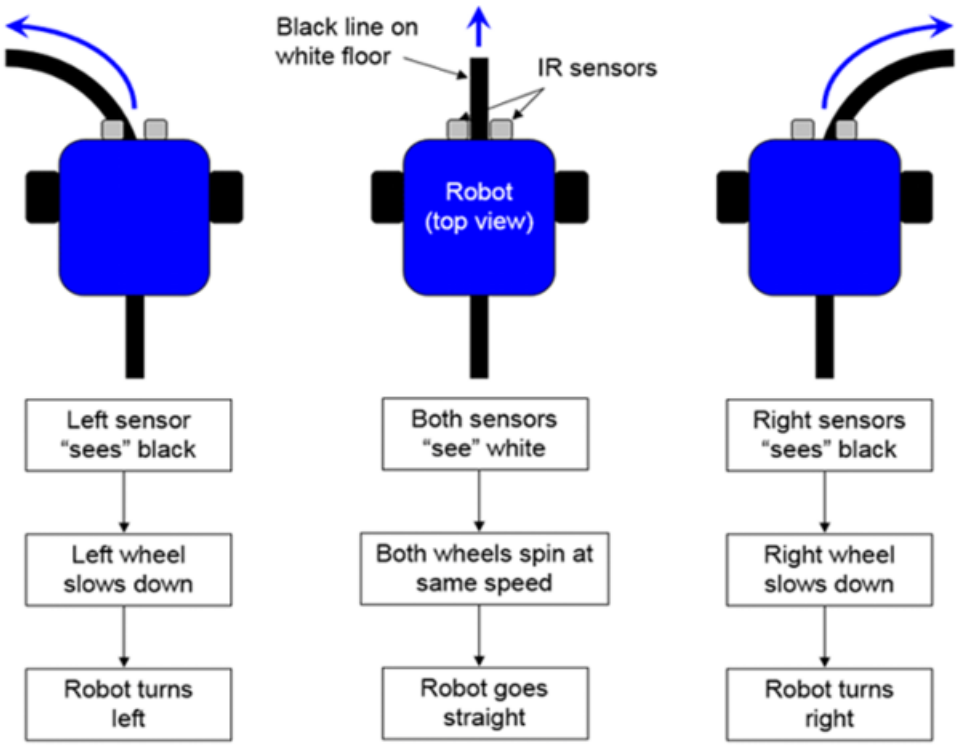
Line Following Buggy with SLAM Capability

The vehicle uses an onboard computer to convert the images and data received from the camera attached on the vehicle into 3d structures which is later processed into a map. This explains the concept of SLAM. As of now the vehicle uses a line following system for movement and actuation.



How does it move?

The robot uses a simple yet effective line-following mechanism for navigation. It is equipped with an onboard infrared (IR) sensor that continuously monitors the surface beneath it. The working principle is based on the reflective property of surfaces: when the IR sensor emits infrared light, it detects the amount of light that is reflected back. If the surface is white or reflective, the IR light bounces back and is detected by the sensor, indicating that the robot is not on the black line. In such a case, the robot recognises that it has deviated from its path and adjusts its direction accordingly. On the other hand, if the surface is black, it absorbs the infrared light, and little to no light is reflected back to the sensor. This signals the robot that it is on the correct path, prompting it to continue moving forward.

For movement, the robot uses two DC motors that are connected to the rear wheels, enabling forward and backward motion. Steering is managed by a servo motor connected to the front wheel assembly. What makes this setup unique is that the steering mechanism isn't fixed to a specific path; instead, it actively scans the area. The IR sensor is mounted on a servo that rotates it to the left, right, and forward, helping the robot determine the direction where the black line continues. Based on this input, the servo adjusts the steering to keep the robot aligned with the path.

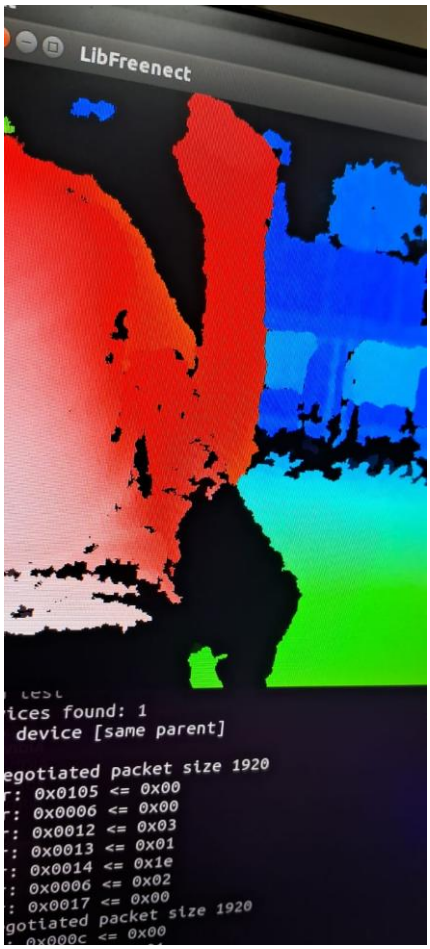
This approach not only allows the robot to follow a predetermined track, but also gives it a degree of adaptability to find the correct route even at intersections or sharp turns.

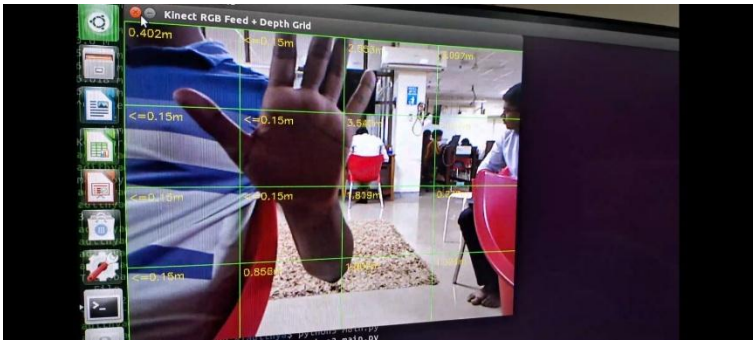
WEEK 1

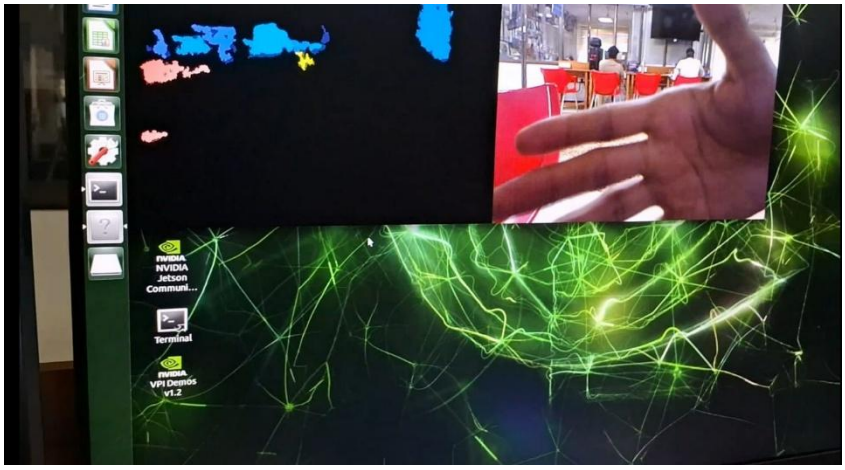
The initial phase of the project involved developing a clear understanding of the buggy's architecture and the individual components integrated into the system. The primary hardware modules identified at this stage were the Xbox Kinect V1, NVIDIA Jetson Nano, and ESP32 microcontroller. I reviewed the respective datasheets and technical documentation for each component to gain a comprehensive understanding of their specifications, capabilities, and interfacing requirements.

Following the hardware analysis, I proceeded to explore suitable software frameworks for processing data from the Kinect V1. After surveying various open-source libraries, I selected **libfreenect** due to its lightweight design and ability to stream both RGB and depth data directly to the Jetson Nano in real-time. I successfully interfaced the Kinect with the Jetson Nano using libfreenect and utilized **OpenCV** for basic image processing and depth-based distance estimation. This setup formed the foundation for subsequent vision-based tasks and concluded the first week of the project.

WEEK 1 PROGRESS







WEEK 2

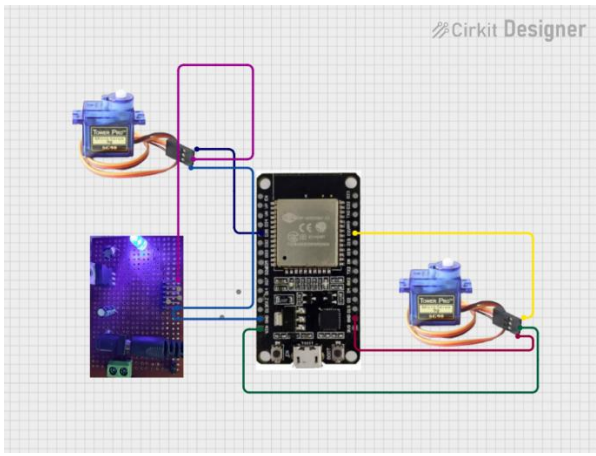
In the second week, I received the remaining components required for the system, including the ESP32 microcontroller, servo motor, and infrared (IR) sensors. I began by integrating these modules with the Jetson Nano to test compatibility and establish communication. I wrote custom firmware for the ESP32 to interface with both the servo and the IR sensor, while making necessary adjustments—such as tuning the IR sensor's sensitivity to improve detection accuracy and ensuring stable PWM control of the servo motor via the ESP32.

