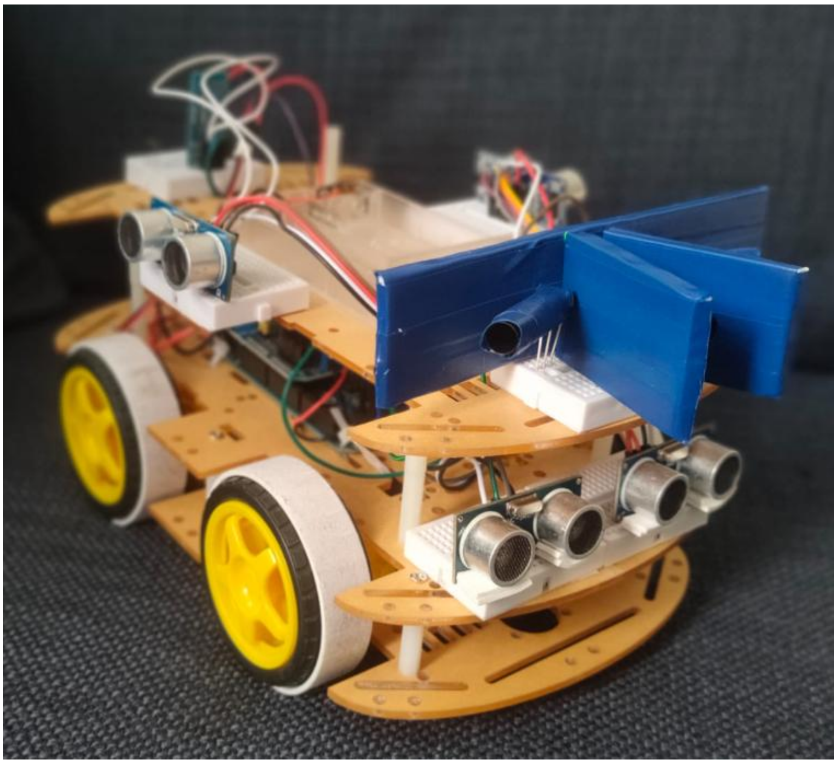
Project Report
Autonomous Cart



Department: Electrical and Electronics Engineering

Submitted by:

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1. Introduction

This project involves the design and implementation of a competitive autonomous cart that locks onto an infrared (IR) signal transmitter, aiming to reach the source in the shortest possible time. The cart must be able to detect and avoid obstacles along the way.

An IR signal source will continuously transmit from the opposite side of the room. The cart must travel from the starting line to the finish line in the shortest time possible. The cart searches for the IR light at all times. As long as the light is detected, it turns toward it—only if no obstacle is in its path. In case of an obstacle, the cart avoids it by taking the optimal path that enables it to reach the finish point in minimal time. If the IR signal is lost, the cart stops and scans the area until it redetects the signal and then proceeds toward it.

The IR transmitter, based on an Arduino Nano, will be configured to emit a modulated signal at 150 Hz or 300 Hz (selectable at any time using a switch).

The cart is controlled by an Arduino Mega microcontroller, which is programmed to detect IR signals, align its movement accordingly, and drive toward the signal while avoiding static obstacles using an ultrasonic sensor.

To drive the cart, four DC motors are used, operated through an L293D motor shield, controlled by the microcontroller. The cart also includes battery modules to supply power to the controller and motor chassis, as well as the ultrasonic sensor for obstacle detection.

2. System Description

2.1 System Operation

The cart must detect an IR transmission source, lock onto it, and autonomously navigate toward it while bypassing obstacles along the given route.

The system is based on the following components:

1. An Arduino Mega microcontroller that manages the operation of the various subsystems, processes sensor data and issues control commands accordingly.
2. An IR transmitter.
3. Three IR receivers, used to detect and track the IR signal source.
4. Four ultrasonic sensors (HC-SR04) that measure the distance to nearby objects in order to avoid obstacles and stop the cart upon reaching the target.
5. A wheeled platform, serving as the vehicle base, onto which all components are mounted.
6. Four DC motors, responsible for steering and propelling the vehicle toward the target.

2.2 Design Constraints

The design constraints are derived from system requirements and various limitations, both geometric and thermal:

- The cart must detect the transmitter signal at a maximum distance of 5 meters.
- The cart must be able to navigate autonomously, avoiding various obstacles (the obstacles are assumed to be on a flat floor with no slopes or elevation changes).
- The system must operate within a temperature range of 0–50°C, in accordance with the allowable operating temperatures of the components, as specified in their datasheets.

2.3 System Requirements

- Ability to detect infrared (IR) signals.
- Ability to drive in all directions.
- Ability to detect obstacles.
- Ability to measure distance to obstacles.
- Capability for data processing and decision-making.
- Ability to activate/deactivate via Bluetooth.
- The system must be fully autonomous.
- The system is designed to operate in flat indoor environments with no bumps, stairs, or elevation changes.

