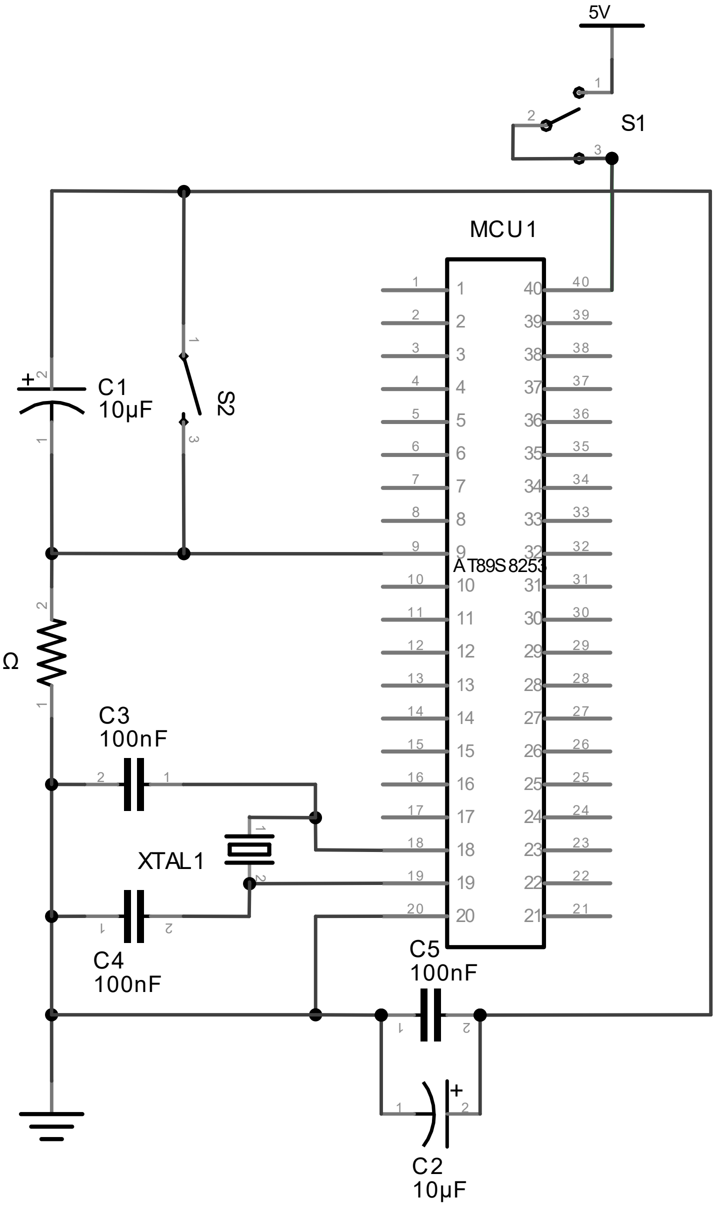

Figure 30: Microcontroller Basic Circuit

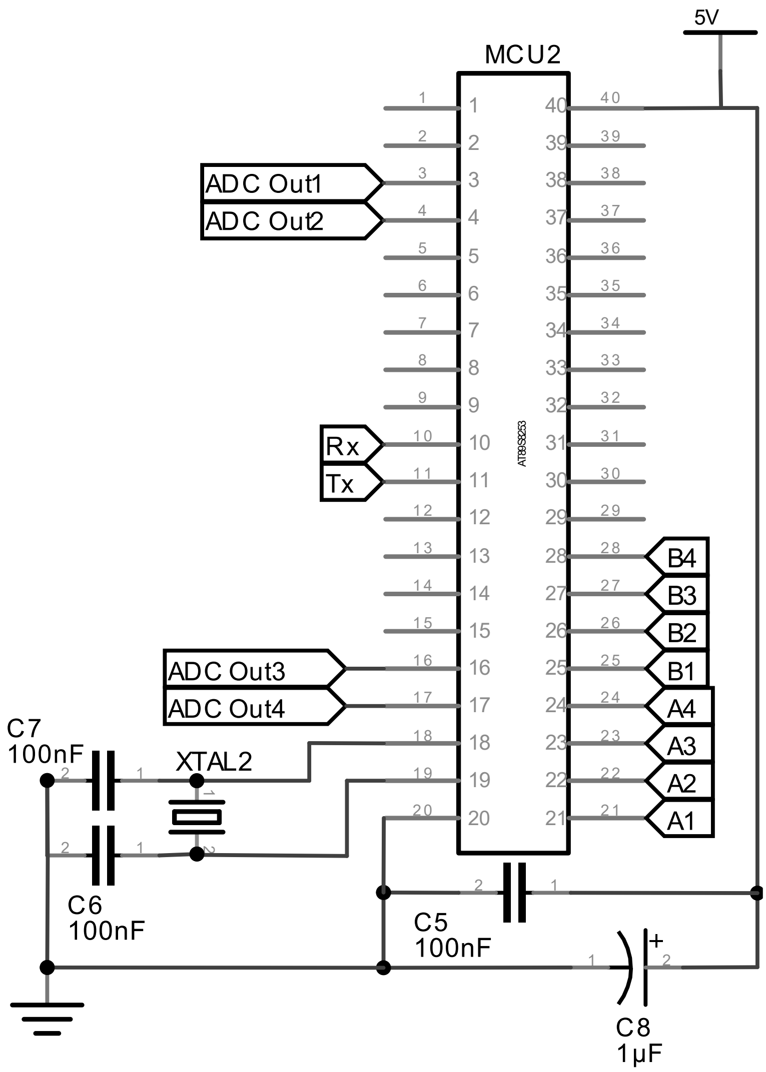

Figure 31: Microcontroller Circuit