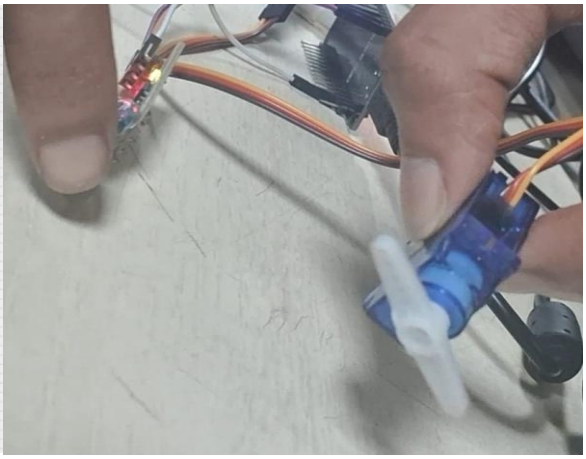
During this phase, I was also introduced to the buck converter, which played a critical role in stepping down the input voltage from 12V to 5V. This allowed me to safely power all actuators and sensors, while ensuring that only logic-level signals were connected to the ESP32's GPIO pins. The use of the buck converter also improved system stability by electrically isolating high-current components from the control logic and preventing voltage mismatches.

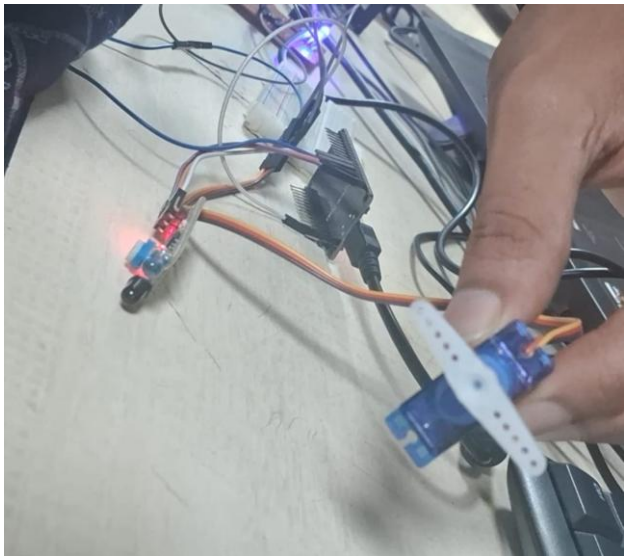
To verify the IR sensor's functionality, I conducted basic tests by placing a reflective object (e.g., a finger) in front of the module. The onboard indicator LED responded correctly, confirming successful detection. Based on the sensor signal, I programmed the ESP32 to trigger a 180-degree sweep of the servo motor to dynamically scan for a black line, providing directional correction during navigation.

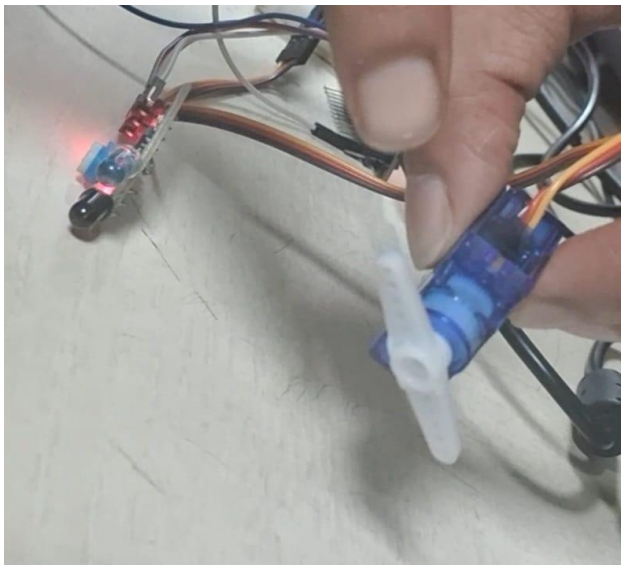
Additionally, I attempted to integrate servo control with a Pixhawk flight controller and simulate its behavior using ArduPilot software. However, this simulation was unsuccessful due to unforeseen configuration or compatibility issues, and further debugging was deferred to prioritize the working ESP32-based system. As the project evolved and system complexity increased, the servo-based scanning approach was eventually revised for greater efficiency. A more robust and responsive design was implemented using two fixed-position IR sensors for real-time line tracking, eliminating the need for mechanical movement and simplifying the overall control logic.

WEEK 2 PROGRESS









WEEK 3

In the third week, I focused on exploring **SLAM (Simultaneous Localization and Mapping)** and **3D mapping techniques** that could be implemented on the buggy. The goal was to enable the system to generate a spatial map of its environment in real time as it moved. While evaluating available solutions, I had to take into account the **hardware limitations** of the **Jetson Nano**, particularly its **limited storage**, **restricted computational power**, and **thermal stability**.

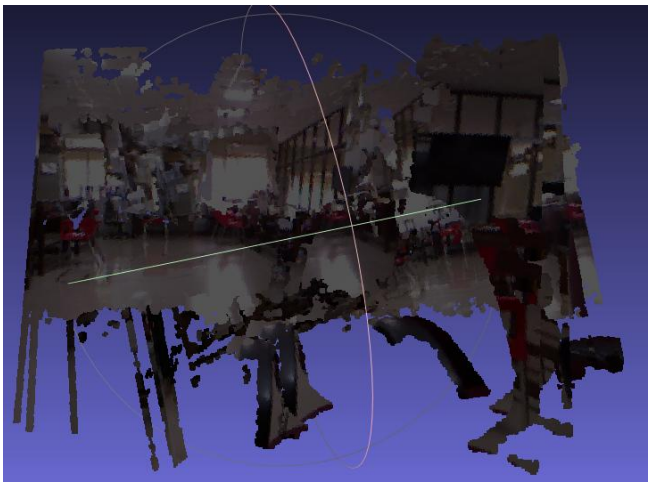
During initial experimentation, I attempted to install and run various open-source SLAM frameworks such as **RTAB-Map**, **ORB-SLAM2**, and **LDSO**. However, repeated failures and system crashes occurred primarily due to memory constraints and resource-heavy dependencies, which overwhelmed the Jetson Nano's capabilities.

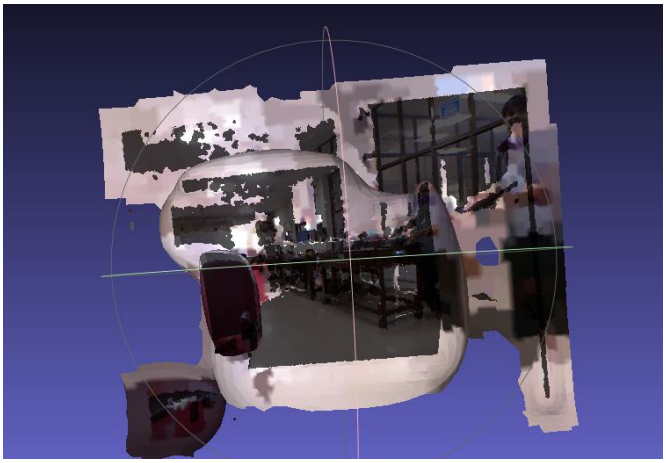
Given these challenges, I pivoted to lighter alternatives and focused on **processing the depth and RGB streams from the Kinect V1**. I explored image-based reconstruction techniques by **stitching sequential frames** and attempted to generate a composite visual representation of the environment. Additionally, I experimented with **Open3D**, a lightweight 3D data processing library, to construct **occupancy maps** and generate **point cloud reconstructions**.

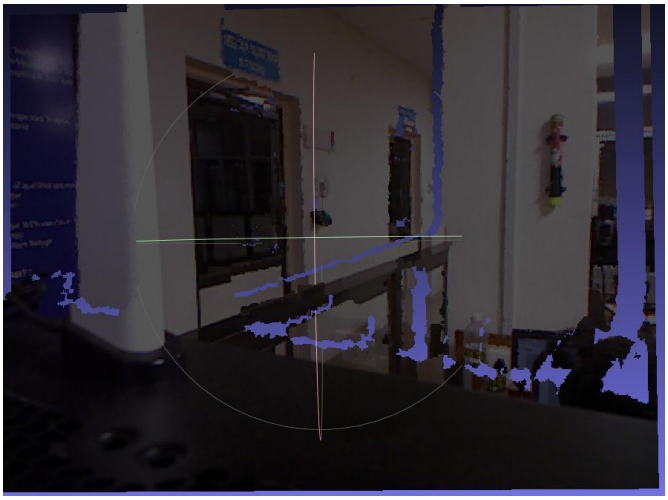
While initial attempts using a stationary Kinect only allowed me to visualize nearby objects (e.g., a hand held in front of the sensor), the resulting 3D occupancy maps confirmed successful integration and rendering. To improve spatial coverage, I began manually capturing point cloud frames at different positions and combining them to approximate a more complete spatial representation of the environment.

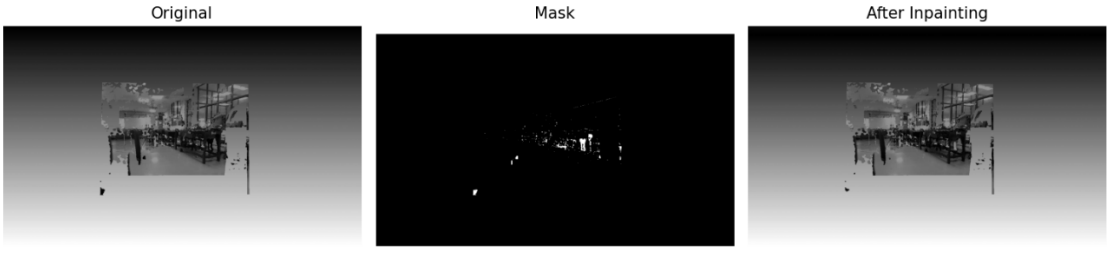
This phase provided valuable insights into the limitations of real-time mapping on low-power hardware and laid the groundwork for future optimization and hardware augmentation (e.g., potential integration of external storage or lightweight neural inference).