2.4 Functional and Technical Specifications

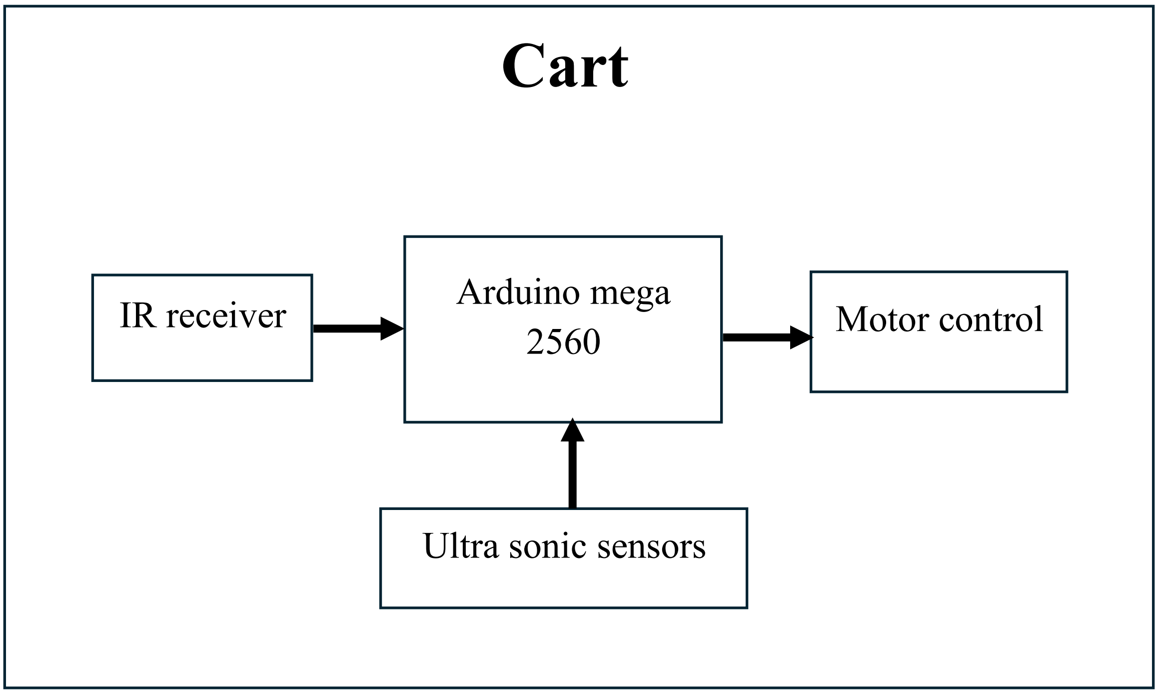
2.4.1 Functional Specification

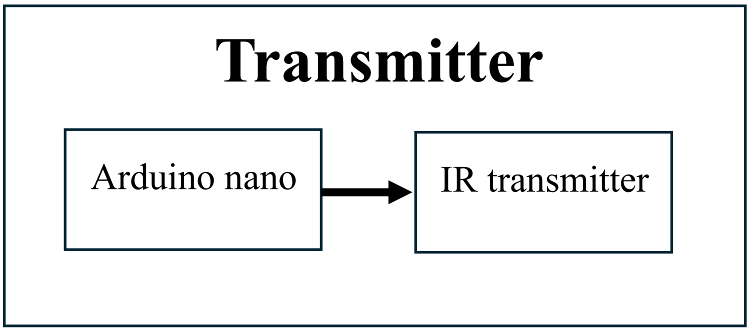
- Functional Definition:
  An autonomous cart equipped with IR sensors that detect infrared signals from a transmitter and navigate toward the source. The cart also includes ultrasonic sensors to detect and avoid obstacles.
- Functional Description:
  The autonomous cart will have the following capabilities:
    - Scanning the room and locating the IR signal source.
    - Driving and maneuvering in all directions.
    - Obstacle avoidance.
    - Data processing and decision-making.
    - Focusing on the IR source and navigating accurately toward it.
    - Detecting static obstacles and measuring their distance.
    - Self-correction of travel direction toward the IR signal.
    - Activation and deactivation via Bluetooth.
- The transmitter will have the following capabilities:
    - Transmitting an IR signal with a 38 kHz carrier wave, modulated at either 150 Hz or 300 Hz (selectable).

2.4.2 Technical Specification

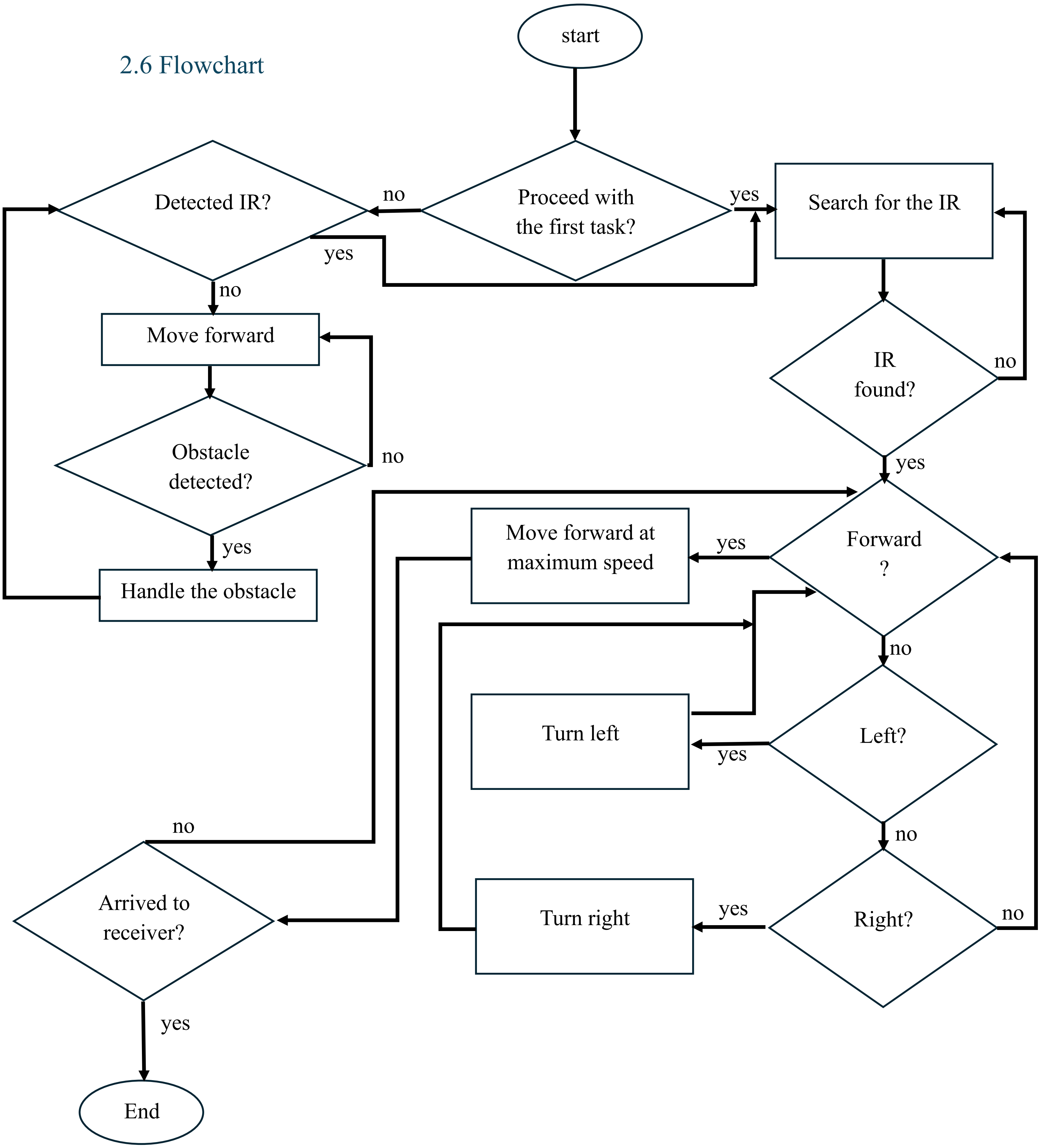
Component Name	Function	Specification
Microcontroller (Arduino Mega 2560) 	Processing incoming data from all sensors, integrating the information, and controlling the motors' speed and direction according to the algorithm designed for various scenarios.	Supply voltage: 11.1 [V]
Bluetooth (HC-06 bluetooth) 	Controlling the cart.	Voltage: 3.3V–6V (Logic: 3.3V) Interface: UART (TX/RX) Baud Rate: Default 9600 bps Range: ~10 meters
Transmitter (Arduino Nano) 	Emission of infrared rays modulated at a frequency of 38 kHz.	Infrared Led IR-333 BC547 transistor for current pushing
Receiver (TSOP 4838 receiver) 	Reception of encoded IR signal from the transmission unit.	Operating frequency : 38 [KHz] Supply voltage 5V Supply current: 5 mA
Drive System (L293D motor shield)  (4 x DC motors TT130) 	Controlling the cart's movement toward the target with speed adjustments based on the implemented algorithm.	Supply voltage: 11.1 [V]
Power Supply (3 x 18650 battery) 	Power supply to the microcontroller and motor chassis.	3.7V and 2.8A to motor shield 11.1V to Arduino mega.
Obstacle Distance Detection Unit (3 x Ultrasonic HC - SR04) 	Detecting obstacle distance and transmitting the information to the controller for processing.	Max Range : 4 [m] Min Range: 2 [cm]

