I. Appendices (Software)

a) Arduino IDE

The development and deployment of the control program for the Arduino board were carried out using the Arduino Integrated Development Environment (IDE). Arduino IDE is an open-source platform that supports multiple operating systems, including Windows, MacOS, and Ubuntu. It provides a user-friendly interface for writing code, compiling, and uploading programs directly to Arduino microcontrollers.

The programming within Arduino IDE is based on the **C++ language**, but with simplified syntax and a collection of predefined functions and libraries that facilitate rapid development. In addition to the default libraries, users can also install and integrate third-party libraries to meet the specific requirements of their projects. This flexibility allows developers to extend the functionality of the system efficiently.

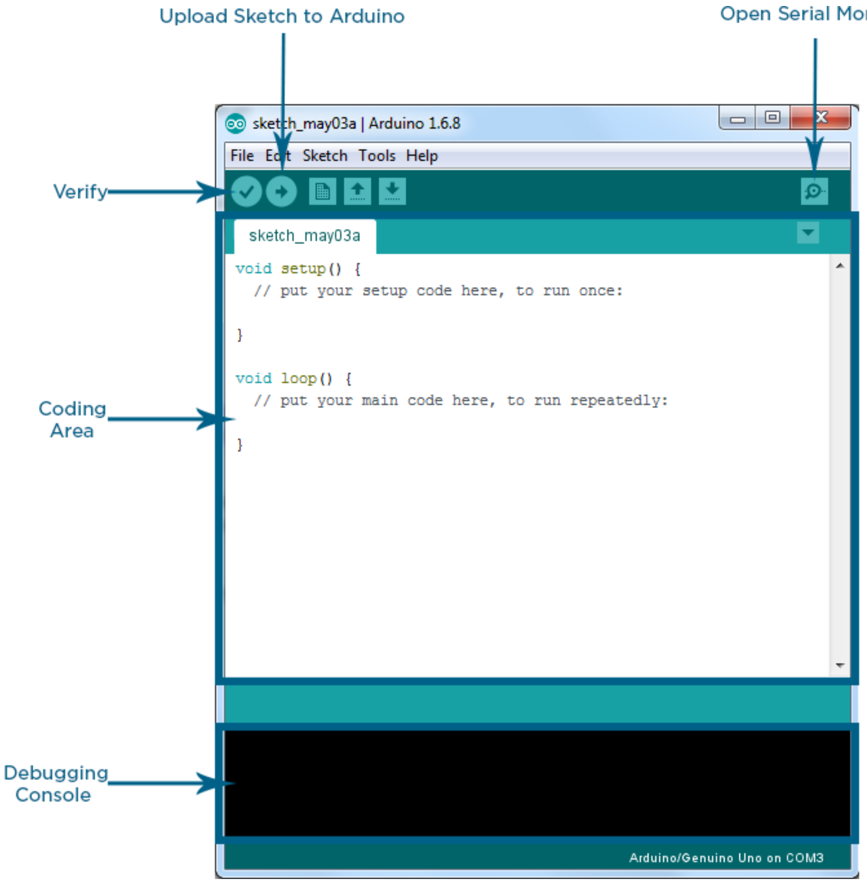

*Figure **Error! No text of specified style in document.**-1 Arduino IDE*

- **Verify**: Used to check and validate the code for errors before uploading it to the Arduino controller.
- **Upload Sketch to Arduino**: Uploads the program (sketch) to the Arduino controller via a USB port connection.
- **Open Serial Monitor**: Provides an interface window for input, reading, and displaying data exchanged between the computer and the Arduino controller.

- **Coding Area**: The workspace where users write and edit code within the Arduino IDE.
- **Output Pane**: The panel that displays information during the **Verify** or **Upload** process, including error messages in the code.

b) ROS (Robotic Operating System)

Robot Operating System (ROS) can be compared to a flexible framework that simplifies the process of developing robotic applications. It is composed of a wide collection of **tools,** libraries, and packages designed to facilitate the creation of complex robots across various robotic platforms. Developing software for robots is inherently challenging, since what is programmed into the robot may not always match what the robot encounters in the real environment. These variations depend heavily on the operating environment, and it is clear that no single individual, laboratory, or institution could realistically achieve comprehensive solutions on their own. As a result, ROS was created to support and encourag**e collaborative** development within the robotics software community. For instance, in one laboratory, specialists might focus on indoor environment mapping, contributing expertise in building maps. Another group could specialize in using those maps for navigation, while yet another might discover effective methods for object recognition in real-world scenarios. ROS is therefore specifically designed to enable these groups to collaborate and integrate their contributions, creating an ecosystem where progress in different domains can be shared and reused, ultimately accelerating robotics research and innovation.