WEEK 3 PROGRESS









WEEK 4

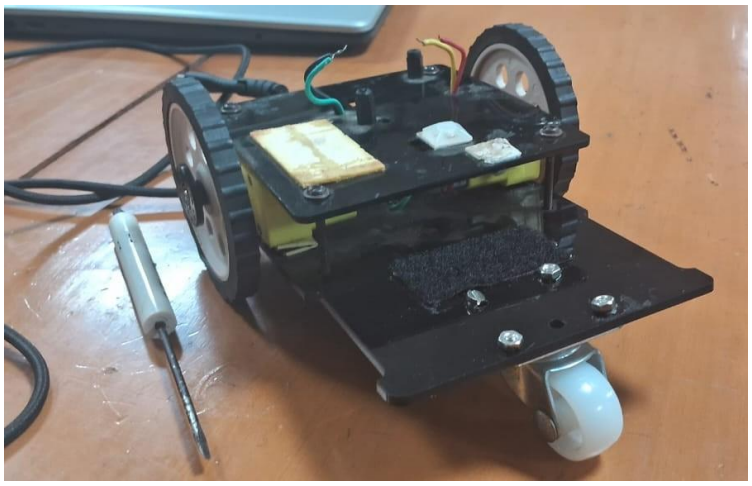
In the fourth week, I focused on **integrating the SLAM and actuation systems** developed in the earlier phases with the **physical buggy frame**. Upon receiving the chassis and **BO motors**, I mounted the motors onto the buggy and began conducting initial mobility tests on a designated test track. This phase marked the transition from modular testing to full system integration.

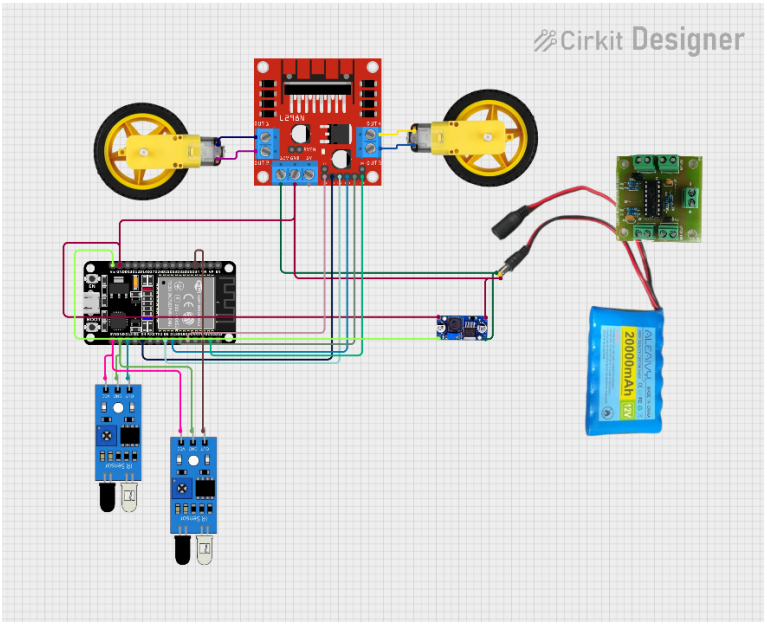
To ensure a systematic approach, I created **CAD models and mechanical layout sketches** of the buggy using **TinkerCAD**. These models helped visualize component placement and mechanical feasibility before physical assembly. Additionally, I used **CirkitDraw** software to simulate the **electrical circuit** of the buggy, enabling me to validate the wiring and power distribution logic in advance.

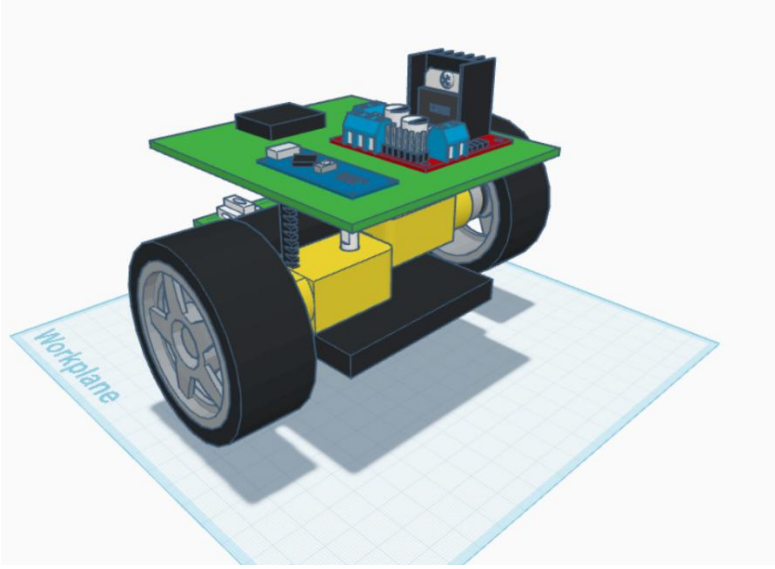
As part of the hardware integration, I studied the electrical and operational characteristics of **BO motors**, particularly their **current and voltage requirements**. This led to the careful selection and configuration of a suitable **motor driver**, specifically the **L298D full-bridge driver**. I ensured that the driver was configured to supply only the necessary current to avoid overheating or overloading the motors. I also familiarized myself with the internal working of the L298D, including its **H-bridge structure**, **PWM control support**, and **dual-channel capability** for driving two motors independently.

With all components—ESP32, motor driver, IR sensors, and power regulation modules—assembled and tested individually, I moved on to the **physical integration** phase. I designed the layout and mounting of each component on the buggy, ensuring optimal space utilization, cable management, and thermal considerations. The finalized component arrangement was documented using a **3D model**, which served as a blueprint for the physical assembly and future iterations.

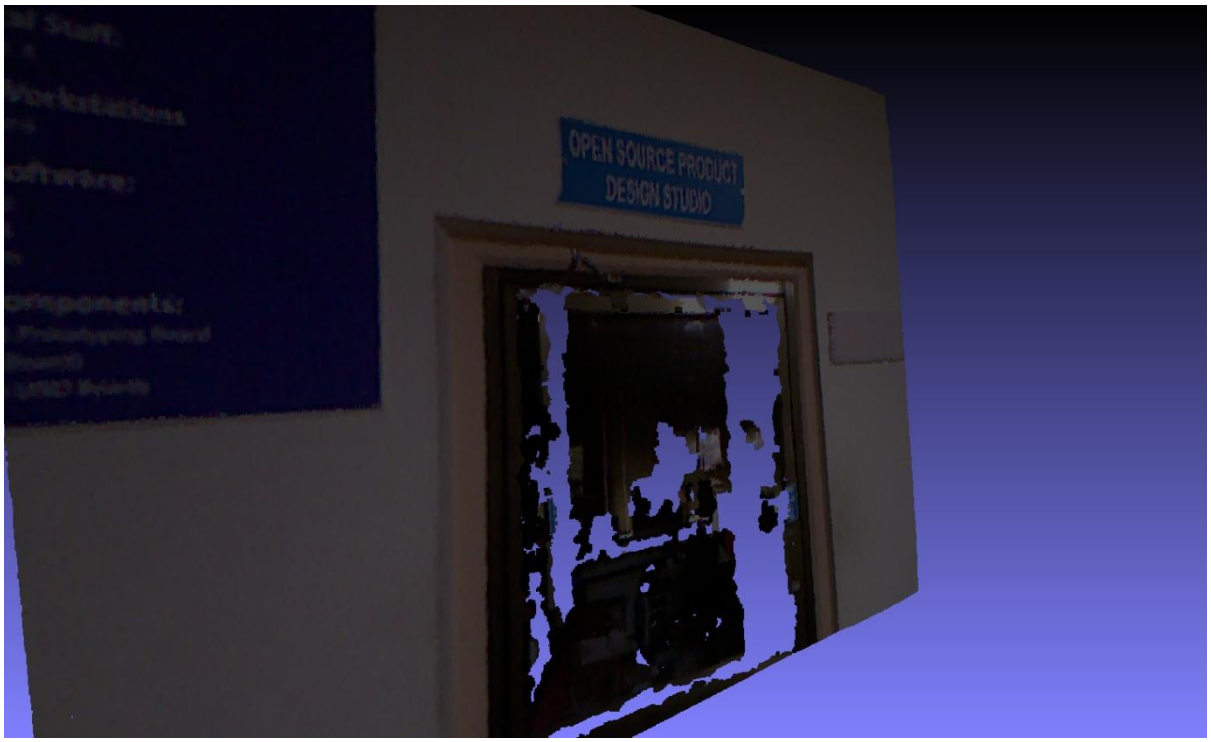
WEEK 4 PROGRESS

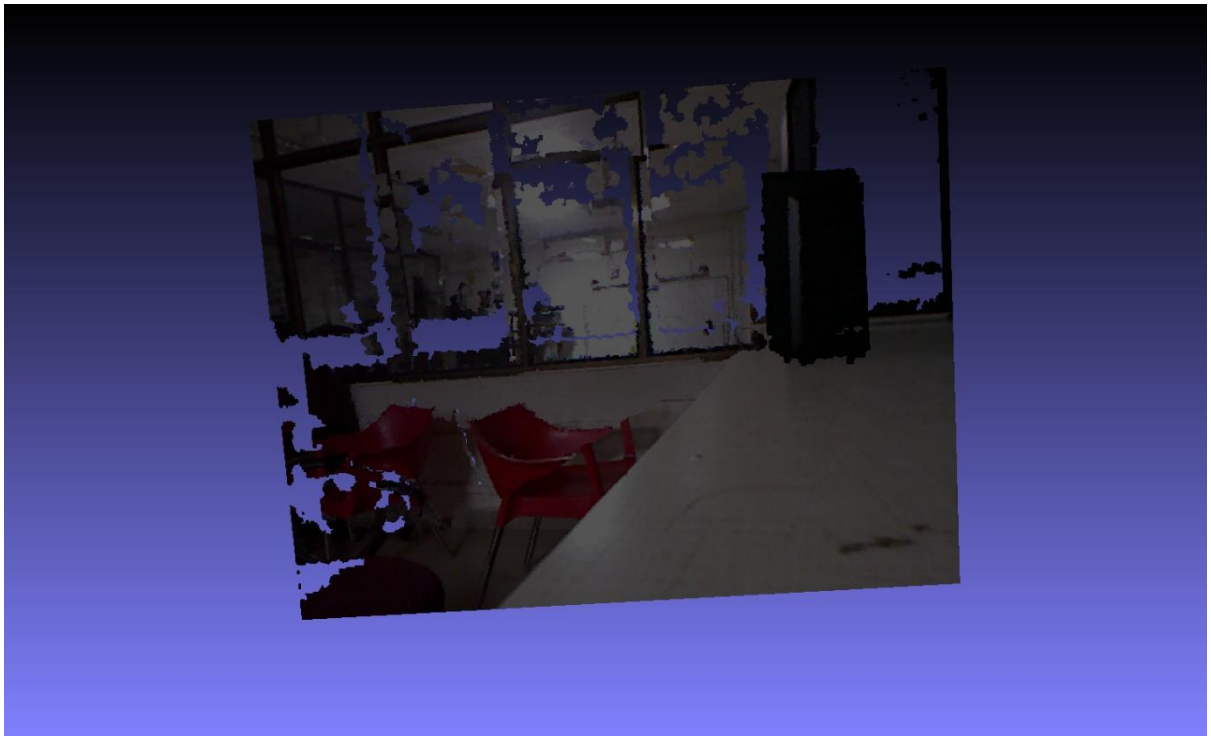


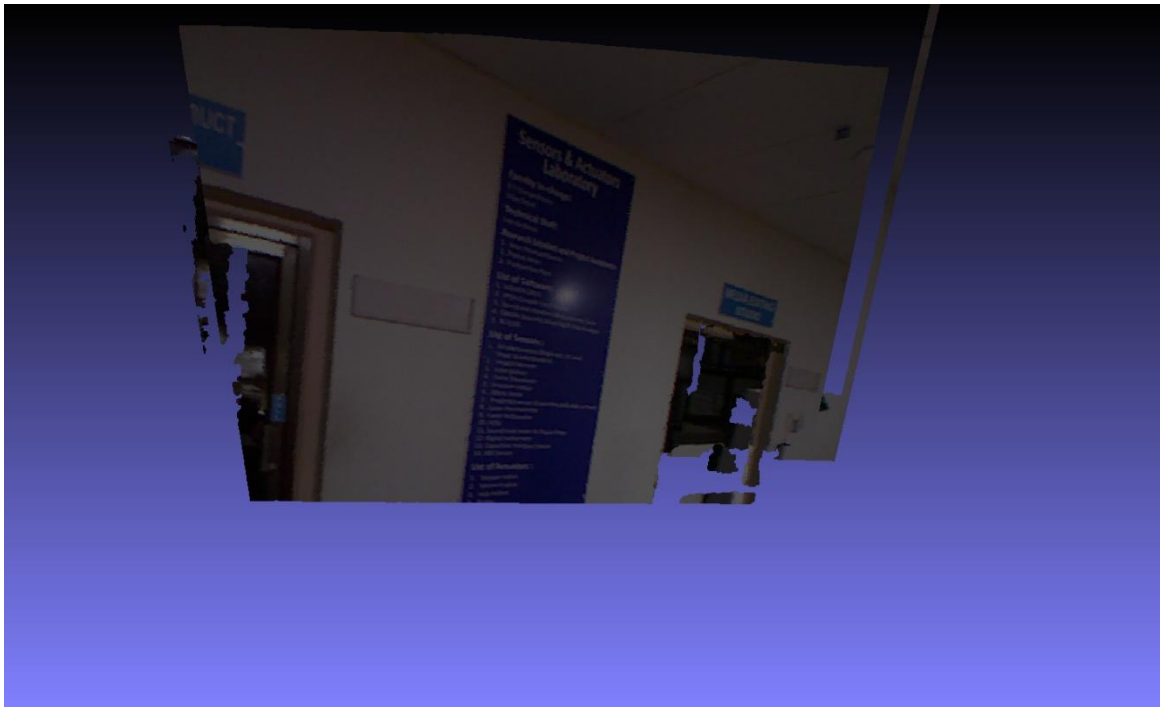


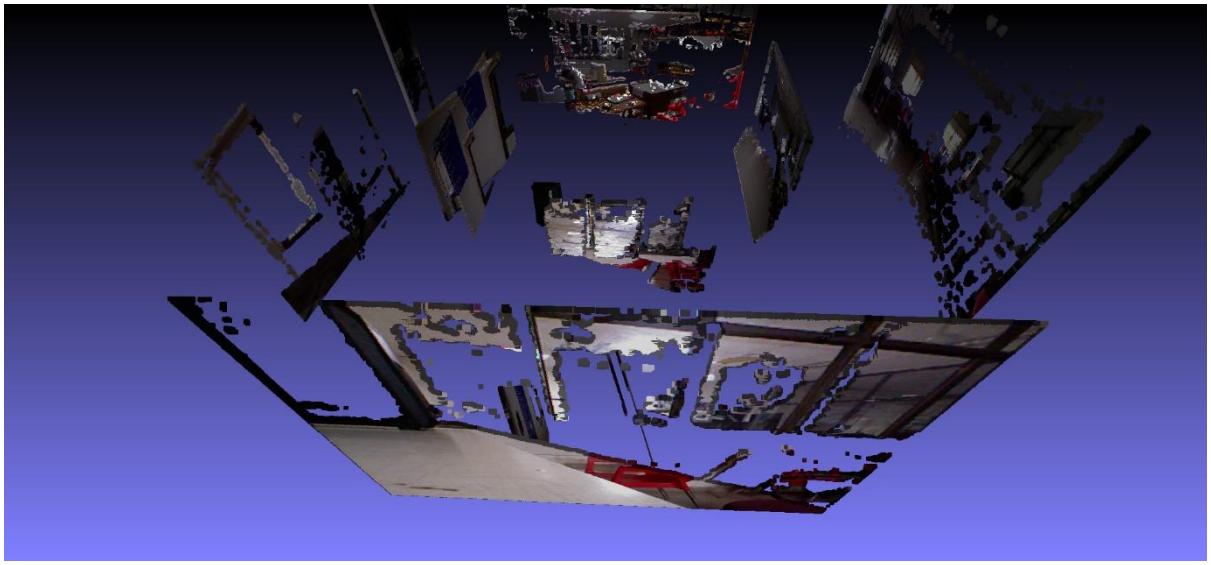


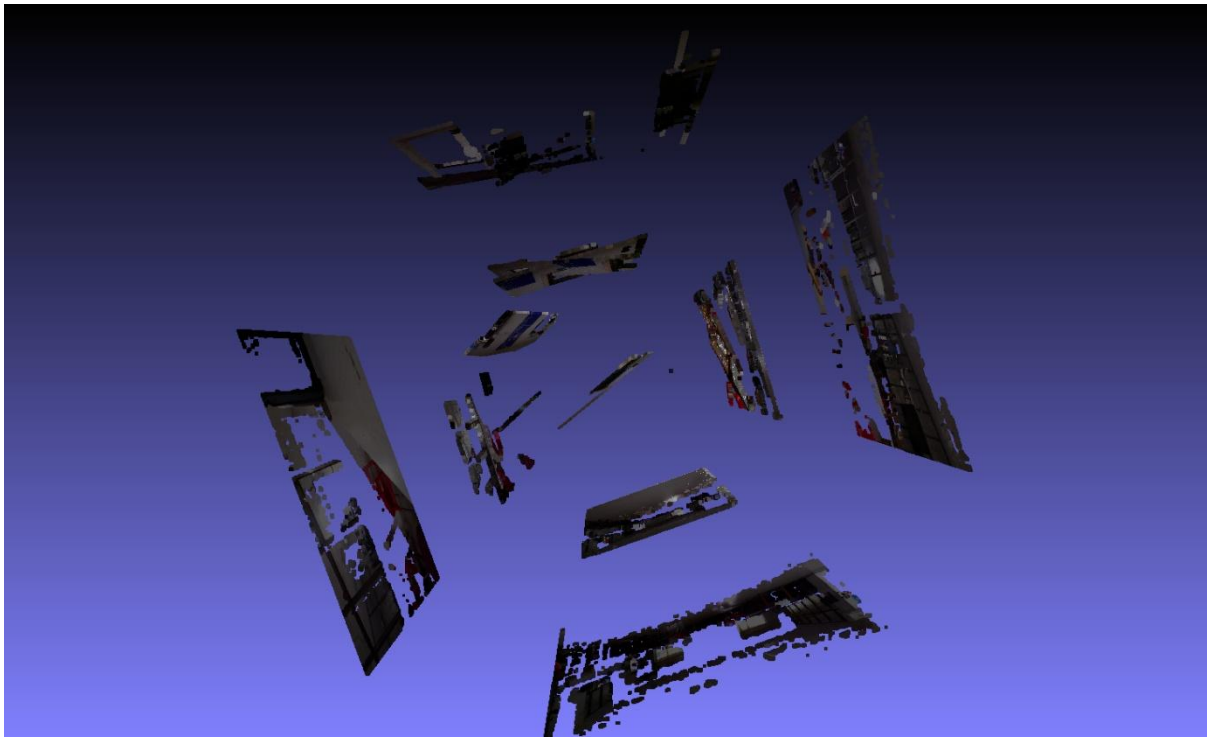
RESULT

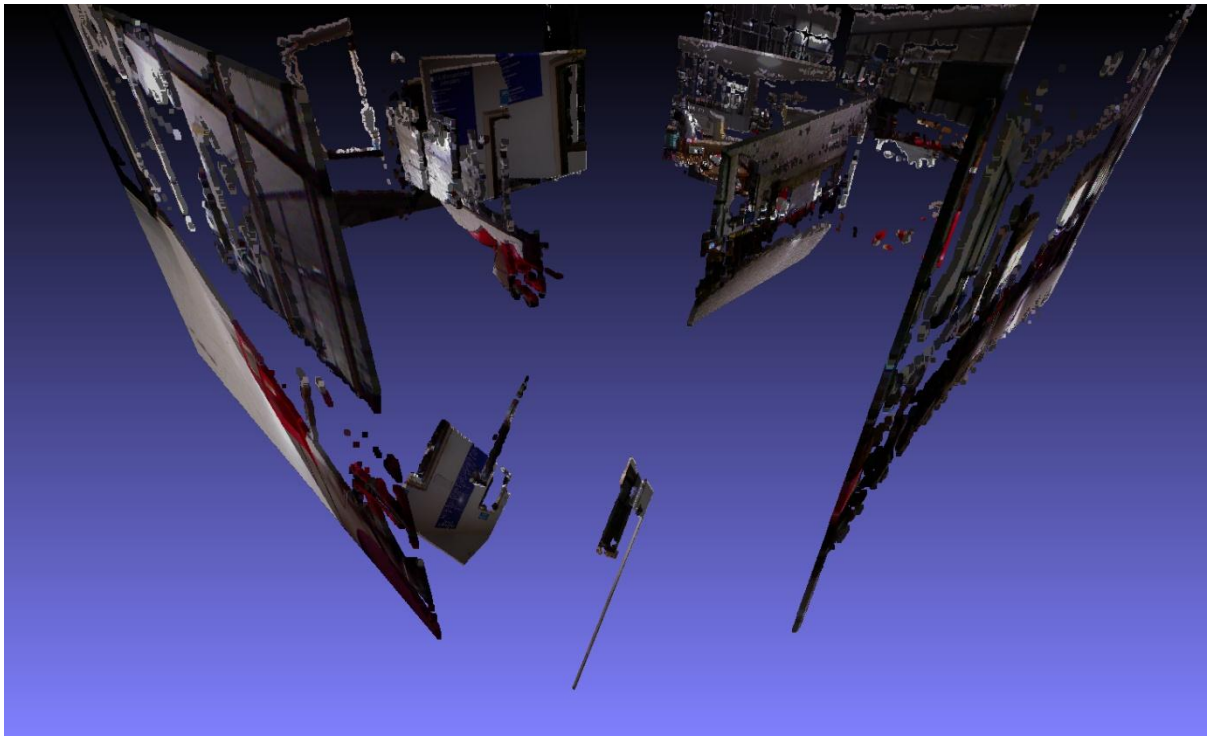


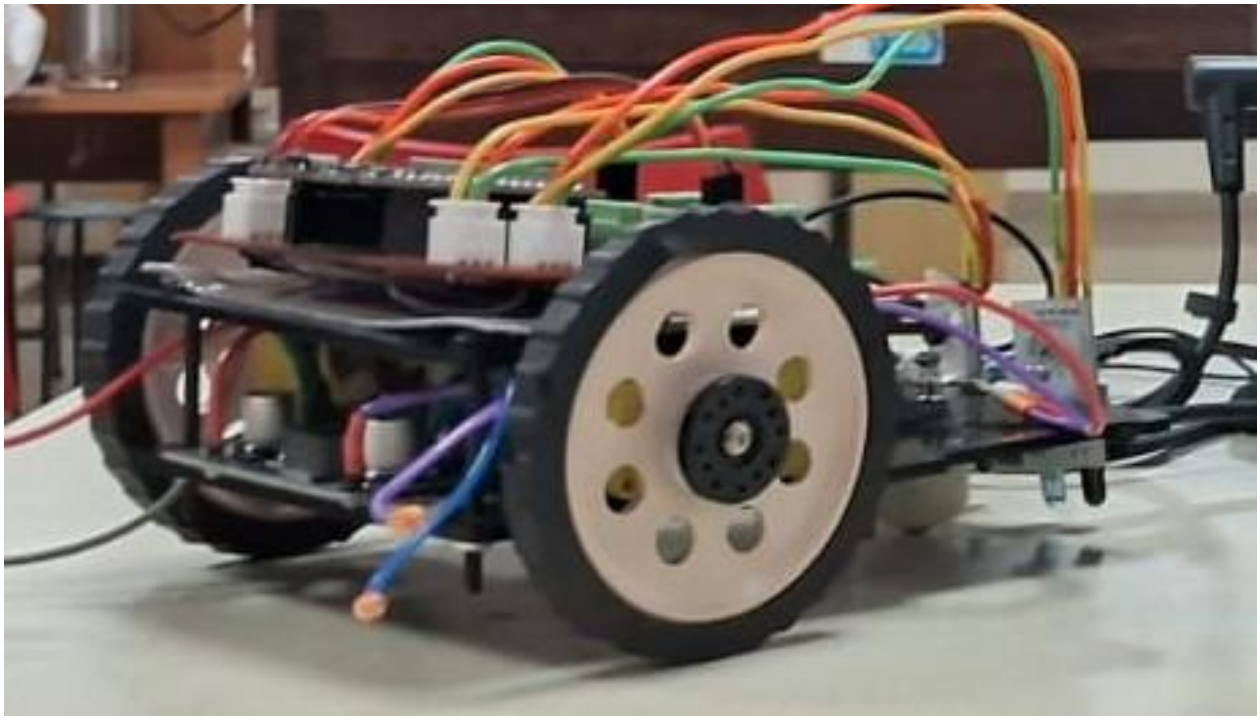


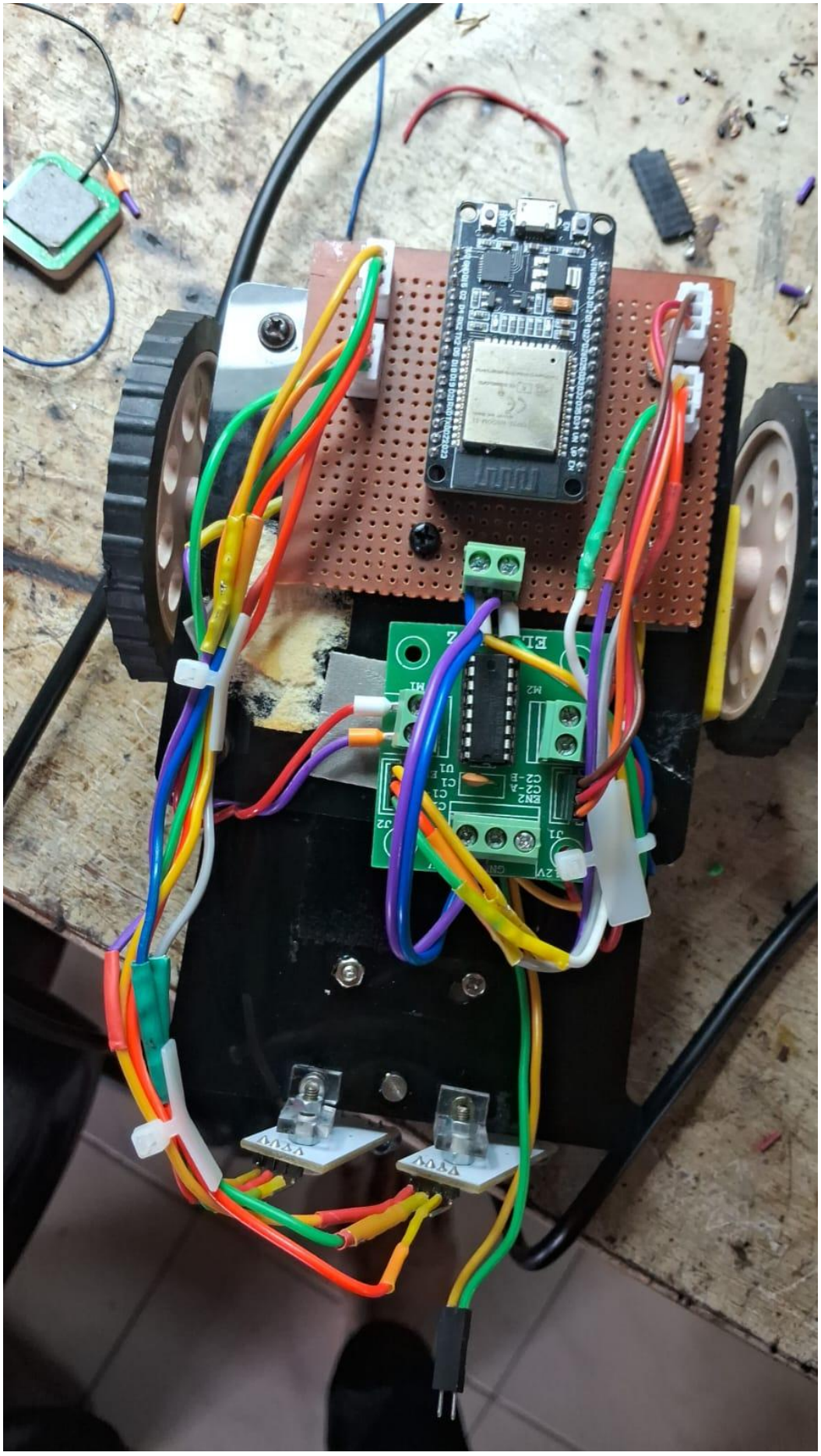


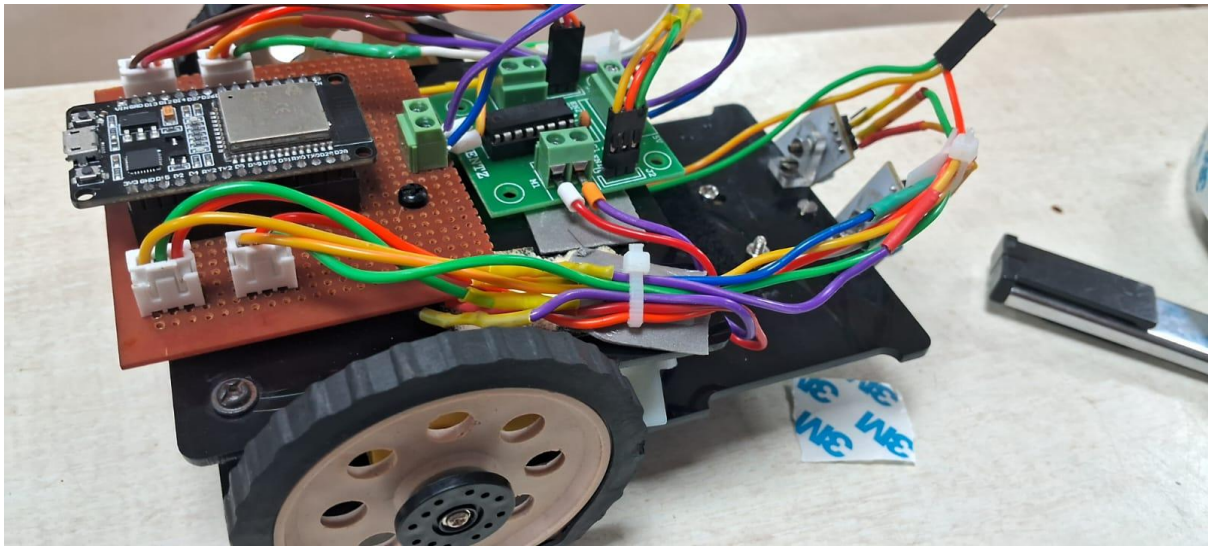


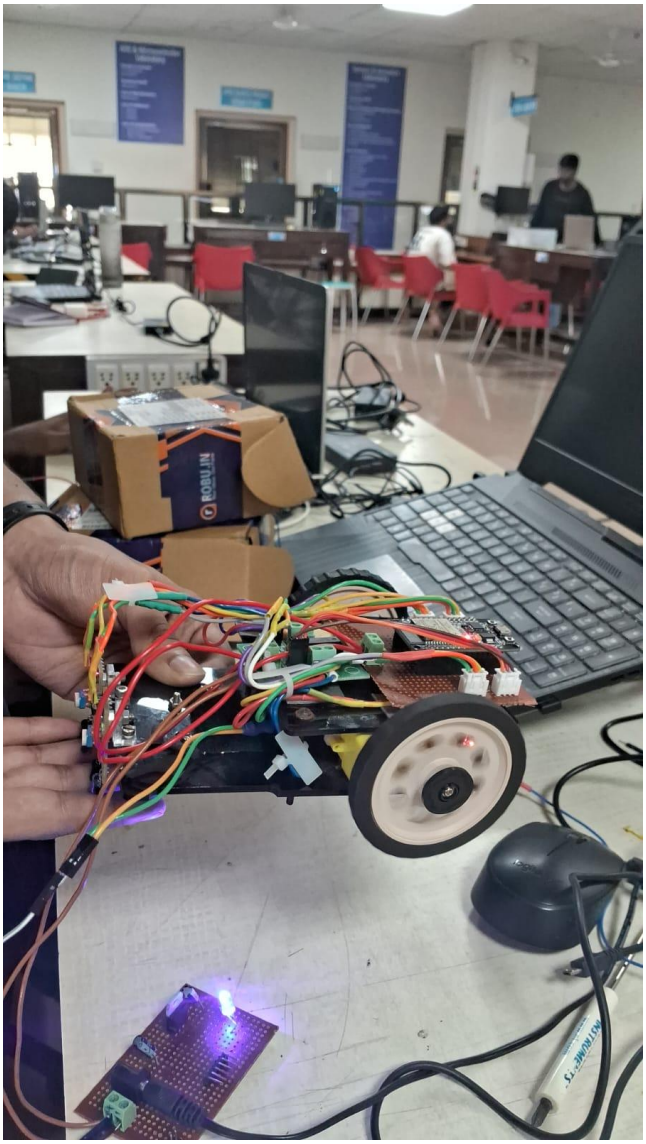












PROJECT LINKS

GITHUB

LATEST BRANCH

https://github.com/adithya1770/nitk/tree/last

BUGGY DRIVING CODES

https://github.com/adithya1770/nitk/tree/working

SOFTWARE'S USED

- ***MeshLab*** **to view point cloud files.**
- ***Python*** **to code all the components and microcontrollers.**
- ***Open3D*** **to retrieve and process the images.**
- **Ubuntu 18.04 was used as the OS on Jetson board.**
- ***Cirkit Designer*** **and *TinkerCAD* was used to design circuits and make models.**
- ***Webots*** **and *Gazebo*** **was used to simulate the vehicle.**

WORKING CODE (LINE FOLLOWER)

```
// === Pin Definitions ===
// IR Sensors
#define LEFT_SENSOR 34
#define RIGHT_SENSOR 15

// Left Motor
#define IN1 19      // Motor A Input 1
#define IN2 18      // Motor A Input 2
#define ENA 22      // Motor A Enable (use PWM if needed)

// Right Motor
#define IN3 4       // Motor B Input 1
#define IN4 21      // Motor B Input 2
#define ENB 16      // Motor B Enable (use PWM if needed)

void setup() {
 // Set motor pins as outputs
 pinMode(IN1, OUTPUT);
 pinMode(IN2, OUTPUT);
 pinMode(ENA, OUTPUT);

 pinMode(IN3, OUTPUT);
 pinMode(IN4, OUTPUT);
 pinMode(ENB, OUTPUT);
```

```
 // Set IR sensor pins as input
 pinMode(LEFT_SENSOR, INPUT);
 pinMode(RIGHT_SENSOR, INPUT);

 // Enable motors (no PWM, full speed for now)
 digitalWrite(ENA, HIGH);
 digitalWrite(ENB, HIGH);

 Serial.begin(115200);
}

void loop() {
 int leftIR = digitalRead(LEFT_SENSOR);   // LOW = black line
 int rightIR = digitalRead(RIGHT_SENSOR);

 Serial.print("Left: ");
 Serial.print(leftIR);
 Serial.print(" | Right: ");
 Serial.println(rightIR);

 // Line following logic
 if (leftIR == LOW && rightIR == LOW) {
  moveForward();
 }
 else if (leftIR == LOW && rightIR == HIGH) {
  turnLeft();
 }
 else if (leftIR == HIGH && rightIR == LOW) {
```

```
   turnRight();
  }
  else {
   stopMotors();
  }

  delay(10);
}

// === Movement Functions ===

void moveForward() {
  digitalWrite(IN1, HIGH);
  digitalWrite(IN2, LOW);
  digitalWrite(IN3, HIGH);
  digitalWrite(IN4, LOW);
}

void turnLeft() {
  digitalWrite(IN1, LOW);
  digitalWrite(IN2, LOW);
  digitalWrite(IN3, HIGH);
  digitalWrite(IN4, LOW);
}

void turnRight() {
  digitalWrite(IN1, HIGH);
  digitalWrite(IN2, LOW);
```

```
  digitalWrite(IN3, LOW);
  digitalWrite(IN4, LOW);
}

void stopMotors() {
  digitalWrite(IN1, LOW);
  digitalWrite(IN2, LOW);
  digitalWrite(IN3, LOW);
  digitalWrite(IN4, LOW);
}
```

Components Summary

JETSON NANO – On board Computer (Controller)

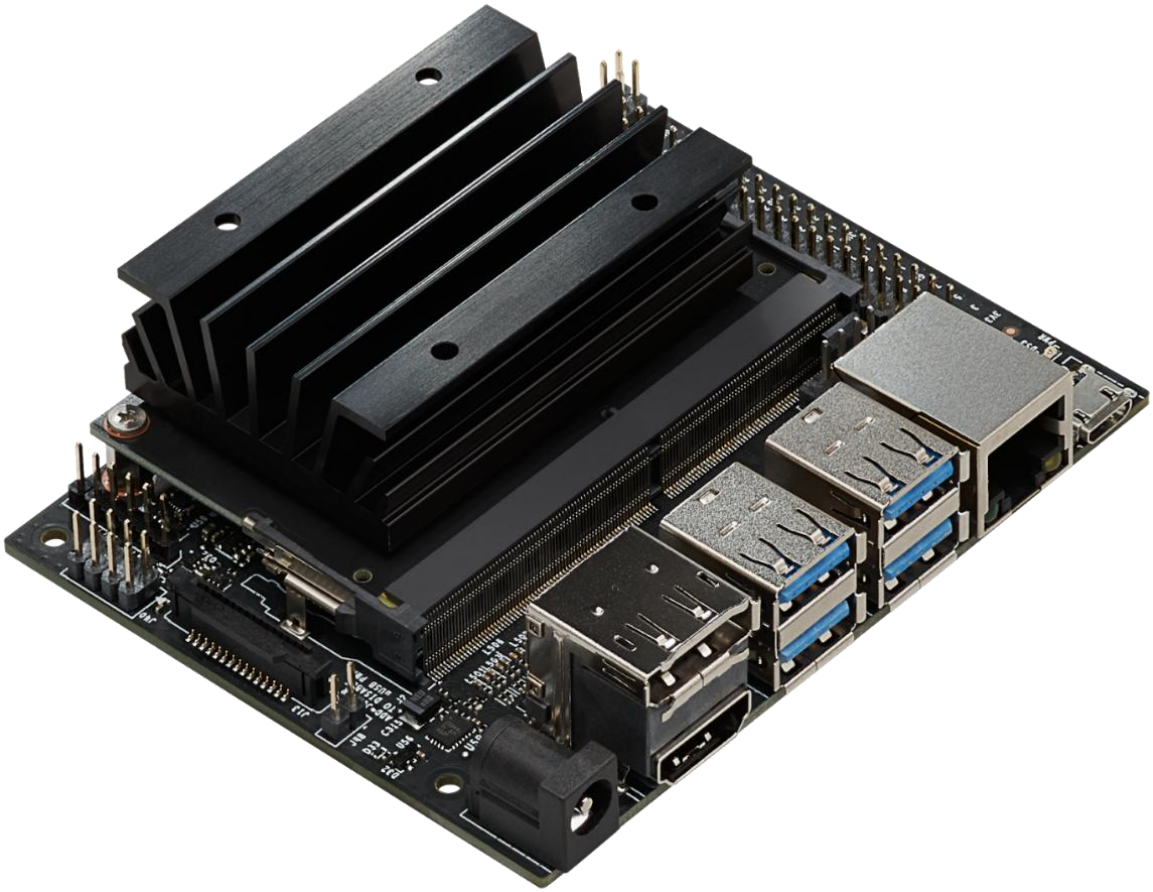
SG90 SERVO MOTOR – Actuators

IR Module – Sensing

Xbox Kinect v1 – Camera

ESP32 – Controller or acts a bridge between actuators and jetson nano.

Jetson Nano



Technical Specifications and Features

Processor:

- CPU: Quad-core ARM Cortex-A57 @ 1.43 GHz.
- GPU: 128-core NVIDIA Maxwell architecture GPU.

- Floating Point Performance: Up to 472 GFLOPS.

Memory and Storage:

- RAM: 4GB 64-bit LPDDR4, 25.6 GB/s bandwidth.
- Storage: microSD card slot for main storage.

Wireless & Connectivity (via expansion or USB):

- Ethernet: Gigabit Ethernet port.
- Wi-Fi and Bluetooth: Not onboard by default, but supported via USB dongle or M.2 module (Jetson Nano 2GB includes Wi-Fi).

Display and Camera:

- Display Output: HDMI 2.0 and DisplayPort 1.2.
- Camera Interface: MIPI CSI-2 (15-pin connector for Raspberry Pi Camera Module v2).

I/O and Expansion:

- USB: 4 × USB 3.0 ports (original model), 1 × USB 2.0 micro-B (device mode), 1 × USB 2.0 (2GB version).
- GPIO: 40-pin expansion header (Raspberry Pi compatible layout).
- Other I/O: I^2C, SPI, UART, PWM, and GPIOs.

Power Supply:

- Power Input: 5V via micro-USB or barrel jack (5V⎓4A recommended for full performance).
- Power Modes: Configurable 5W or 10W modes.

Software and Development:

- OS Support: Ubuntu-based JetPack SDK with Linux4Tegra.
- Frameworks: Support for TensorFlow, PyTorch, OpenCV, Keras, Caffe, ROS, and more.
- AI SDKs: Includes NVIDIA DeepStream, CUDA Toolkit, cuDNN, TensorRT.

References

- Jetson Nano Specifications and Datasheet
- Jetson Operating System

SG90 Servo

Technical Specifications and Features

Motor Type: SG90 is a 9g micro servo motor with analog control.
Material: Gear set made from plastic (typically nylon).

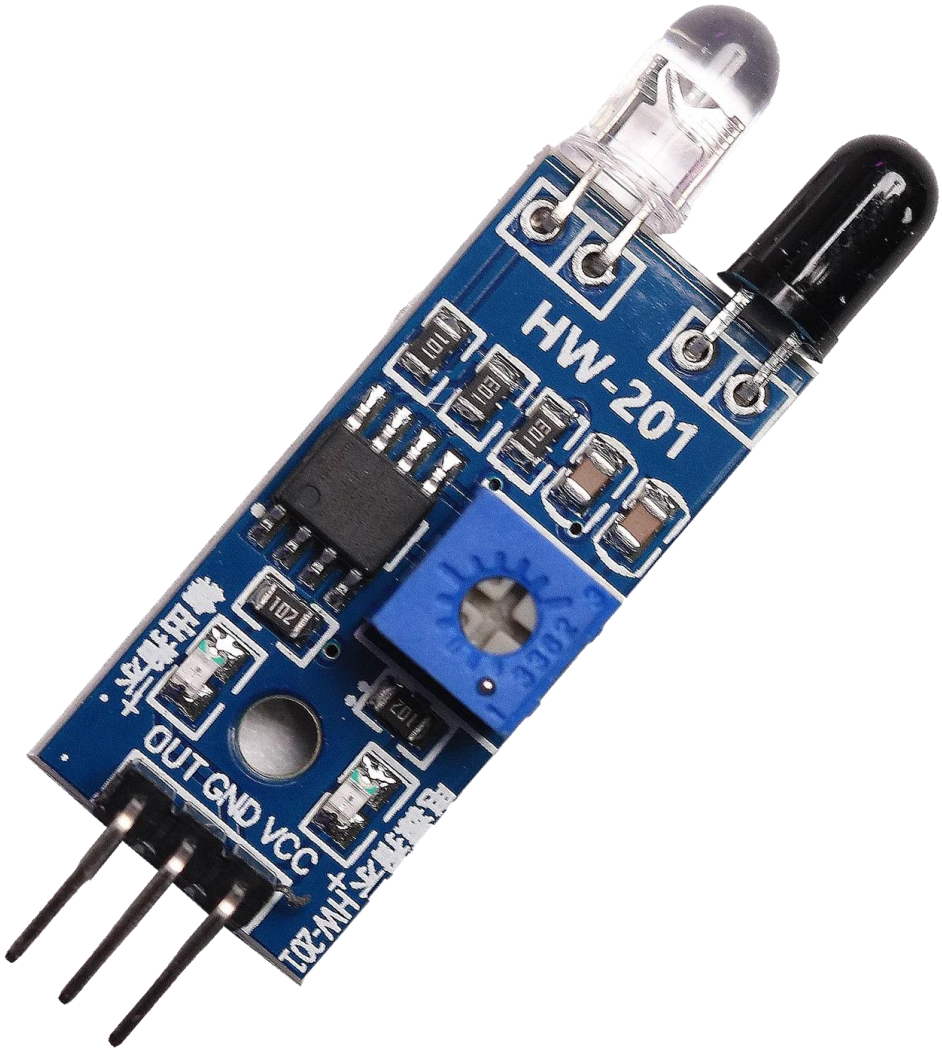
Weight and Dimensions: Weighs about 9g; dimensions approx. 22.5 × 11.8 × 31 mm.
Operating Voltage: 4.8V to 6.0V (typically 5V).
Stall Torque:

- At 4.8V: ~1.8 kg·cm
- At 6.0V: ~2.2 kg·cm
  Operating Speed:
- At 4.8V: ~0.1 s/60°
- At 6.0V: ~0.08 s/60°
  Rotation Range: ~180°, controlled via PWM signal.
  PWM Control: Standard 50Hz PWM (20 ms period), where:
- 1 ms pulse ≈ 0°
- 1.5 ms pulse ≈ 90° (neutral)
- 2 ms pulse ≈ 180°
  Connector: 3-pin female connector (Brown = GND, Red = VCC, Orange = PWM signal).

References

- SG90 Actuator Datasheet
- SG90 Working

IR Sensor (LM393)



Technical Specifications and Features

Sensor Type: Infrared reflective sensor module based on LM393 comparator.

Functionality: Detects objects or surface contrast by comparing reflected IR light intensity.

Components

- Infrared LED (Emitter)
- Photodiode or Phototransistor (Receiver)
- LM393 Comparator IC
- Trimpot (Potentiometer for sensitivity adjustment)
- Indicator LEDs (Power and Output)

Operating Voltage

- 3.3V to 5V DC (compatible with microcontrollers like Arduino, Raspberry Pi, ESP32)

Current Consumption

- Typically 10–20 mA (may vary slightly depending on module)

Detection Range

- Approximately 2 mm to 30 mm
- Most accurate for high contrast surfaces (e.g., black line on white background)

Output

- Digital Signal (High/Low logic level)
    - Output Low (0): Object detected (IR reflected)
    - Output High (1): No object detected (no IR reflection)

Interface

- Typically 3-pin or 4-pin header:

    - VCC (Power Input)
    - GND (Ground)
    - OUT (Digital Output)
    - EN (Optional Enable Pin in some variants)

Tuning

- Sensitivity adjustable via onboard trimpot
- Turning the potentiometer changes the comparator threshold, allowing fine-tuning for different distances or surface reflectivity

Applications

- Line-following robots
- Obstacle and edge detection
- Proximity sensors for automation
- Motor speed measurement (with encoder wheel)

Limitations

- Limited to short-range detection
- Susceptible to interference from strong ambient infrared sources like sunlight
- Works best in controlled lighting environments

References

- IR Sensor Datasheet
- IR Sensor Schematics

XBOX Kinect v1

Technical Specifications and Features

Sensor Type: RGB-D motion sensing input device developed by Microsoft for Xbox 360 and later used in PC applications.
Purpose: Captures depth and color data to enable body tracking, 3D scanning, and gesture recognition.

Components

- RGB Camera (Color)
- Depth Sensor (IR projector + IR camera)
- Multi-array Microphone (4 microphones)
- Tilt Motor for vertical adjustment
- Accelerometer

Operating Voltage

- Requires 12V DC input (via proprietary connector or adapter)
- USB for data connection to host (USB 2.0)

Power Consumption

- Approximately 2.5W–5W

Camera Specifications

- RGB Camera:
    - Resolution: 640×480 @ 30 FPS (default), up to 1280×1024 via unofficial mods
    - Field of View: ~57° horizontal, ~43° vertical
- Depth Camera:
    - Resolution: 320×240 @ 30 FPS
    - Depth Range: ~0.8 m to 4.0 m
    - Technology: Structured light using IR dot projector

Microphone Array

- 4 microphones with beamforming and ambient noise suppression
- Enables voice commands and sound localization

Motorized Tilt

- Automatic tilt adjustment of up to ±27°
- Controlled via software commands over USB

Interface

- Proprietary connector (Xbox 360) or USB adapter for PC use

- USB 2.0 for data
- Separate power connection (12V)

Compatibility

- Xbox 360 (native)
- PC (with Kinect for Windows SDK or OpenNI/NiTE)
- Compatible with Windows, Linux (via OpenNI/libfreenect), and ROS

Software & SDK

- Microsoft Kinect SDK (Windows)
- OpenNI & NITE (open-source alternative)
- OpenCV, PCL, and Open3D support for point cloud and image processing