2.5 Block Diagram



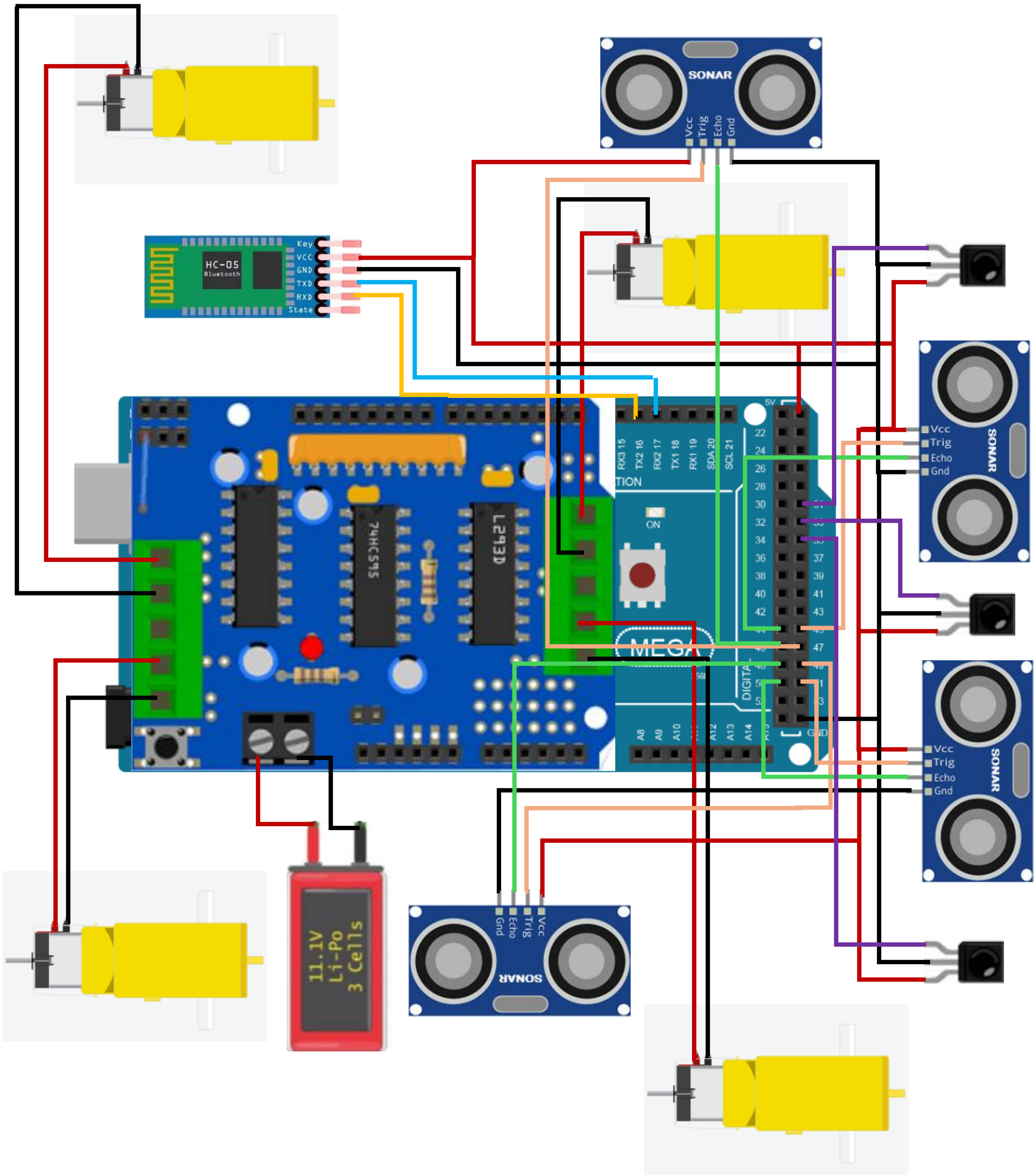


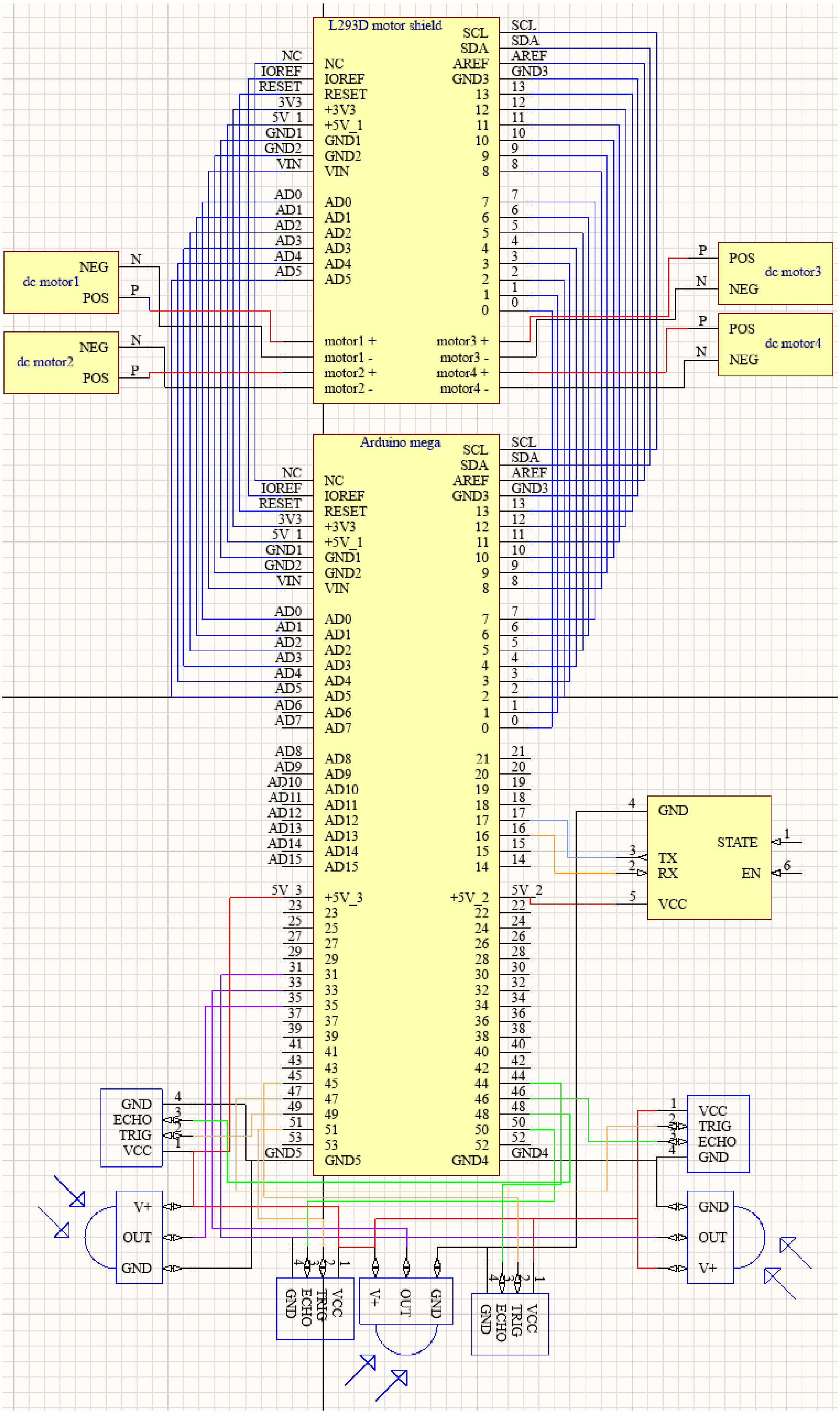
2.6 Flowchart