with Peripheral Interfacing

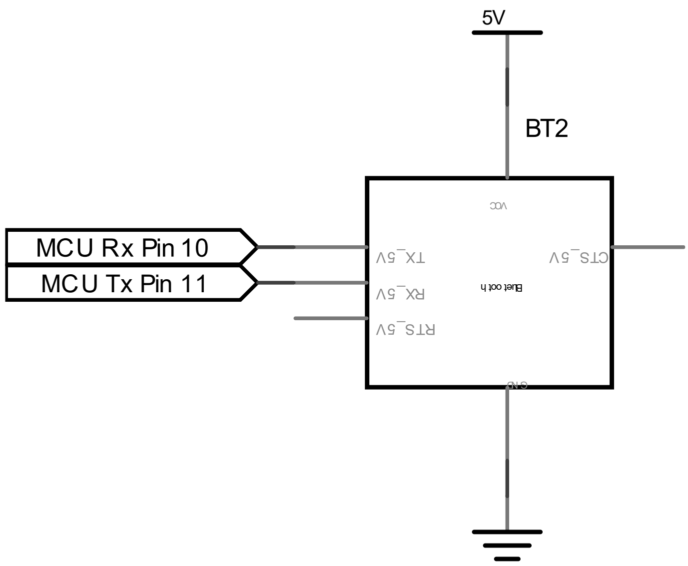

Figure 32: HC-05 Bluetooth Module Interfacing with Microcontroller

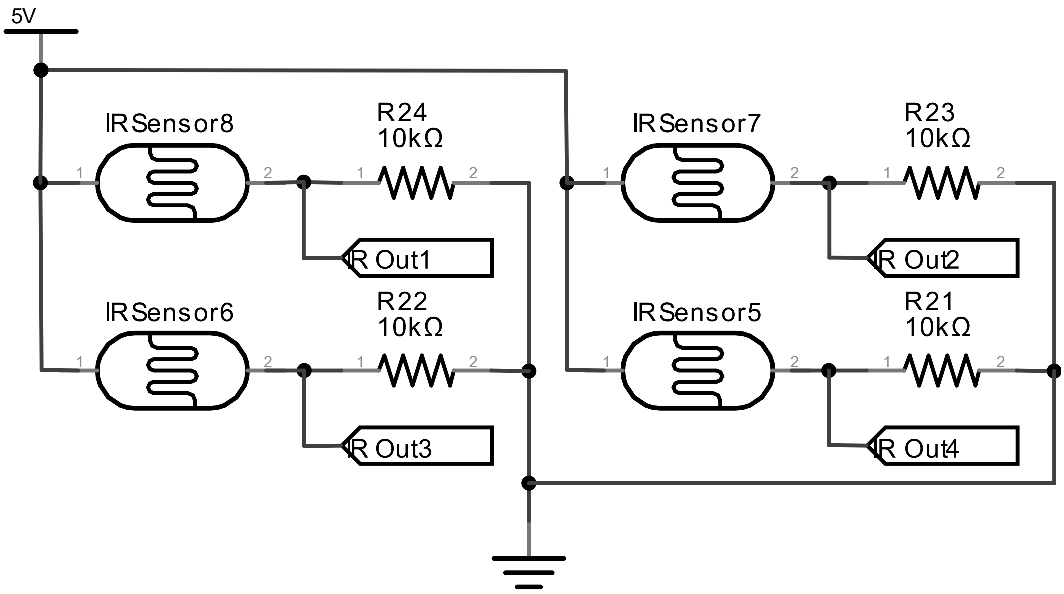

Figure 33: Circuit of Infrared Sensors and Interfacing with the Microcontroller

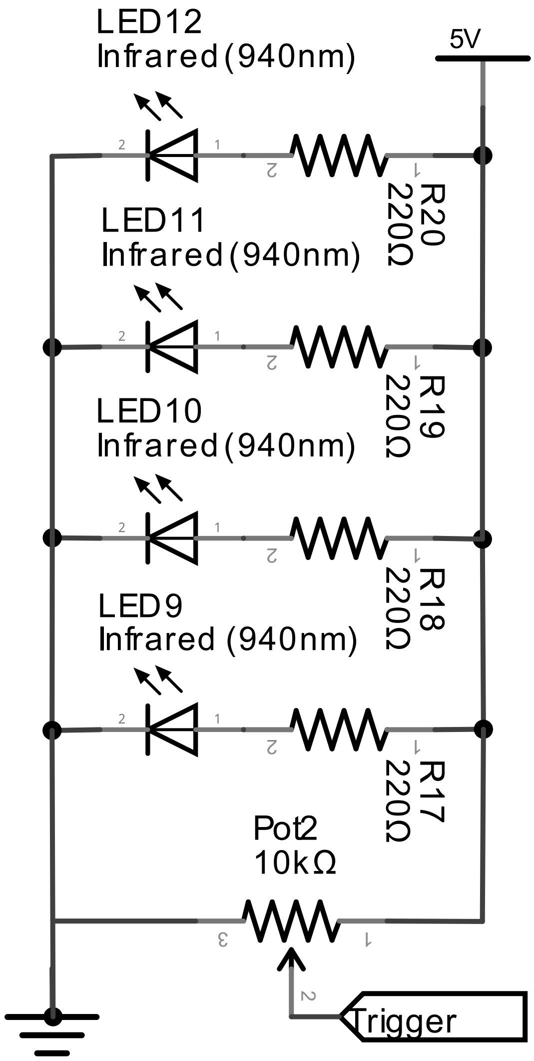

Figure 34: Circuit of Infrared Emitters

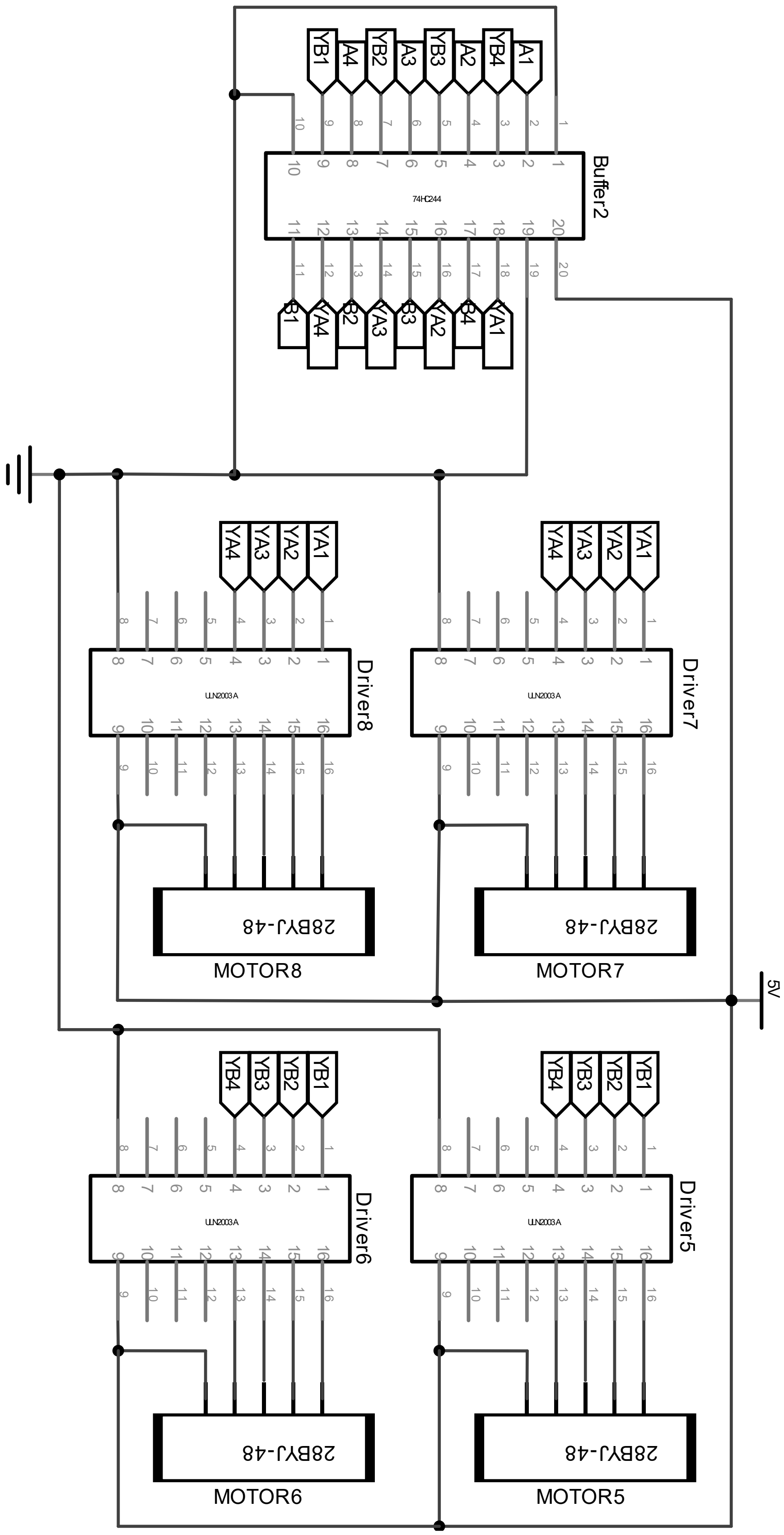

Figure 35: Interfacing of Stepper Motors, Motor Drivers, and Bus Buffer to Microcontroller

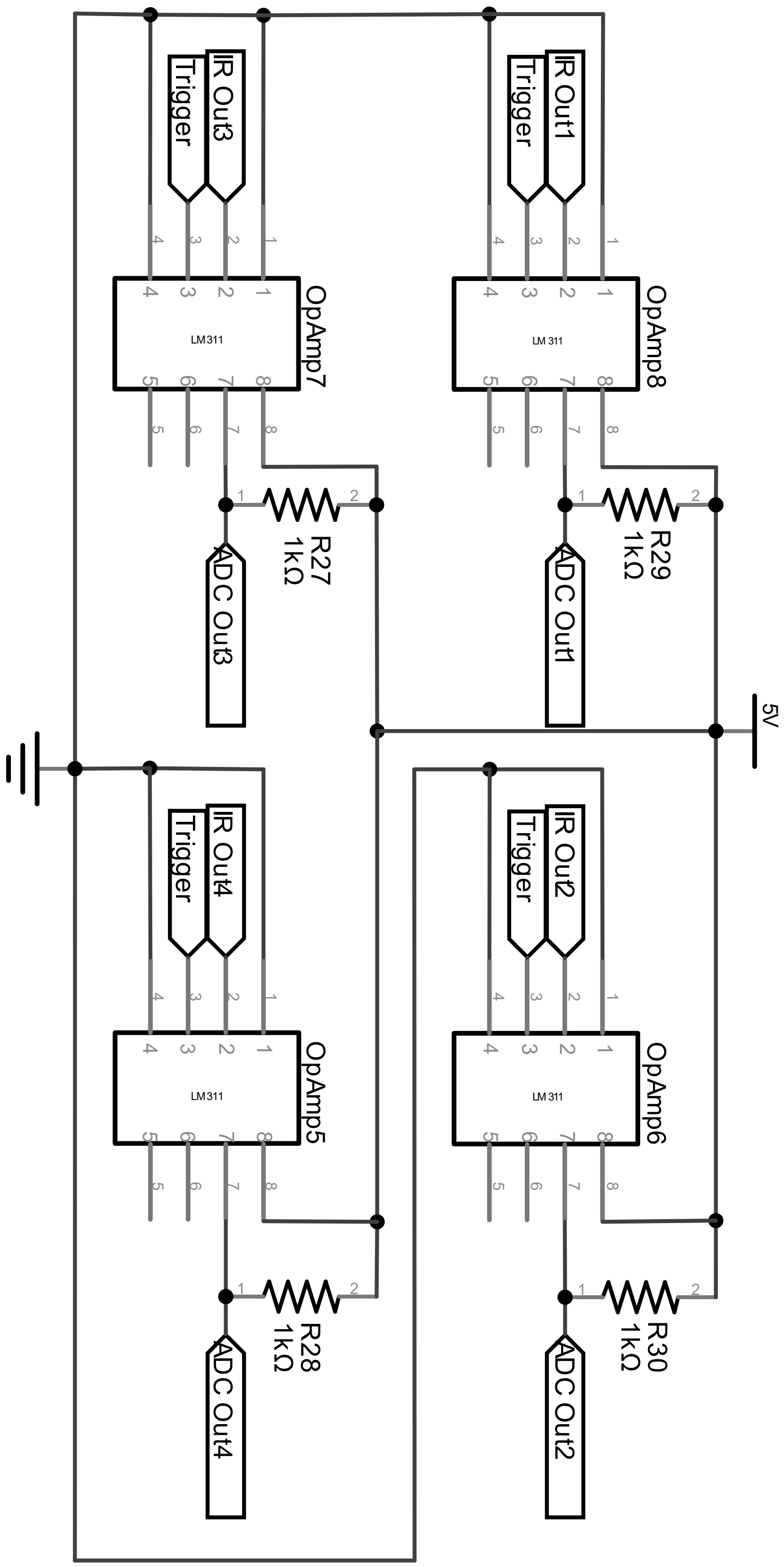

Figure 36: Interfacing of Infrared Sensors and ADC Circuit with Microcontroller