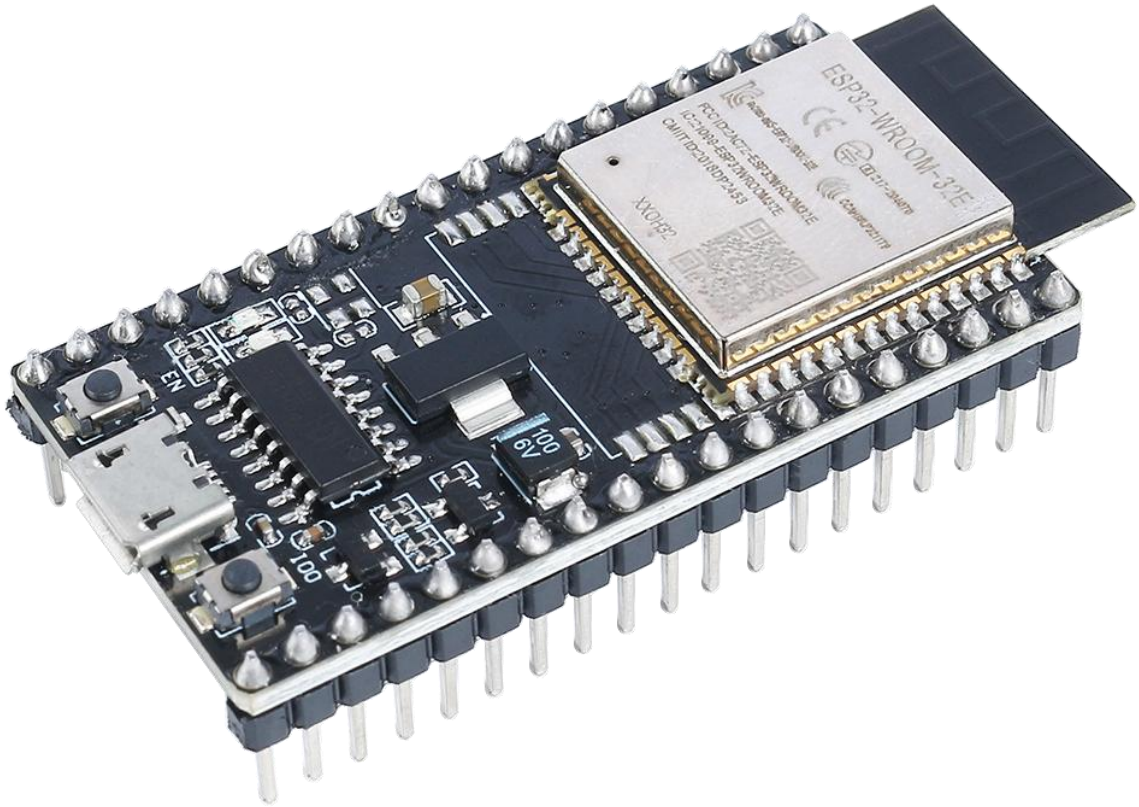
Applications

- Gesture and body tracking
- 3D scanning and point cloud generation
- Robotics and SLAM
- Voice recognition and control
- AR/VR prototyping

References

- Develop with Xbox Kinect v1
- What is Kinect?

ESP32



Technical Specifications and Features

Microcontroller: ESP32 — a low-power system-on-chip (SoC) microcontroller with integrated Wi-Fi and Bluetooth, developed by

Espressif Systems. It is widely used in IoT, robotics, and embedded systems projects.

Processor

- Dual-core Xtensa® 32-bit LX6 microprocessor (can also be configured as single-core)
- Clock Speed: up to 240 MHz
- Performance: up to 600 DMIPS
- Ultra-low-power co-processor for sensor monitoring during sleep

Memory

- SRAM: 520 KB
- ROM: 448 KB
- External Flash Support: Up to 16 MB (typically 4MB in Dev Boards)

Connectivity

- Wi-Fi: IEEE 802.11 b/g/n
- Bluetooth: v4.2 BR/EDR and BLE
- Ethernet MAC Interface
- SPI, I^2C, I^2S, UART, CAN

GPIO

- Total GPIO Pins: 34
- Most pins support PWM, ADC, DAC, SPI, I^2C, UART
- 12-bit SAR ADC (up to 18 channels)
- 2 × 8-bit DAC

- Capacitive Touch: 10 inputs
- Hall Sensor and Temperature Sensor built-in

Timers and PWM

- 4 × 64-bit Timers
- 2 × 32-bit Timers
- PWM for up to 16 channels (LEDC)

Power Supply

- Operating Voltage: 2.2 V to 3.6 V (typically 3.3V)
- Deep Sleep Current: <5 µA
- Power Modes: Active, Modem Sleep, Light Sleep, Deep Sleep, Hibernation

Storage

- SPI Flash (external): 4 MB to 16 MB (depending on board)
- Optional microSD card support via SPI

Security

- Hardware acceleration for encryption (AES, SHA-2, RSA, ECC, etc.)
- Secure boot and Flash encryption
- Random Number Generator

Development and Programming

- Programming Interfaces: USB-UART, JTAG
- Programming Languages: C/C++ (Arduino IDE, ESP-IDF), MicroPython, Lua

- Tools & SDKs:
    - Arduino Core for ESP32
    - Espressif IDF (official SDK)
    - PlatformIO

Dimensions (Common Dev Boards)

- ESP32 DevKit v1: ~51mm × 25mm
- NodeMCU-32S: ~48mm × 25mm

Applications

- IoT Devices and Home Automation
- Wireless Sensor Networks
- Wearables
- Robotics and Drones
- Smart Agriculture
- Voice Assistants (ESP32-LyraT)

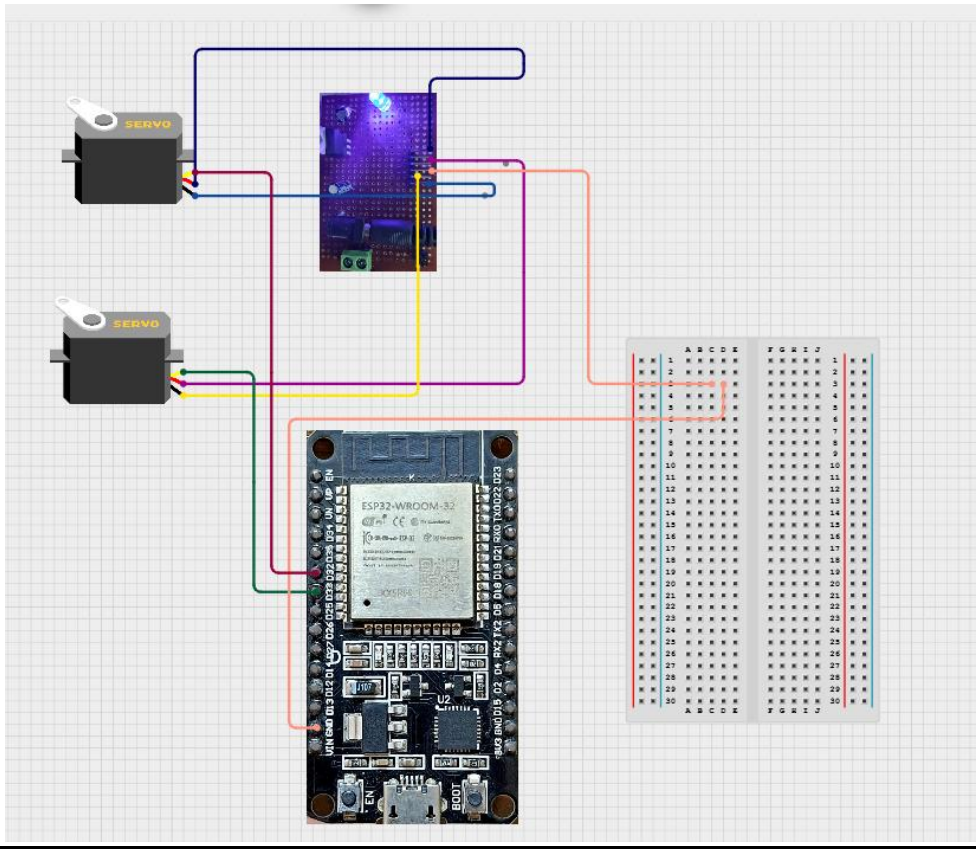
Limitations

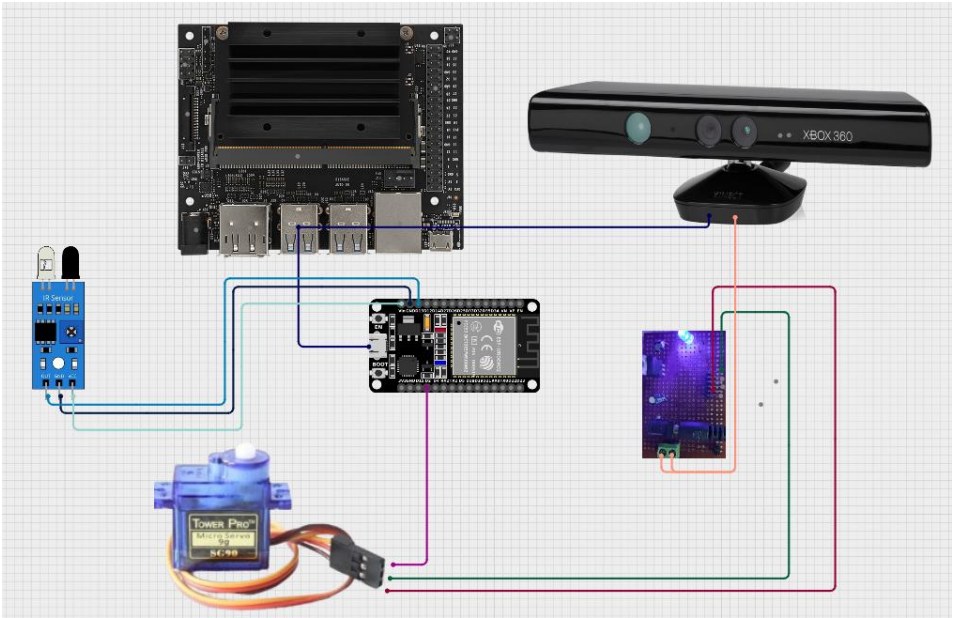
- 3.3V logic (not 5V tolerant)
- Some GPIOs have specific boot functions — care needed during design
- High-frequency operations may require attention to power and grounding

References

- Espressif Official Datasheets and Technical Reference Manual
- ESP32 DevKit v1 Schematic

CONNECTION DIAGRAM





This is the connection laid between the *ESP32* two servos (used one instead of two in the project), the servos are powered through a buck convertor and a common ground is established between the buck convertor and *ESP32* microcontroller. The buck convertor is used to convert 12v to 5v.

The above diagram shows the entire connection between the *Jetson* board and the actuation system which consists of the IR sensor, *SG90* Servo. The IR senses and control the movement of the actuator while the *Kinect* effectively maps the space.