2.7 Schematic Diagram

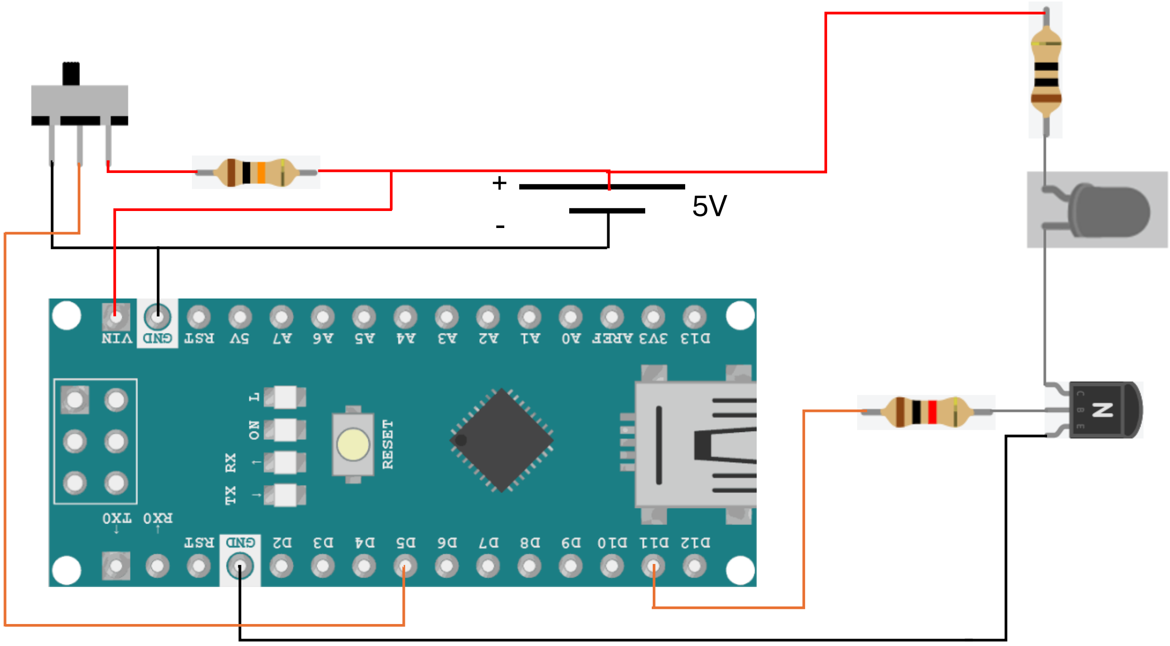
2.7.1 Obstacle Detection, Bluetooth, and Drive Units