*Figure **Error! No text of specified style in document.**-2 Robotic Operating System ROS*

c) Ubuntu Operating System

Ubuntu is an open-source operating system designed to run on computers of varying performance levels, from low-end to high-performance machines. It is built on the foundation of Linux, which is itself an operating system capable of running computers much like Windows. What makes Linux stand out from other operating systems is its **open-source nature**, which allows users to freely download, modify, and enhance its source code, and even redistribute or sell customized versions as their own products. However, Linux is primarily operated through a Command Line Interface (CLI), which can be challenging for general users due to its lack of a graphical interface. To address this limitation, Ubuntu was developed using Linux code, enhanced with a Graphical User Interface (GUI)**.** This addition makes it significantly more user-friendly, enabling easier access to applications and tools while maintaining the flexibility and robustness of Linux.

*Figure **Error! No text of specified style in document.**-3 Ubuntu Logo*

d) Solidwork and Fusion 360 Software

When making a decision to select a prototype design, it is essential to determine whether it is feasible to implement and whether it can properly integrate with electronic systems. Therefore, it is necessary to draft a conceptual model first before proceeding with the actual construction of the robot. To achieve this, software such as SolidWorks **and** Fusion 360 is employed for creating three-dimensional (3D) designs.

Both SolidWorks and Fusion 360 are powerful tools widely used in the field of engineering design. These programs fall under the categories of Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE**)**, running primarily on Microsoft Windows. They allow engineers to design in 2D, 3D, and assembly modes, along with other advanced features. In practice, these applications are highly popular among engineers because they simplify the process of designing complex projects and prototypes while ensuring precision and efficiency.

*Figure **Error! No text of specified style in document.**-4 Solidwork and Fusion 360 Software*

e) Kicad Software

KiCad is an open-source software suite used for designing electronic schematics and printed circuit boards (PCBs). It provides tools for schematic capture, PCB layout, footprint assignment, and 3D visualization of electronic boards. KiCad supports multi-layer PCB designs, includes a wide library of electronic components, and allows users to create custom symbols and footprints. Because it is open-source, it is free to use and widely adopted by students, hobbyists, and professionals for developing prototypes and production-ready electronic hardware.

*Figure **Error! No text of specified style in document.**-5 Kicad Software*

II. Appendices (Hardware)

a. Nvidia Jetson Nano Xavier Nx Development Kit

In this project, we employed the NVIDIA Jetson Xavier NX Development Kit as the microprocessor, which runs on the Ubuntu 18.04 LTS operating system and requires the installation of ROS Melodic packages**.** The Jetson Xavier NX is equipped with a 6-core NVIDIA Carmel ARM® v8.2 64-bit CPU**,** featuring 6 MB of L2 cache and 4 MB of L3 cache. It includes 8 GB of RAM and a powerful 384-core NVIDIA Volta™ GPU with 48 Tensor Cores**,** making it highly suitable for real-time computation, robotics applications, and AI-based processing.

*Figure **Error! No text of specified style in document.**-6 Nvidia Jetson Nano Xavier Nx Development Kit*

Function	Name	Pin no.	Pin no.	Name	Function
DC power	3.3 V	**1**	**2**	5 V	DC power
I2C (SDA)	GPIO **2**	**3**	**4**	5 V	DC power
I2C (SCL)	GPIO **3**	**5**	**6**	GND	
GPCLK0	GPIO **4**	**7**	**8**	GPIO **14**	UART (TXD0)
	GND	**9**	**10**	GPIO **15**	UART (RXD0)
	GPIO **17**	**11**	**12**	GPIO **18**	PCM CLK (I2S)
	GPIO **27**	**13**	**14**	GND	
	GPIO **22**	**15**	**16**	GPIO **23**	
DC power	3.3 V	**17**	**18**	GPIO **24**	
SPI (MOSI)	GPIO **10**	**19**	**20**	GND	
SPI (MISO)	GPIO **9**	**21**	**22**	GPIO **25**	
SPI (CLK)	GPIO **11**	**23**	**24**	GPIO **8**	SPI (CE0)
	GND	**25**	**26**	GPIO **7**	SPI (CE1)
I2C EEPROM	**GPIO 0**	**27**	**28**	GPIO **1**	I2C EEPROM
	GPIO **5**	**29**	**30**	GND	
	GPIO **6**	**31**	**32**	GPIO **12**	PWM0
PWM1	GPIO **13**	**33**	**34**	GND	
PCM FS (I2S)	GPIO **19**	**35**	**36**	GPIO **16**	
	GPIO **26**	**37**	**38**	GPIO **20**	PCM DIN (I2S)
	GND	**39**	**40**	GPIO **21**	PCM Dout (I2S)

*Figure **Error! No text of specified style in document.**-7 Jestson Nano Xavier Nx Development Kit GPIO Guide*

Specifications

- Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz
- 8GB LPDDR4-3200 SDRAM (depending on model)
- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
- Gigabit Ethernet
- 2 USB 3.0 ports; 2 USB 2.0 ports.
- Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards)
- 2 × micro-HDMI® ports (up to 4kp60 supported)
- 2-lane MIPI DSI display port
- 2-lane MIPI CSI camera port
- 4-pole stereo audio and composite video port
- H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)
- OpenGL ES 3.1, Vulkan 1.0
- Micro-SD card slot for loading operating system and data storage
- 5V DC via USB-C connector (minimum 3A*)
- 5V DC via GPIO header (minimum 3A*)
- Power over Ethernet (PoE) enabled (requires separate PoE HAT)
- Operating temperature: 0 – 50 degrees C ambient

b. Microcontroller Teensy 4.1

- **Overview**

The Teensy 4.1 is a powerful microcontroller board developed by PJRC, designed for high-performance embedded systems, robotics, and real-time applications. It is based on the NXP i.MX RT1062 ARM Cortex-M7 processor, which operates at a clock speed of **600** MHz, making it one of the fastest microcontrollers available in its class. The Teensy 4.1 stands out due to its real-time performance**,** enabled by the high-speed ARM Cortex-M7 core and floating-point unit (FPU)**.** This allows for precise mathematical operations required in robotics, such as sensor fusion, odometry calculation, and control algorithms (e.g., PID control).

The microcontroller also integrates DMA (Direct Memory Access) support, enabling efficient high-speed data transfer between peripherals and memory without burdening the CPU. This feature is essential in robotics applications involving Lidar, encoders, and IMU sensors. The Teensy 4.1 was chosen for this project because it can interface directly with encoders, motor drivers, and sensors**,** while maintaining smooth communication with ROS via **rosserial**. Its high processing speed and abundant I/O make it ideal for implementing real-time odometry, PID control, and sensor data acquisition in the autonomous delivery robot.

*Figure **Error! No text of specified style in document.**-8 Teensy 4.1 Microcontroller*

c. ARM Core Benefits

The Teensy 4.1 is equipped with a powerful 32-bit ARM Cortex-M7 core**,** which performs significantly better than traditional 8-bit microcontrollers.

- **32-bit Core**: Capable of executing operations in 4-byte (32-bit) instructions, providing higher precision and speed compared to 8-bit controllers.
- **CPU Clock**: Operates at up to **600 MHz**, making it one of the fastest microcontroller boards in its class.
- **Memory**: 1024 KB (1 MB) RAM, (8MB) Flash Memory, Optional expansion with external QSPI flash and PSRAM
- **DMA Controller**: Supports **Direct Memory Access (DMA)**, which relieves the CPU from memory-intensive tasks by handling data transfers between peripherals and memory efficiently.

- **Summary**

Microcontroller	ARM Cortex-M7 at 600 MHz
Operating Voltage	3.3V
Input Voltage (Recommended)	5.0 V
Input Voltage (Limits)	5.0V
Digital I/O Pins	I/O 55
Analog Input Pin	12
Total DC Output Current on all I/O Lines	130 mA
DC Current for 3.3V Pin	800 mA
DC Current for 5V Pin	800 mA
Flash Memory	8MB KB all available for the user application
SRAM	96 KB
Clock Speed	84 MHz
Length	61.00 mm
Width	18.00 mm

Table 1 Specification of Teensy 4.1

Power of Teensy 4.1

- This is the input voltage pin for supplying power to the Teensy 4.1 board. It can receive power from an external source (such as 5 Volts from a USB cable or from another regulated power source). You may connect VIN either directly from an external supply or through a power jack. The recommended range for VIN is 3.6V to 5.5V.

- **5 Volts (5v Pin):** This pin provides 5V output from the USB connection or from the external VIN supply when powered through USB. It is regulated and can be used to power other external devices that require 5V, but only with limited current depending on the USB or external supply source.
- **3 Volts (3v Pin):** This pin provides a regulated 3.3V output generated by the onboard regulator. It is used internally to power the ARM Cortex-M7 processor and other components, and can also be used to power external circuits. The maximum current available from this 3.3V pin is approximately 250 mA (shared with onboard usage).
- **Regulator:** The onboard regulator converts the VIN supply into 3.3V for the NXP iMXRT1062 ARM Cortex-M7 microcontroller on the Teensy 4.1. This ensures stable operation of the processor and peripherals.

GPIO of Teensy 4.1

The Teensy 4.1 provides 55 high-speed 3.3V GPIO pins, including 18 analog inputs, 35 PWM outputs, and support for multiple communication protocols (UART, SPI, I²C, CAN), with interrupt capability and flexible functions for robotics, automation, and embedded systems.

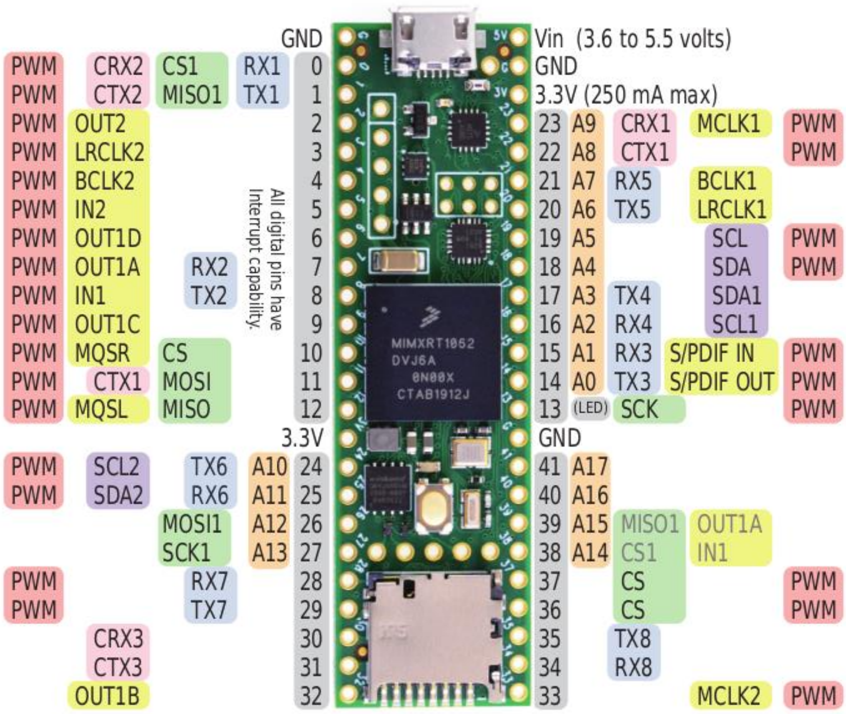

*Figure **Error! No text of specified style in document.**-9 GPIO Pin of Teensy4.1*

d. YD LIDAR TG-30

The YD-LIDAR TG30 is a high-precision two-dimensional LiDAR sensor designed for real-time environmental scanning and mapping in robotics and autonomous navigation applications. It employs time-of-flight (TOF) measurement technology, enabling accurate distance detection even under varying lighting conditions. The TG30 can generate a dense set of 2D point cloud data, which is essential for Simultaneous Localization and Mapping (SLAM) and obstacle detection in this research.

*Figure **Error! No text of specified style in document.**-10 YD-Lidar TG30*

Key Specifications

- **Scanning Frequency**: Adjustable from **5 Hz to 12 Hz**, allowing balance between scan density and speed.
- **Detection Range**: Up to **30 meters** (with optimal conditions and reflective targets).
- **Field of View**: **360° full rotation**, providing complete environmental coverage.
- **Distance Resolution**: Typically around **1 cm**, with stable accuracy for mapping tasks.
- **Data Output**: Provides **LaserScan data via USB/serial interface**, commonly integrated with ROS drivers for real-time mapping.
- **Performance**: Works reliably under various lighting conditions and can detect **static and dynamic obstacles**, making it well-suited for autonomous robots.

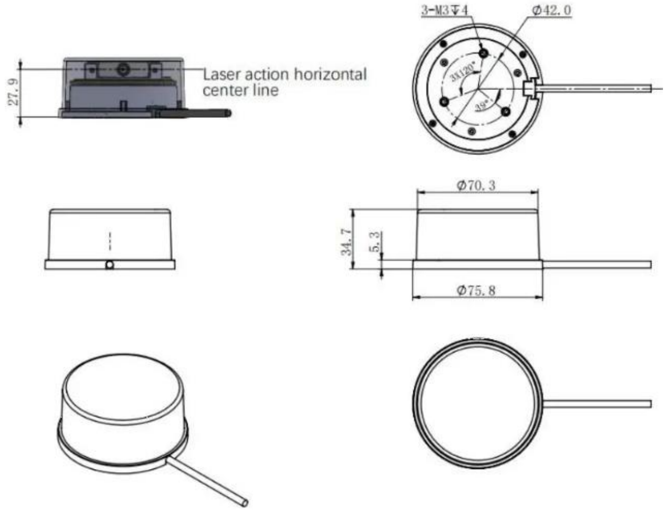

*Figure **Error! No text of specified style in document.**-11 Dimension of YD-Lidar TG30*

Reference Design YD Lidar TG30

The internal design of the YD-Lidar TG30 is as follows:

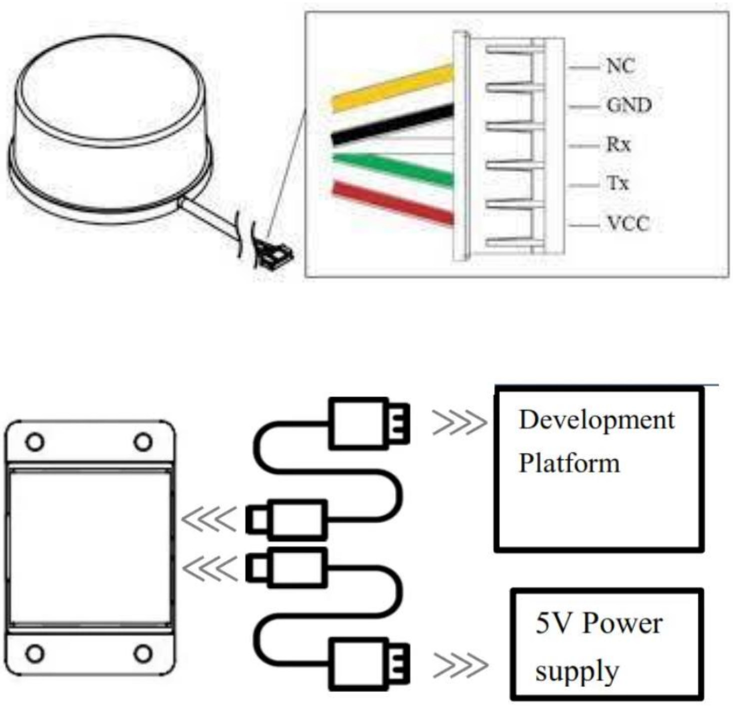

*Figure **Error! No text of specified style in document.**-12 Internal Design and Pinout of YD-Lidar TG30*

e. SMILE Motor Driver

The Smile Motor Driver is a compact, high-performance motor control module designed for robotics and automation applications that require precise and efficient operation of DC motors. It supports multiple motor channels, allowing simultaneous control of multiple actuators within a single compact board. Its design integrates power management, signal processing, and driver circuitry to deliver stable and responsive motor control in mobile robotic platforms.

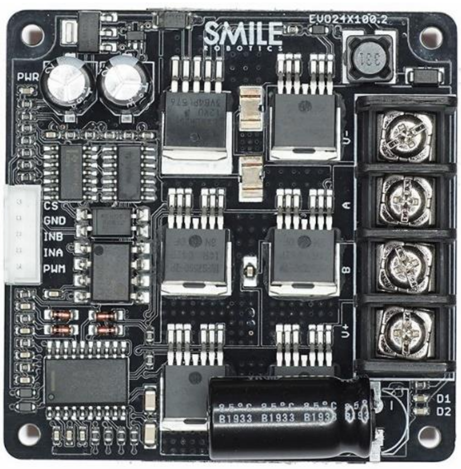

*Figure **Error! No text of specified style in document.**-13 Smile Motor Driver*

Key Features

- **Multi-Channel Support**: The board typically provides four independent H-bridge channels**,** allowing it to control up to four DC motors **or** two stepper motors simultaneously.
- **High Current Capability**: Each channel can handle significant current (commonly up to 2A–3A per channel)**,** making it suitable for medium-sized DC motors used in robotics.
- **Input Control**: Works with **PWM (Pulse Width Modulation)** signals to control motor speed. Direction control pins allow forward/reverse rotation. Can be driven by microcontrollers such as **Arduino, Teensy, ESP32, or STM32**.
- **Voltage Range**: Supports a wide input voltage range (typically 7V–30V), making it flexible for various battery-powered robots.
- **Protection Circuits**: Equipped with overcurrent, thermal shutdown, and short-circuit protection**,** ensuring safe operation.

Board Layout

- **Motor Output Terminals**: On the right side (four screw terminals) – each pair connects to a DC motor.
- **Control Pin Header**: On the left side – pins labeled for PWM, DIR (direction), GND, and VCC**.** These are connected to the microcontroller.
- **Power Input**: Large screw terminals also accept motor power supply (battery pack or DC source).
- **Integrated Components**: MOSFETs for efficient motor driving, Capacitors for noise filtering, ICs for current regulation and control logic.

Smile Motor Driver Pinout

Pin No	Function	Description
1	V+	Positive Input Voltage
2	V-	Negative Input Voltage
3	A	DC-MotorA
4	B	DC-MotorB
5	Gnd	Ground
6	InA	Motor DirectionA
7	InB	Motor DirectionB
8	Pwm	Pulse Width Modulation

Figure ***Error! No text of specified style in document.****-14 Table of Pinout of Motor Driver*

f. DC MOTOR RS-775

The RS-775 is a high-power brushed DC motor commonly used in robotics, automation, and industrial applications that require high torque and speed. It features a robust construction with a metal casing, precision bearings, and efficient commutation, making it suitable for continuous operation under load. In this research, the RS-775 is employed as the primary actuator for the autonomous food delivery robot's differential-drive system, providing the mechanical power necessary to move the robot and carry payloads over varying floor surfaces.

*Figure **Error! No text of specified style in document.**-15 DC Motor RS775*

Key Feature

- **Motor Type**: Brushed DC Motor (RS-775 class).
- **Operating Voltage**: Typically **12V – 36V DC** (commonly used at 24V for stable performance).
- **Power Output**: Around **100–300W**, depending on the model.
- **No-Load Speed**: ~4,000 – 20,000 RPM (before gearing)
- **Torque**: High torque when paired with a planetary gearbox
- **Current Draw**: No-load current ~1–2 A, Stall current**:** up to 15–30 A (requires powerful driver)

Pinout of DC-Motor RS775

Model	RS775
Operation	24 Volts DC
Rated Voltage	24 Volts DC
No Gear Speed	9000 RPM
No Load Current	<2.2A
After Gear Speed	468 RPM
Rated Wattage	60 Watts
Torque	1.47 Nm Or 15 Kgf.cm
Efficiency	78%
Rated Current	18.7A
Reduction Ratio	1:19.2k
Weight	50

*Figure **Error! No text of specified style in document.**-16 Table of Pinout of DC-Motor 775*

g. MPU 6050 Gyroscope Sensor

The MPU6050 is a compact six-axis motion tracking device that integrates a 3-axis gyroscope and a 3-axis accelerometer on a single chip. This allows it to measure both angular velocity and linear acceleration, making it ideal for applications requiring orientation, motion detection, and stabilization. The sensor communicates via the I²C (Inter-Integrated Circuit) protocol, enabling easy integration with microcontrollers such as the Teensy 4.1**.**

*Figure **Error! No text of specified style in document.**-17 MPU 6050 Gyroscope Sensor*

_ 3-Axis Gyroscope

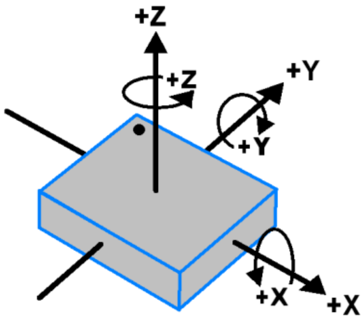

*Figure **Error! No text of specified style in document.**-18 3 Axis Gyroscope*

_ 3-Axis Accelerometer

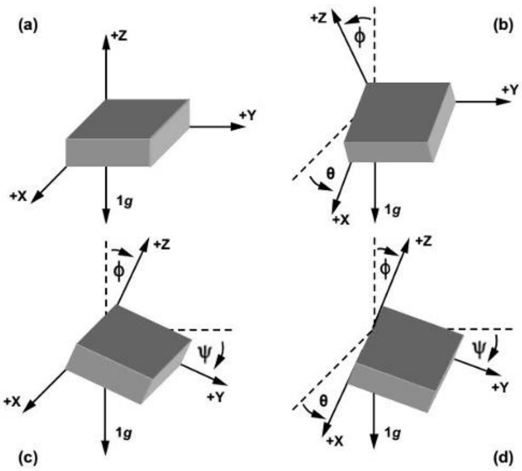

*Figure **Error! No text of specified style in document.**-19 3-Axis Accelerometer*

h. XL4016 Buck Converter

The XL4016 is a high-efficiency DC-DC buck converter module designed to step down higher input voltages to a stable, lower output voltage with minimal energy loss. It is based on the XLSEMI XL4016 integrated circuit, which operates at a high switching frequency to achieve compact size and efficient power regulation. The module can deliver an output current of up to 8 A (with adequate heat dissipation) and supports an adjustable output voltage range, typically from 1.25 V to 36 V, depending on the input supply. In this research, the XL4016 buck converter is used as a power management component to supply regulated voltage from the robot's main battery pack to various electronic subsystems. It plays a critical role in ensuring that sensitive components such as the NVIDIA Jetson Xavier NX, Teensy 4.1, sensors, and motor driver modules

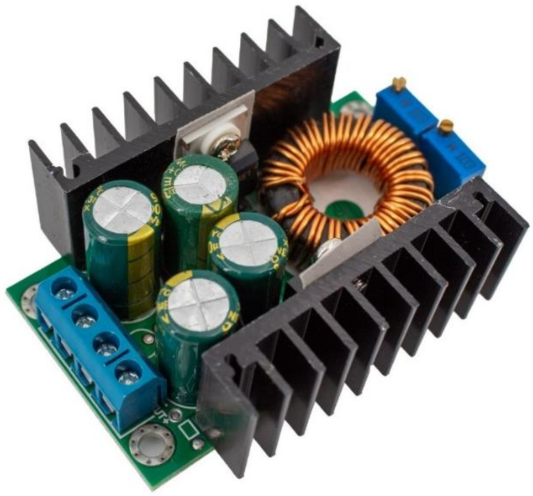

*Figure **Error! No text of specified style in document.**-20 XL4016 Buck Converter*

_ **IN+** – Positive input voltage terminal (connect to the positive terminal of the battery or power source).

_ **IN-** – Negative input voltage terminal (connect to the ground/negative terminal of the battery or power source).

_ V**OUT+** – Positive regulated output voltage terminal (connect to the positive input of the load/device).

_ **VOUT-** – Negative regulated output voltage terminal (connect to the ground of the load/device).

_ **EN (Enable)** – Logic control pin to enable or disable the output (if provided; often tied high by default).

_ **Adjust (Potentiometer)** – A multi-turn potentiometer to adjust the output voltage (clockwise increases voltage, counterclockwise decreases).

i. USB 5V BUCK CONVERTER

The 5V USB Buck Converter is a compact DC-DC step-down power module designed to provide a stable 5V regulated output from a higher voltage input source. It uses high-efficiency switching regulator technology to convert voltages such as 7–24 V (depending on the model) down to a fixed 5 V output, making it ideal for powering USB devices and 5 V logic circuits in embedded systems. In this research, the 5V USB buck converter is utilized to power peripheral devices such as microcontrollers, sensors, or auxiliary electronics that require a constant 5 V supply. Its USB output interface allows for easy connection to standard USB-powered devices, enabling direct compatibility with development boards or communication modules without the need for custom wiring.

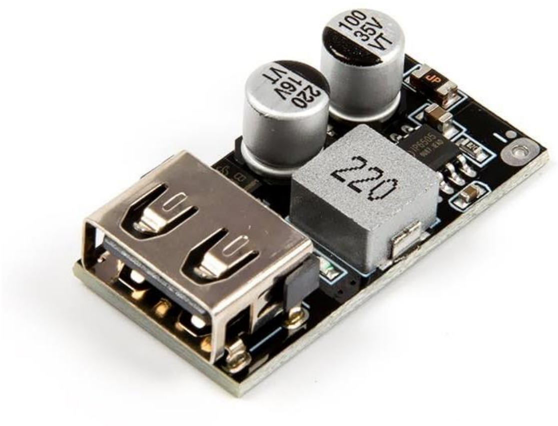

*Figure **Error! No text of specified style in document.**-21 USB 5V Buck Converter*

The converter typically features low voltage ripple, overcurrent protection, and short-circuit protection, ensuring safe and reliable operation even under fluctuating load conditions. Its onboard electrolytic capacitors and inductive coil provide effective filtering, which is essential for maintaining stable voltage when powering sensitive electronics like the Teensy 4.1 or sensor modules. By integrating this module into the autonomous food delivery robot's power distribution system, the 5V USB buck converter ensures that critical 5 V subsystems receive a clean, regulated power supply, thus enhancing overall system stability and preventing voltage-related malfunctions. Its small size, high efficiency, and direct USB interface make it a convenient and effective solution for embedded robotics applications.

The typical **5V USB Buck Converter** module has a very simple pinout layout. On most versions, you'll find the following terminals:

1. **VIN+** – Positive input voltage terminal (connect to the positive terminal of the battery or higher voltage source, e.g., 7–24 V).
2. **VIN-** – Negative input voltage terminal (connect to the ground/negative terminal of the battery or source).
3. **USB Output (5V)** – Standard USB Type-A port that provides regulated 5 V output to connected devices.

j. MINI 560 STEP DOWN CONVERTER

The Mini560 is a compact and high-efficiency DC-DC step-down (buck) converter designed to provide a stable lower voltage output from a higher voltage power source. Based on a high-frequency synchronous rectification design, it can achieve efficiencies up to 95%, making it highly suitable for portable and battery-powered robotic applications where minimizing power loss is critical. The module typically supports an input voltage range of 7–20 V and can deliver a regulated output voltage of 5 V or 9 V depending on the model variant, with a continuous output current capability of up to 3 A. Its small PCB footprint makes it easy to integrate into tight spaces within the robot's electronic compartment.

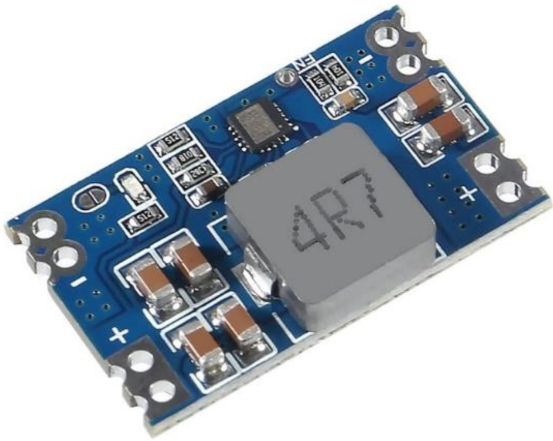

*Figure **Error! No text of specified style in document.**-22 Mini 560 Step Down Converter*

The converter includes **short-circuit protection**, **overcurrent protection**, and **thermal shutdown**, enhancing the safety and reliability of the robot's power system. Its integrated inductor and high-quality capacitors contribute to a compact yet robust design, capable of withstanding fluctuations in input voltage caused by motor load changes

The **Mini560 Step-Down Converter** has a very simple pinout, typically marked on the PCB. Here's the standard pinout list:

1. **VIN+** – Positive input voltage terminal (connect to the positive terminal of the battery or power source, usually 7–20 V depending on the model).
2. **VIN-** – Negative input voltage terminal (connect to the ground/negative terminal of the battery or source).
3. **VOUT+** – Positive regulated output voltage terminal (connect to the positive input of the load/device, typically fixed at 5 V or 9 V depending on the version).
4. **VOUT-** – Negative regulated output voltage terminal (connect to the ground of the load/device).

k. Robot Wheel

This wheel is a lightweight plastic wheel with a rubber tire, designed to provide grip and stability for robots, trolleys, or small mechanical systems. Its simple yet strong construction makes it a good choice for differential-drive or four-wheel robots.

*Figure **Error! No text of specified style in document.**-23 Robot Wheel'*

Physical Features

- **Material:** Inner hub: Hard plastic or nylon for strength and durability. Outer rim: Rubber or thermoplastic elastomer (TPE) to provide good traction on smooth and slightly rough surfaces.
- **Spokes:** Reinforced radial spoke design for added strength without increasing weight.
- **Hole/Bore:** Central hole for mounting onto a motor shaft or hub, often compatible with standard DC geared motors or stepper motors.

Common Specifications (Typical for this type of wheel)

- **Diameter:** 65 mm – 100 mm (depending on model).
- **Width**: Around 20 mm.
- **Bore size**: Often 6 mm or 8 mm, designed to fit common DC motor shafts.
- **Load capacity**: Light duty (suitable for small robots, not heavy industrial use).

Applications

- Mobile robots (differential drive, line-following robots, autonomous robots).
- DIY robotics kits.
- Prototyping small AGVs (Automated Guided Vehicles).

This is a **lightweight plastic hub wheel with a rubber tire**, widely used in robotics projects for traction and stability, typically mounted on DC geared motors or stepper motors in differential-drive robots.

- The following figure illustrates our team’s activity in developing the robot
.

*Figure **Error! No text of specified style in document.**-24 Activity of Robot Mechanic Installation*

*Figure **Error! No text of specified style in document.**-25 Robot Mechanic Welding*

*Figure **Error! No text of specified style in document.**-26 Robot Circuit Installation*

*Figure **Error! No text of specified style in document.**-27 Robot Circuit Installation*

*Figure **Error! No text of specified style in document.**-28 Activity of Installation of Mechanic Part*

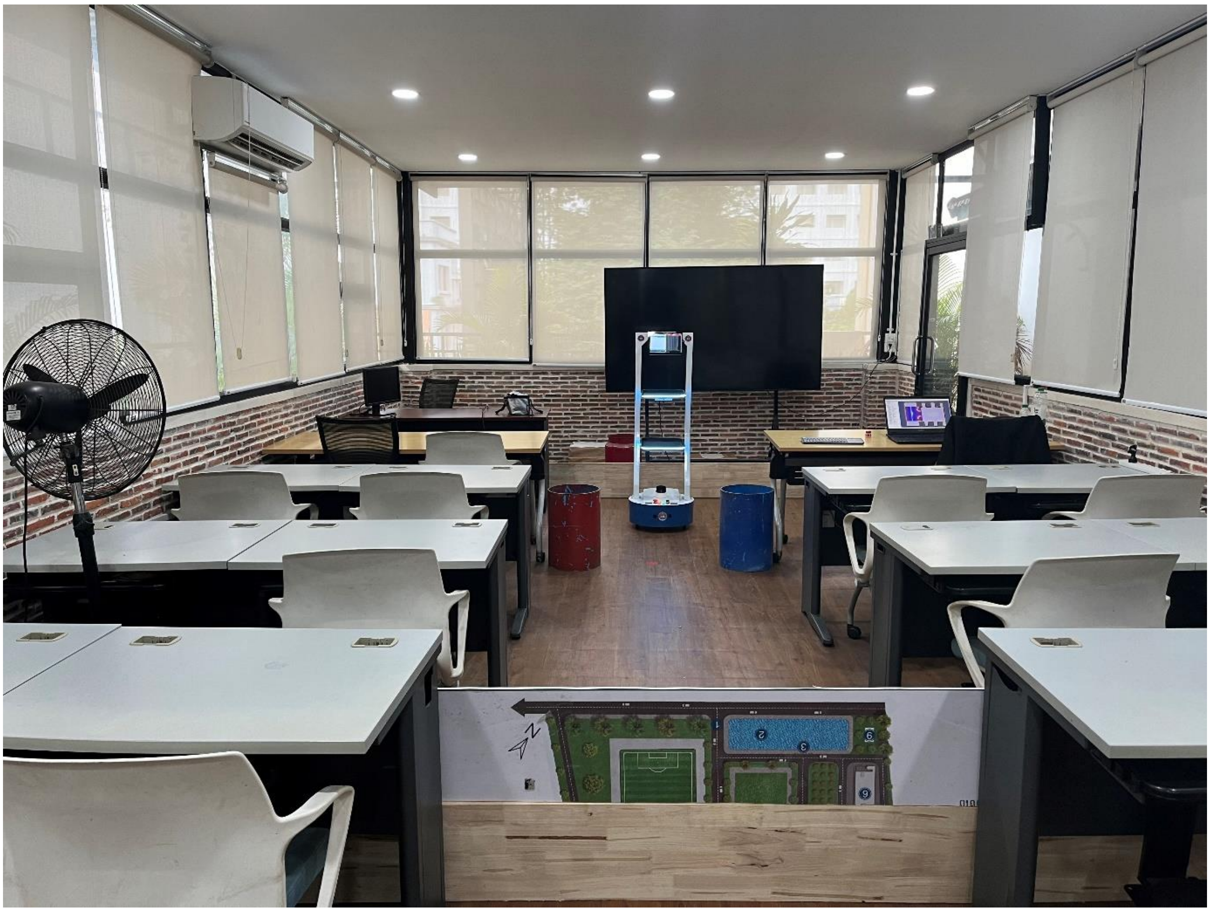

*Figure **Error! No text of specified style in document.**-29 Autonomous Delivery Robot*