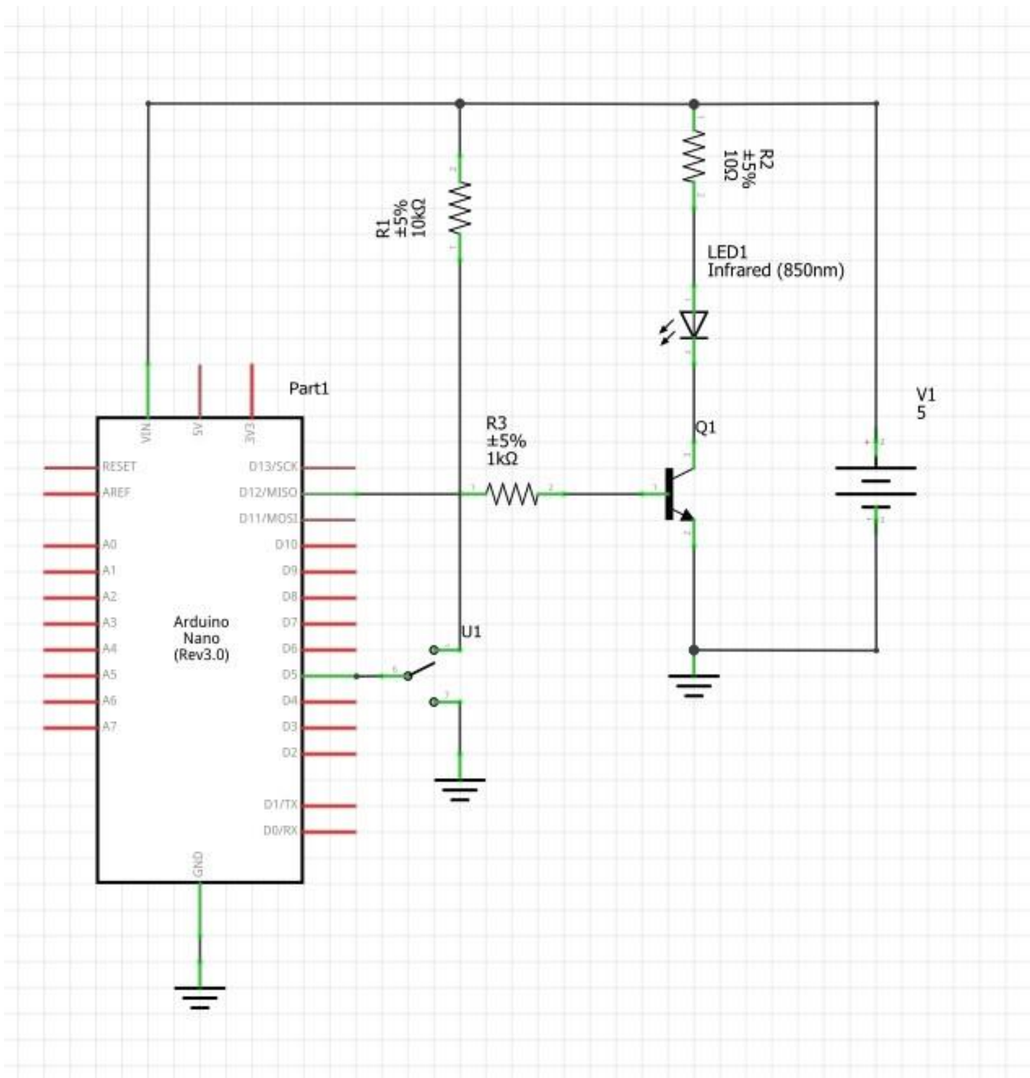




L293D motor shield
Arduino mega
dc motor1
dc motor2
dc motor3
dc motor4
NEG
POS
N
P
NC
IOREF
RESET
3V3
5V_1
GND1
GND2
VIN
AD0
AD1
AD2
AD3
AD4
AD5
SCL
SDA
AREF
GND3
motor1 +
motor1 -
motor2 +
motor2 -
motor3 +
motor3 -
motor4 +
motor4 -
AD6
AD7
AD8
AD9
AD10
AD11
AD12
AD13
AD14
AD15
+5V_3
5V_3
+5V_2
5V_2
GND5
GND4
GND
STATE
TX
RX
EN
VCC
ECHO
TRIG
V+
OUT

2.7.2 transmitter





3. System Design

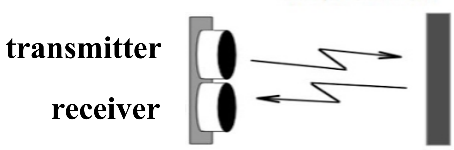
3.1 Design of the Obstacle Distance Detection Unit

The purpose of this unit is to provide the system with the ability to detect objects at varying distances and angles (forward, left, and right), using four ultrasonic sensors—two positioned at the front and two on the sides. By processing the collected data, the system can avoid obstacles encountered along the path to the IR transmitter.

This unit is based on the HC-SR04 ultrasonic distance sensors. Each sensor emits a high-frequency sound wave in the direction of an object. The sound wave reflects off the object and returns to the sensor.
If the echo is received, the sensor calculates the distance to the object based on the time delay between sending and receiving the signal and the speed of sound.

Each ultrasonic sensor consists of two components:

- One **transmitter** (marked "T")
- One **receiver** (marked "R")



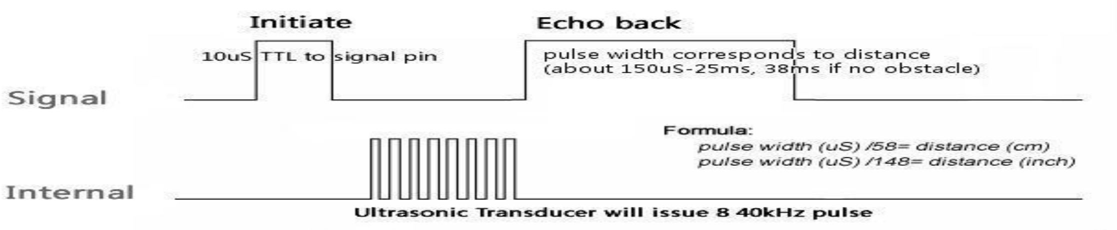
Operation of the Ultrasonic Sensor:

The ultrasonic sensor consists of an ultrasonic wave transmitter and receiver.

The transmitter emits an ultrasonic signal at a frequency of 40 kHz into the room. When this signal hits an object in front of the sensor, it reflects back and is received by the receiver.

The sensor operates under the following conditions:

- First, the sensor receives a 10 µs trigger pulse, known as the Trigger signal.
- After receiving the trigger, the sensor transmits 8 consecutive ultrasonic pulses at 40 kHz.
- It then enters the listening mode, known as the Echo state, where it waits to detect the reflected signal.



Echo Timing and Distance Calculation:

During the Echo phase, the sensor waits for the return of the transmitted signal and measures the time it takes to receive it.

To calculate the distance between the sensor and the object, the following formula is used:
Distance = Speed × Time

Since the speed of sound is known to be approximately 340 m/s, and the time is measured from the moment the sound wave was emitted until it is received back (using the Echo signal), the distance to the object can be calculated.

However, since the wave travels the distance twice (to the object and back), the result must be divided by 2:

Distance = (Speed × Time) / 2

According to our algorithm:

The cart will proceed forward only if the measured distance is greater than ~35 cm. If an object is detected closer than this threshold, the system will respond based on predefined conditions and logic.

Conclusions:

- High accuracy in detecting objects placed directly in front of the sensor.
- Stable and consistent readings across multiple samples.

3.2 Drive System Design

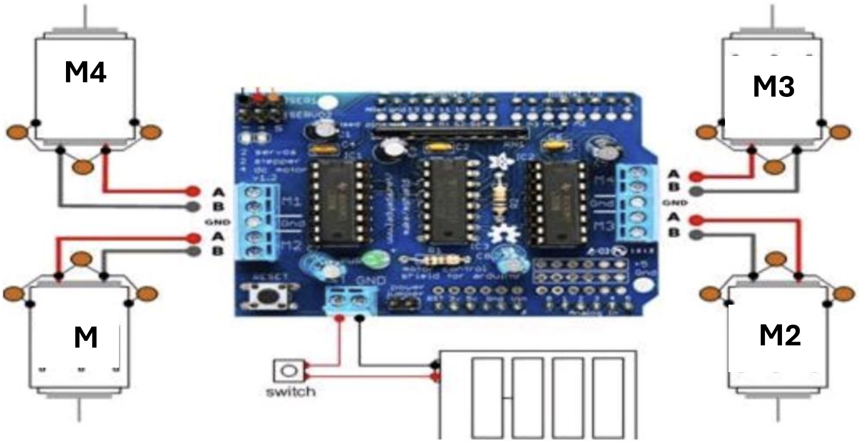
The purpose of this unit is to move the cart from one point to another.

Components:

- 4 × TT130 Gear DC Motors
- Motor Control Shield for Arduino

For this unit, four TT130 DC motors were selected, along with a motor control shield mounted on the Arduino Mega controller. The shield functions as a current driver for the motors, providing sufficient current to operate them at varying speeds as required.

Since the motors draw a significant amount of current, and in this project there are four motors, the Arduino Mega alone cannot supply the necessary current for their operation. Therefore, the motor control shield was installed.
To power the motors, an external power source is connected, supplying 11.1V to ensure proper operation.



The motor control shield is connected to the Arduino Mega via header pins, allowing us to control the operation of the motors according to the logic defined in the following table:

Direction of Rotation	**M2,M3**	**M1,M4**
Backward	BACKWARD	BACKWARD
Right	BACKWARD	FORWARD
Left	FORWARD	BACKWARD
Forward	FORWARD	FORWARD

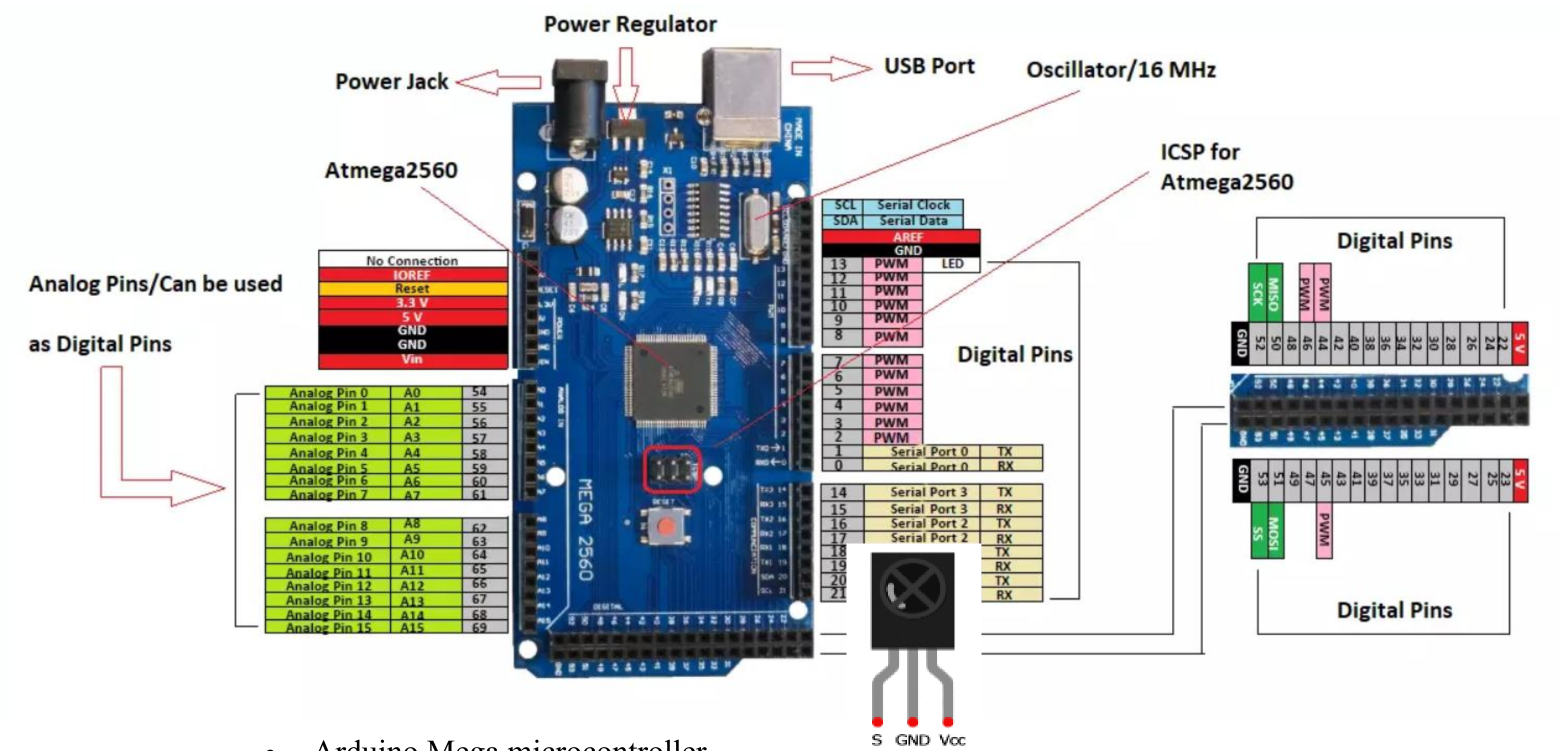
The cart's movement depends on various conditions based on the readings received from the system's sensors.
Each movement is assigned to a specific function, which applies the appropriate voltages to each motor individually to perform its task.

3.3 Control and Data Processing Unit Design

The purpose of this unit is to collect all the information and data received from the various subsystems in the project and make decisions regarding the next operational steps of the cart, ultimately enabling it to achieve its goal.

Hardware used in this unit – Arduino Mega 2560:

- In this project, there is no requirement for exceptionally high data processing capability; therefore, using this type of microcontroller fully meets the project's needs.
- The controller's size and weight are relatively small, making it suitable for our application.



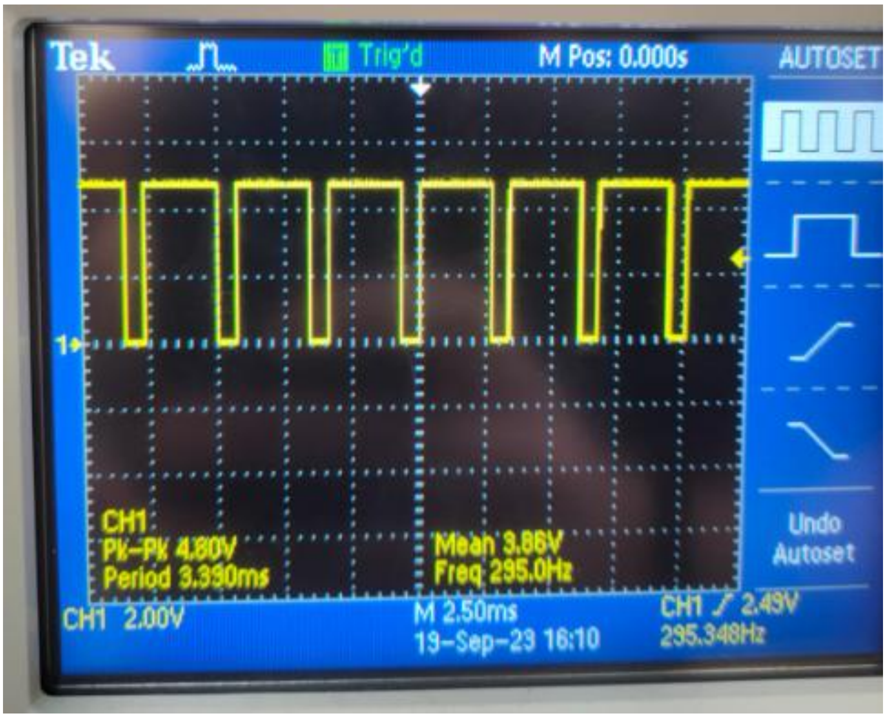
- Arduino Mega microcontroller

In our receiver setup, we used three IR sensors of type TSOP4838: one positioned on the left side, one on the right side, and one at the front.
Their purpose is to work together to send information to the controller in order to adjust the movement direction and navigate as accurately as possible toward the transmitter source.

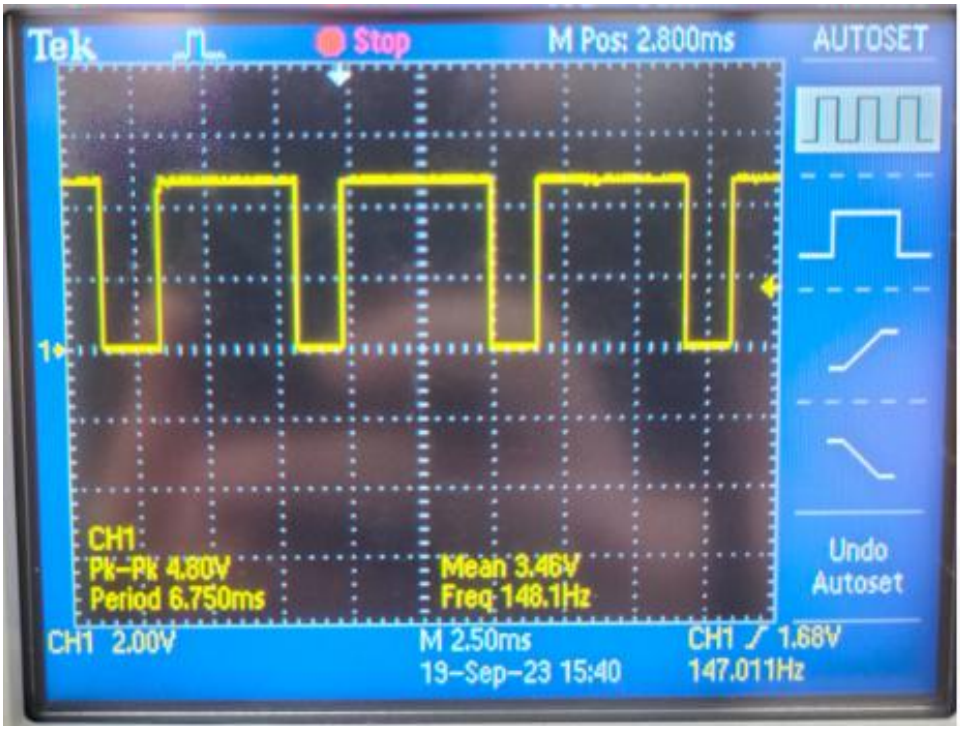
Advantages of the unit:

- Enables reception of modulated signals at an operating frequency of 38 kHz
- Low-cost and reliable receiver operating within the desired frequency range (38–40 kHz)
- Reception range of the transmitter under lab conditions: up to 7 meters
- Infrared light reception angle: 90°

Test results obtained:



IR Signal Reception Results – 300 Hz



IR Signal Reception Results – 150 Hz

It can be observed that the selected sensor successfully detects the desired signal.

Conclusions

- The reception sensor operates with high sensitivity and a high success rate.
- Proper signal modulation and appropriate sensor detection are key factors for success in the task.
- The reception range of the unit meets the project requirements.

3.5 Transmission Unit Design

The purpose of this unit is to provide an IR signal that the cart can detect and navigate toward.
In the environment where the project was designed and tested, there are various sources of IR signals—such as lamps, sunlight, and the human body—that could interfere with the cart's ability to identify the IR signal from our transmitter.

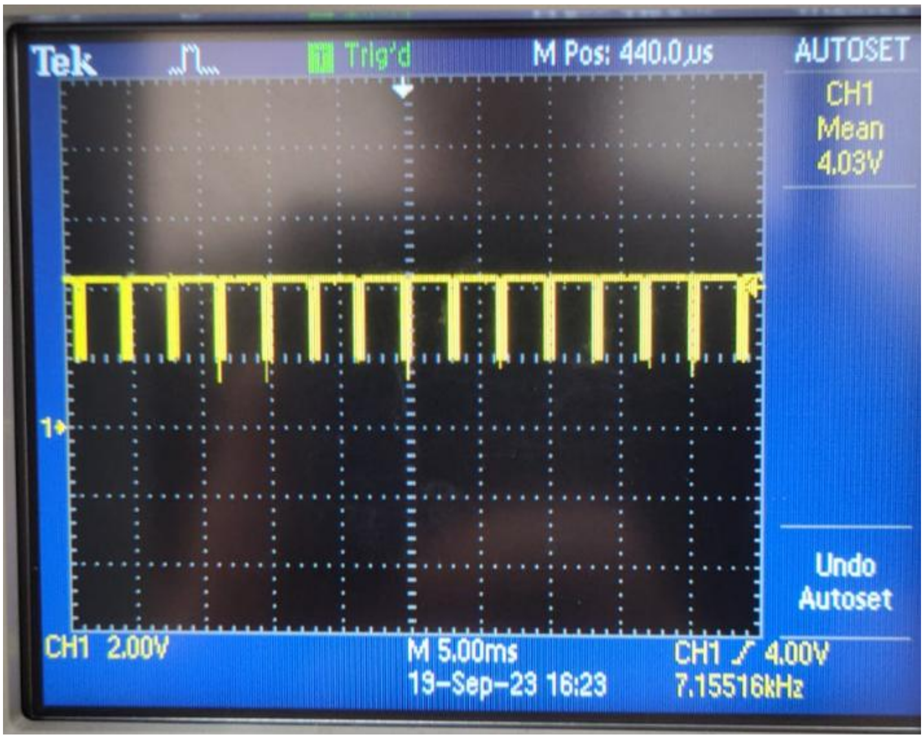
To avoid receiving these unwanted signals, it was decided that the signal transmitted from the transmission unit would be modulated with specific information according to a known protocol called SONY, which allows sending modulated data at a frequency of 38 kHz—a frequency that our reception unit is designed to decode.

Transmission Unit Components:

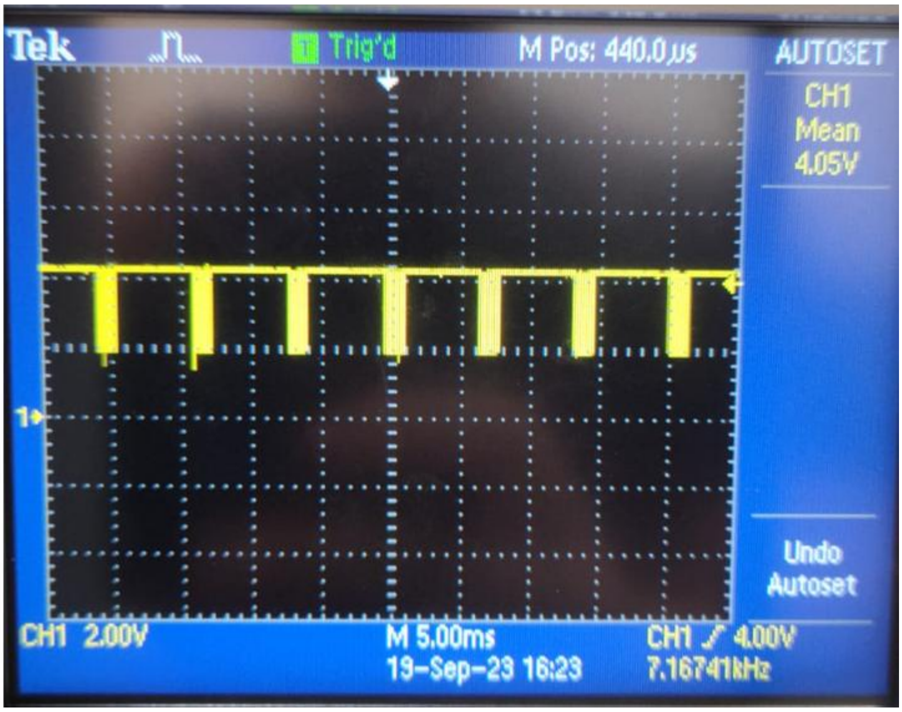
- Arduino Nano
- IR333A LED transmitter
- Resistors: 50 Ω, 1 kΩ
- NPN Transistor BC547

Signal modulation is performed by the Arduino Nano of the transmission unit. The controller sends a series of pulses at a 38 kHz carrier frequency, with a modulation frequency of either 150 Hz or 300 Hz, selectable by the user via a small switch.
The output pin (Pin 11) of the microcontroller is connected to a bipolar transistor that functions as a switch, turning on and off to make the IR LED flash at the desired frequency.
To protect the transistor, it was decided to limit the base current from Pin 11 of the microcontroller using a 1 kΩ resistor.

In testing this unit, emphasis was placed on achieving a transmission distance of more than 5 meters with a duty cycle of 1/5, and at the desired infrared frequency of 38 kHz.
During laboratory tests using an oscilloscope, the output frequency of the unit was measured, as shown in the following figure:



Frequency Measurement at the Output of the Transmission Unit – 300 Hz



Frequency Measurement at the Output of the Transmission Unit – 150 Hz

The IR diode is connected to V Pin 5 of the controller, as this output can supply up to 200 mA.
Pin 11 of the controller outputs an electrical signal at a frequency of 38 kHz with a low current sufficient to activate the transistor.

The IR diode is connected to V Pin 5 and receives the required current to operate at maximum efficiency.
According to the manufacturer, the maximum current that can be applied to the IR diode is 100 mA; in our setup, the current is approximately 80 mA.

Calculating the voltage at the transistor's collector:
From the IR diode datasheet, the voltage drop across the diode is 1.4 V.

$$5 - V_{Diode} = 5 - 1.4 = 3.6[V]$$

Conclusion:

$$V_{CE} > V_{CE\ sat} = 0.3[V]$$

Therefore, the transistor is in the active region, and we can state that:

$$I_c = \beta I_B$$

For a transistor β value determined after a series of tests, we obtained

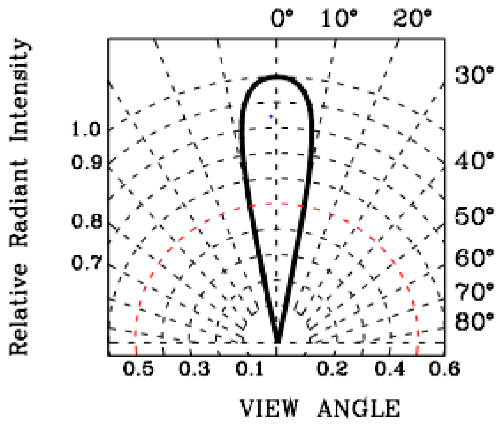
$$I_c = 78\ [mA]$$

To ensure the desired current consumption, we calculate the collector resistor as follows:

$$\frac{5 - 0.7}{78[mA]} = 55[\Omega]$$

These values ensure that the currents will perform the task in the most efficient way.

Another critical factor in the design of this unit was the shape of the transmitter. As can be seen from the IR diode's datasheet, the transmission of the infrared signal occurs with angular dispersion in space.
Such dispersion within a closed room can cause detection errors by the reception unit, potentially leading it to interpret these reflections as false targets.



Angular Dispersion of the Infrared Beam

To overcome the issue of signal dispersion, it was necessary to focus the transmitted signal.
The solution implemented to improve reception was to fit a cover made of coiled straw wrapped with insulating tape over the sensor.
This cover almost completely blocks the penetration or emission of infrared signals outside the desired direction, thereby significantly reducing beam dispersion.

4. Engineering Tasks

4.1 Task Description

- Writing the project proposal
- Gaining in-depth knowledge of the microcontroller
- Selecting appropriate hardware components and platforms for task execution
- Understanding and working with DC motors and their current drivers
- Learning to use Bluetooth for system ON/OFF control
- Learning to use infrared sensors (receivers and transmitters)
- Designing an infrared transmission unit for the required range
- Writing an algorithm for detecting and locking onto an infrared light source
- Writing an algorithm for the control and data processing unit

- Integrating the entire system
- Testing the system under different operating conditions, identifying faults and issues, developing a suitable test set, and implementing fixes
- Gaining proficiency with the Arduino IDE software
- Writing the project report
- Presenting the project

4.2 Engineering Challenges

- Writing an algorithm for accurate and continuous IR signal detection
- Integrating all system components
- Handling IR light reflections from various objects in the environment
- Addressing weak wheel-to-floor friction during turns
- Transmitting the IR signal to the required range in the project
- Wiring and connecting the system
- Operating under varying conditions depending on a portable power source (batteries)

Problem & Solution Table:

Problem	Solution
In the second track, the cart's deviation while avoiding obstacles was too sharp	Adjusted delay timing and reduced motor speed
In both tracks, the cart did not stop at the desired distance	Increased the minimum stop distance, as the high speed affected reaction time
Reception testing and blocking	Limited the receiver's field of view to 90° using a straw cover to block unwanted IR signals from other directions
Initially used AAA batteries, which discharged quickly and caused slow motor rotation	Replaced with 3 rechargeable lithium batteries, which last significantly longer
Transmission unit test	Using the oscilloscope, observed a square wave output at the required frequencies (150 Hz and 300 Hz)
Optimal duty cycle found to be 20%	—

4.3 Test Plan and Results

During the design and construction stages, each subsystem was tested individually to achieve the most efficient results for the competition.
Each designed subsystem was connected in series to the Arduino software to monitor results in real-time, process data, and perform the necessary actions accordingly.

It should be noted that two subsystems were not included in the test set:

- Drive system – excluded because it does not provide or process input data; it only executes commands from the main controller.
- Data processing unit – excluded because its role is to receive results from other subsystems and distribute commands according to competition requirements.

5. Conclusion

5.1 Appendices

- http://www.circuitbasics.com/arduino-ir-remote-receiver-tutorial/
- https://create.arduino.cc/projecthub/mohannad-rawashdeh/ir-remote-control-and-arduino-control-ac-voltage-device-353a9b?ref=similar&ref_id=26663&offset=2
- https://www.arduino.cc/reference/en/language/functions/communication/serial/available/
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- https://moodle.braude.ac.il/pluginfile.php/581819/mod_resource/content/1/IR333_A_Transmitter.pdf
- https://moodle.braude.ac.il/pluginfile.php/581820/mod_resource/content/1/tsop322_Receiver.pdf

5.2 photos

Photos of the cart and the transmitter: