PEELING BACK THE LAYERS OF MICROCONTROLLERS

A Case Study of the Working of Microcontrollers in the Automation of Industrial Kitchens

by Jaivardhan Jain

Abstract

This research delves into the role of microcontrollers in mobile robotics, with a specific emphasis on their application in industrial kitchens. It elucidates the operational intricacies of microcontrollers, integral components of modern robotics. A case study featuring a prototype kitchen robot is presented, showcasing its ability to efficiently execute simple tasks such as stirring, all orchestrated by microcontrollers. The study sheds light on how these microcontrollers navigate the complexities of bustling kitchen environments.

Preface

In a world emphasising on speed and efficiency more than ever before, automation is the need of the hour. For this purpose, there is a need for something that can serve as the brain, take an input and use it to perform some actions. Microcontrollers are an economical and popular means for the same.

Today, more than 17 billion devices use microcontrollers for consumer targeted applications around the world and yet we have only scratched the surface with regards to the potential of uses of microcontrollers. In fact, the market size of microcontrollers is estimated to double in the next 8 years.

In this project, I worked with Illuminify Technologies Pvt. Ltd. (trademark Accio Robotics) to better understand the working of microcontrollers in real-world applications. Under their guidance, I built a prototype for a robot that would help in the automation of industrial kitchens by carrying cooking instruments or doing basic activities like stirring.

The addition of automation can create significant gains in efficiency for industrial kitchens. Automation in such kitchens can reduce time and effort, while simultaneously preventing the occurrence of human error.

I would like to extend my thanks to the team at Accio Robotics for all their guidance and mentorship

- **Jaivardhan Jain**

October, 2023

accio robotics

Certificate Of Internship

This is to certify that Jaivardhan Jain of the Cathedral and John Connon School has completed a research project with our team in September 2023. During this project, he has successfully learnt about the workings of microcontrollers and their components, their application in the real world and built a prototype for a kitchen robot that could be used to automate industrial kitchens.He has written a research paper on his learnings from this project under our guidance.

I wish him the best for his future endeavours.

Sincerely
Pranav Srinivasan
Co-founder & Director

ILLUMINIFY TECHNOLOGIES PVT. LTD.
Director

Contents

What are integrated circuits?

An integrated circuit (IC or colloquially - chip) is a set of electronic circuits on a flat piece of semi-conductor material (wafer), that is often silicon. An IC contains a large number (hundreds of thousands to millions) of transistors and other electronic components integrated together. An IC can function as a timer, counter, memory, microcontroller etc.

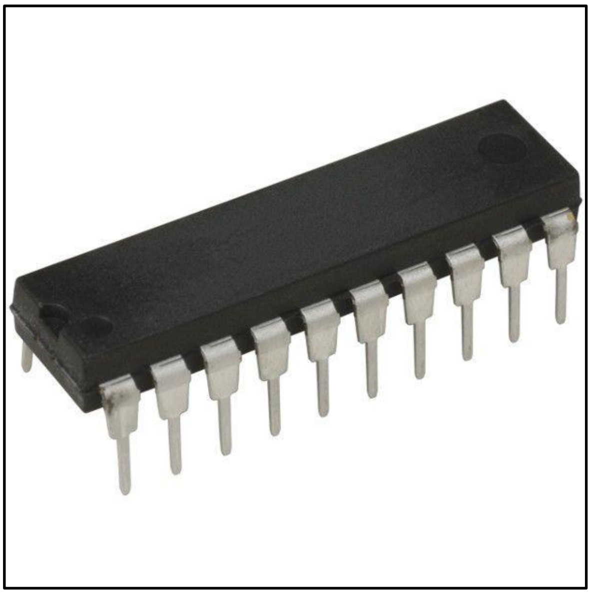


Fig 1: Integrated Circuit

An IC is the building block of all modern electronic devices. As the name suggests it is an integrated system of various miniature and interconnected components.

Multiple IC's can be combined together to form a package, which could combine various functionalities.

Fig 2: Package of Integrated Circuits

What is an Embedded System?

An embedded system is a combination of hardware and software designed for some specific function. These may be programmable or have fixed functionality.

What is a Microcontroller?

A microcontroller unit or ‘MCU’ is an integrated circuit that controls devices in a larger embedded system. It can be considered to be the brain of an embedded system or a miniature PC without a complex front-end operating system.

A typical microcontroller would consist of a processor, memory and input/output peripherals (any component that interfaces with the outside world) on the same chip.

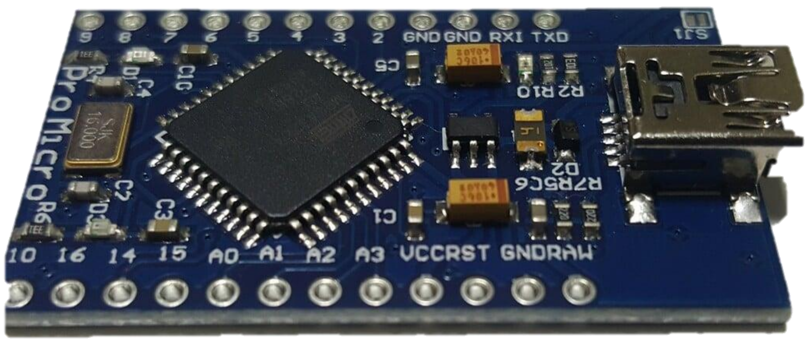


Fig 3: Microcontroller

In summary, a microcontroller is one application of integrated circuits, i.e. all microcontrollers are ICs but not all ICs are microcontrollers. Furthermore, an embedded system is a combination of software and hardware that uses a microcontroller as its brain.

Differences between MCUs and Personal Computers

Microcontroller	PC
Function: Microcontrollers are compact, specialized and are meant for real-time control and embedded systems.	**Function:** These are general purpose computers meant for a wide range of tasks.
Processing Power: Microcontrollers have a low to moderate processing power but are optimized for specific tasks.	**Processing Power:** PCs have a relatively higher processing power capable of running resource-intensive software.
Memory: They have limited memory. They often use flash memory for program storage.	**Memory:** They have much higher memory capacities and often include hard drives or solid-state drives for storage.
User Interface: These typically lack a traditional graphical user interface (GUI) but may have simple displays for feedback	**User Interface:** PCs contain sophisticated GUIs, monitors and keyboards and mice for input and output purposes.
Customization: Can be customized with specific firmware to perform the required task, making them adaptable.	**Customization:** While they have a wide-range of functions, they are not easily customizable at the firmware level for specific tasks.

What is binary?

Binary is a numbering scheme in which there are only two possible values for each digit, 0 and 1. It serves as the basis for all computing systems.

The term binary also refers to any digital encoding/decoding systems in which there are exactly two possible states. For eg. in transistors 1 represents flow of electricity and 0 represents no flow of electricity.

In binary computing systems, the smallest unit of data is known as a bit (binary digit) and can only hold two values (0 and 1). The larger unit of value known as the byte is the combination of 8 bits.

Computers can represent numbers using binary inside the CPU and RAM. This is done by considering binary to be modular arithmetic with the module being 1 and using combinations of a large number of bits. This means that each subsequent bit represents the subsequent power of 2 when switched on.

Table 2: Representation of decimal numbers in binary

Binary	Decimal
00000000	0
00000001	1
00000010	2
00000011	3
00000100	4
00001010	10
11101000	232
101100110100	2868
1000111111110102	18,426

Memory in Microcontrollers

There are three main types of storage in modern microcontrollers: random access memory (RAM), electrically erasable programmable read-only memory (EEPROM) and flash memory.

Random Access Memory (RAM)	Electrically Erasable Programmable Read-Only Memory (EEPROM)	Flash Memory
It is a volatile memory, i.e., it can only be accessed when the system is powered up and the contents in it shut down as the system shuts down.	It is non-volatile memory. Its contents remain even after the system is switched off.	It is non-volatile memory. Its contents remain even after the system is switched off.
It has a faster access time.	It can only program one byte at a time, but is faster than Flash memory in write and erase operations at the byte level.	It can program a whole sector (block of bytes) at a time, but requires to program the whole sector even if it needs to program just one byte. It is the slowest.
It is the most expensive. It is orders of magnitude more expensive than EEPROMs of the same size.	It is orders of magnitude more expensive than flash memory of the same size.	It is the least expensive because it wears out easily due to the constant block writing and erasing.
It is mainly used to store temporary data like variables and constants	It is mainly used to store user instructions and data. The microcontroller then accesses the instructions one-by-one and sequentially executes them.	It has similar uses to EEPROMs but is used when larger amounts of data is needed to be stored as it is relatively inexpensive.
It has lower storage capacity due to its high cost and limited usage.	EEPROMs have a larger storage capacity than RAM.	These have the highest storage capacities.

Some microcontroller manufacturers use either Flash or EEPROM while others use both to provide more flexibility to the end-user.

Central Processing Unit (CPU)

The CPU is a component of the microcontroller that fetches instructions from the memory, decodes them, and then executes them. It has two main components:

Control Unit (CU)

The control unit fetches and decodes the instructions (given in bits) from the input.

Arithmetic Logic Unit (ALU)

As the name implies, the main task of an ALU is to perform Arithmetic, Logic or Shifting as specified by the user. The ALU executes the instructions decoded by the CU.

Instruction Pipelining

CPUs also utilize a concept called Instruction Pipelining. This is not a physical component in the CPU, but rather optimizes the use of time and resources during the fetching, decoding and execution of instructions.

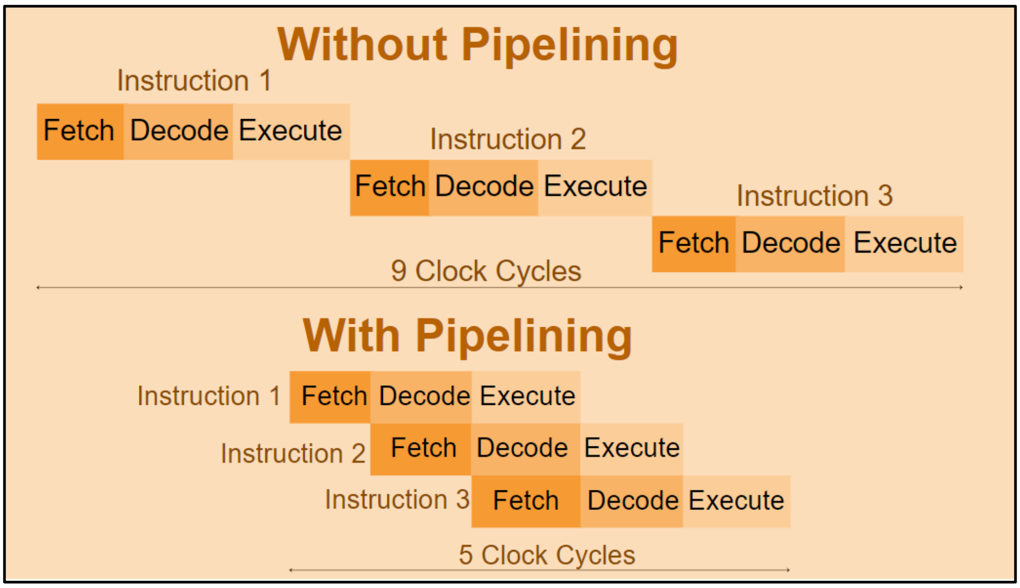
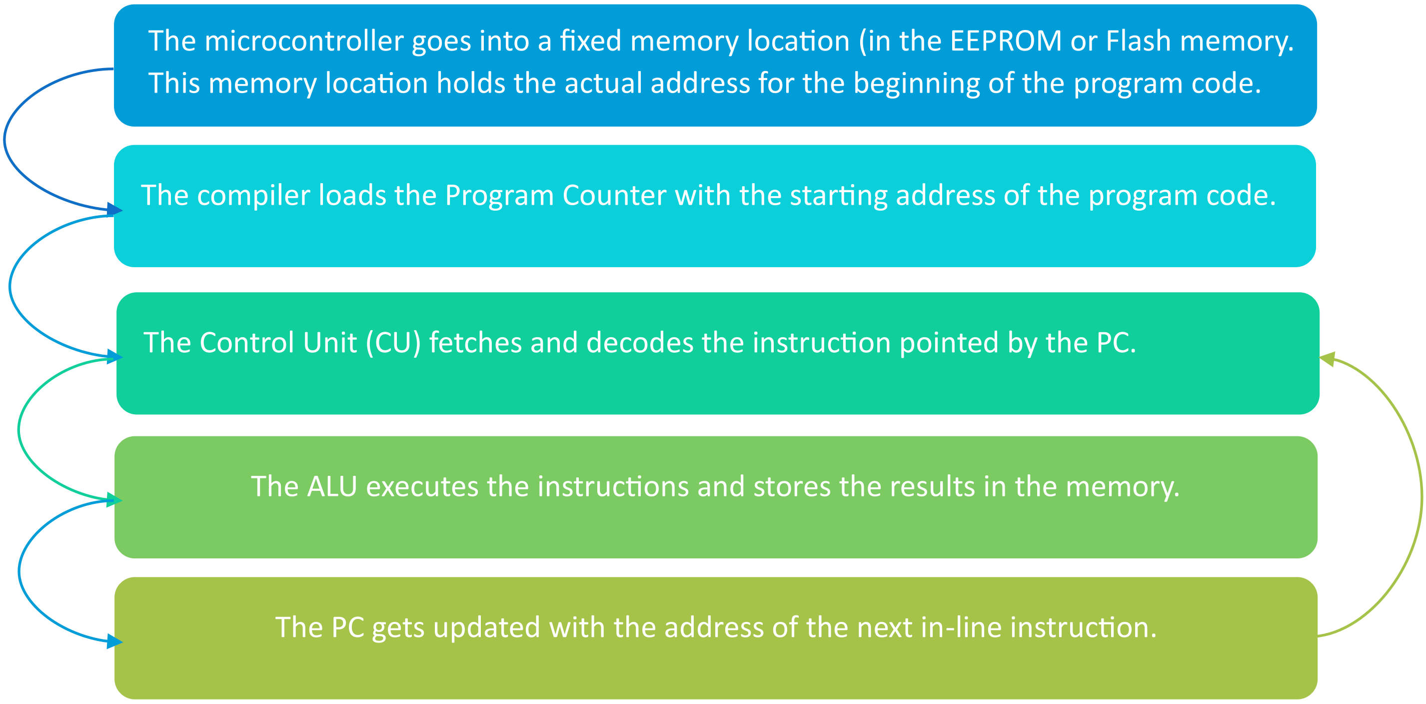


Fig 4: Instruction Pipeline

How do Microcontrollers Work?



Microcontroller Architecture

Microcontroller architecture refers to the design and organization of a microcontroller's internal components and how they work together to perform various tasks. Microcontrollers differ greatly based on their architecture.

Microcontroller Peripherals

Microcontrollers come with additional peripherals to develop an interface with the external environment as well as to meet the demands of the sophisticated applications. These peripherals are add-on features for a microcontroller such as timers/counters, analog to digital convertors, digital to analog converters etc.

Microcontrollers in Robotics

Robotics is an interdisciplinary branch of science, electrical engineering, mechanical engineering, and computer science that deals with the physical motion of the robots. Microcontrollers affect a robot's underlying Control Framework.

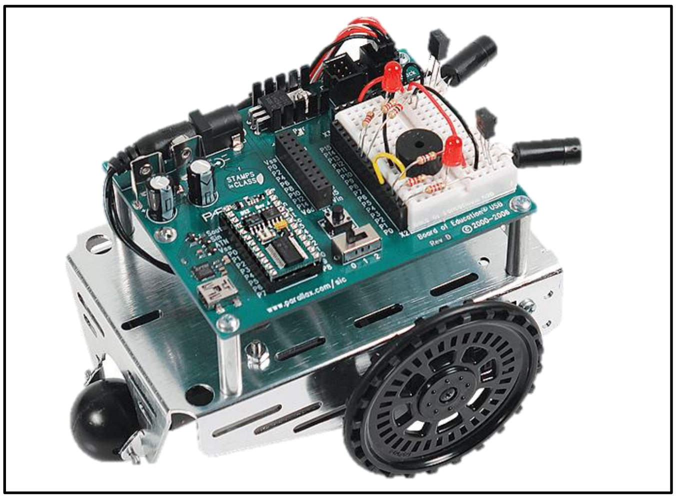


Fig 5: Robot with Microcontroller

The Control Framework simply depicts how the Current Output of a system is aligned with its Desired Output.

There are two types of Control Frameworks:

Open-Loop Control System:

If a human is needed to align the current output of a system with the desired output, then such a system is called an Open Loop Control System.

Closed-Loop Control System:

If a system can sense the current output of a system while enforcing itself to achieve the desired output without the intervention of any human, then such a system is termed as a Closed-Loop Control System.

Types of Robots

Industrial Robots

These are robots that can work 24/7 and do repeated tasks.

Tele-operated Robots

These are robots that have all the components but cannot act independently. They are remote-controlled by a human operator.

Operator Assist Robots

Such robots need explicit instructions but can move on their own after receiving said instructions.

Autonomous Robots

Such robots can operate entirely independent of human operators.

Microcontroller-controlled robots in Industrial Kitchens

Industrial kitchens, also known as commercial kitchens, are specialized food preparation facilities designed for large-scale food production and service.

Certain work in such kitchens can be repetitive and dull, thus, reducing employee motivation and increasing chances of human error.

Moreover, by following a fixed routine without having to take breaks, the addition of microcontroller-controlled robots can greatly improve efficiency in industrial kitchens.

Kitchen Robots do not usually have to pick up a large/heavy payload, which will usually be limited to plates or cooking equipment. This allows them to be small and agile.

Technology is still not quite at the level to have fully automated warehouses and so it is important to have robots that can work safely with humans.

A kitchen robot is an autonomous/human-assisted robot that is designed to reduce/replace human effort in an industrial kitchen environment.

A kitchen robot could potentially be automated guided carts (AGCs) which are robots that can navigate the kitchen using embedded markers or advanced LiDAR (a technology which uses robots to receive the world by recording reflections from a spinning laser array) and carry a small payload. Such robots follow a fixed path which is a possible cause for error as their path may be blocked, which could cause large efficiency losses. They could also be collaborative robots (cobots). These robots can be considered to be in-between tele-op and autonomous robots. Finally, these kitchen robots could also be articulated robotic arms. These can be static or mobile and can help in carrying very small payloads or doing repetitive tasks.

ChefMate - Personal Project Undertaken

For this project, I used a mobile articulated robotics arm.

While the robot built in this project is currently tele-operated, it has LiDAR capabilities for navigation in the future.

Like every other robot, ChefMate consists of 3 main modules:

- Mechanical construction
- Electrical Components
- Computer Programming

Mechanical Construction

ChefMate can be divided into 2 main mechanical sections:

- The Mobile Robot
- The Robotic Arm

The mobile robot is made up of mild steel. Though this material is three times heavier than aluminum, it is also 3 times cheaper. Since in this application there is no significant advantage of the robot being lighter, mild steel was used.

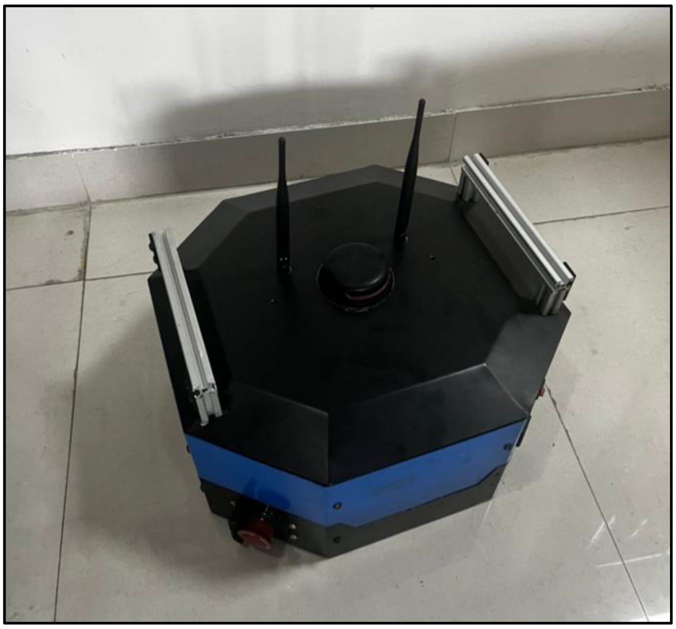


Fig. 6: The mobile robot of ChefMate

The robotic arm is a 3D-printed component made up of polycaprolactone (PLC). PLC provides excellecnt impact strenght and durability. It also has a low melt temperature of only around 60˚C as compared to over 200˚C for other filament materials like PLA and ABS. This saves energy and makes PLC more sustainable for use in prototyping.

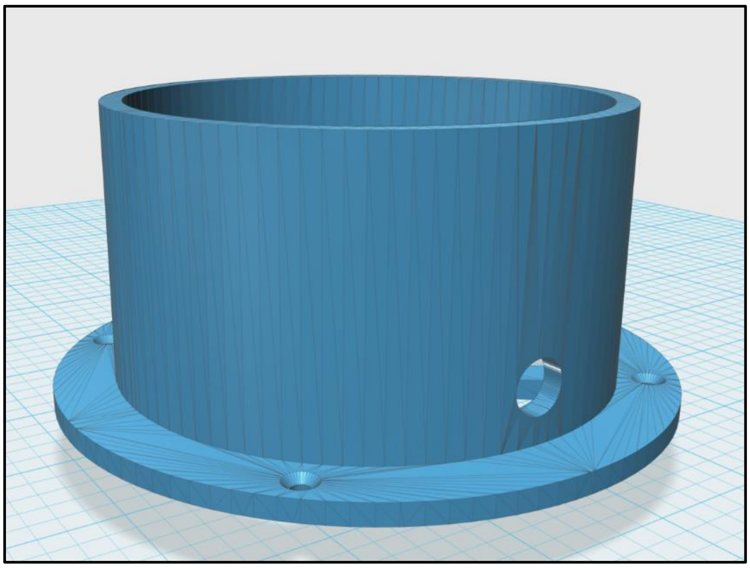


Fig. 7: Arm Base CAD File

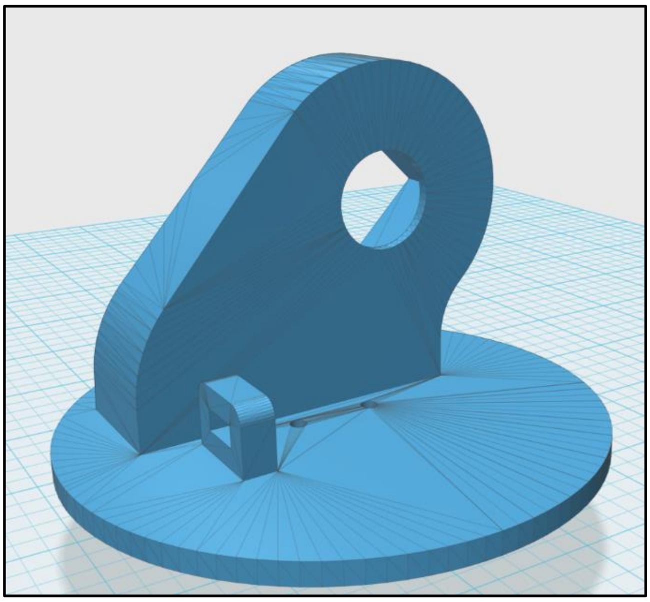
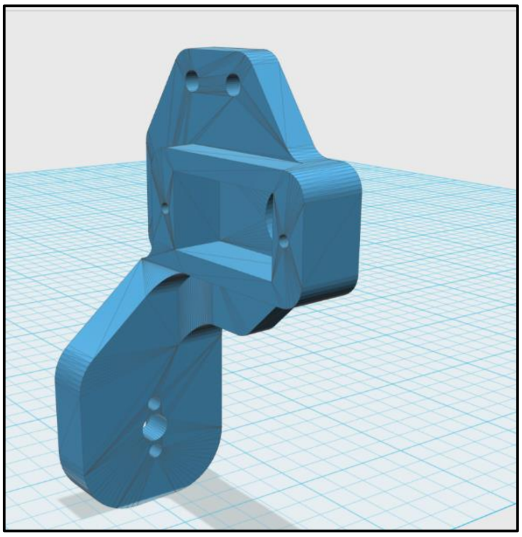


Fig. 8: Arm Waist CAD File

Fig 9: Gripper Base CAD File



Electrical Components

From an application standpoint, electrical components in robotics can be broadly categorized into three main groups:

Power Source:

In the realm of robotics, a power source is analogous to food for humans or fuel for cars. It serves as the essential reservoir of power, supplying energy that actuators and sensors can leverage to enable a robot's functionalities.

The robotic arm is powered by a Lithium Iron Phospate ($LiFePO_4$ or LFP) battery.
Such batteries have a longer life span, require no maintainence, are extremely safe, are lightweight and have improved discharge and charge efficiency as compoaredto lead-acid batteries and other lithium batteries.

Actuators:

Actuators play a crucial role by transforming input from the power source into physical movements within the mechanical structure. This includes actions like wheel movement for locomotion, gripper adjustments for pick-and-place operations, and other manipulations.

ChefMate uses a robotic arm and the motors and wheels as actuators.

Sensors:

Robotic sensors emulate the five fundamental human senses, empowering robots to perceive and analyze their surroundings. They facilitate tasks such as gauging atmospheric temperature, assessing soil humidity, recognizing object size and shape, detecting obstacles in the path, visualizing the environment, and even understanding human speech.
In essence, these three components work synergistically, with the power source providing

energy, actuators translating it into motion, and sensors offering the capability to perceive and respond to the surrounding environment.

ChefMate uses a LIDAR (Light detection and ranging) sensor.

LIDAR works by transmitting a laser light is sent from a source (transmitter), which is then reflected from nearby objects. The reflected light is detected by the system receiver and the time of flight (TOF) is used to develop a distance map of the objects in the scene.

Other:

The robot also uses some other components whose function is described below:

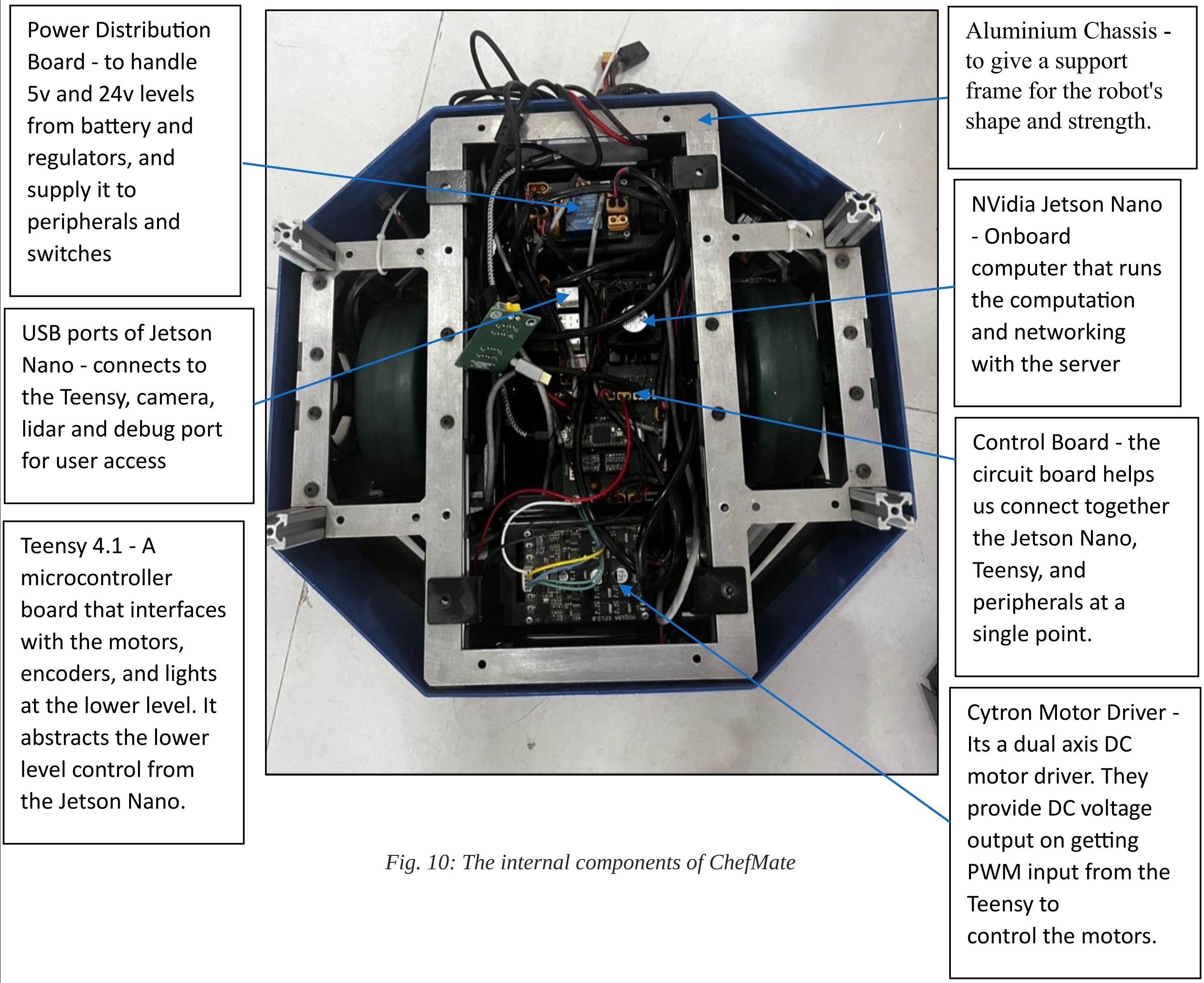


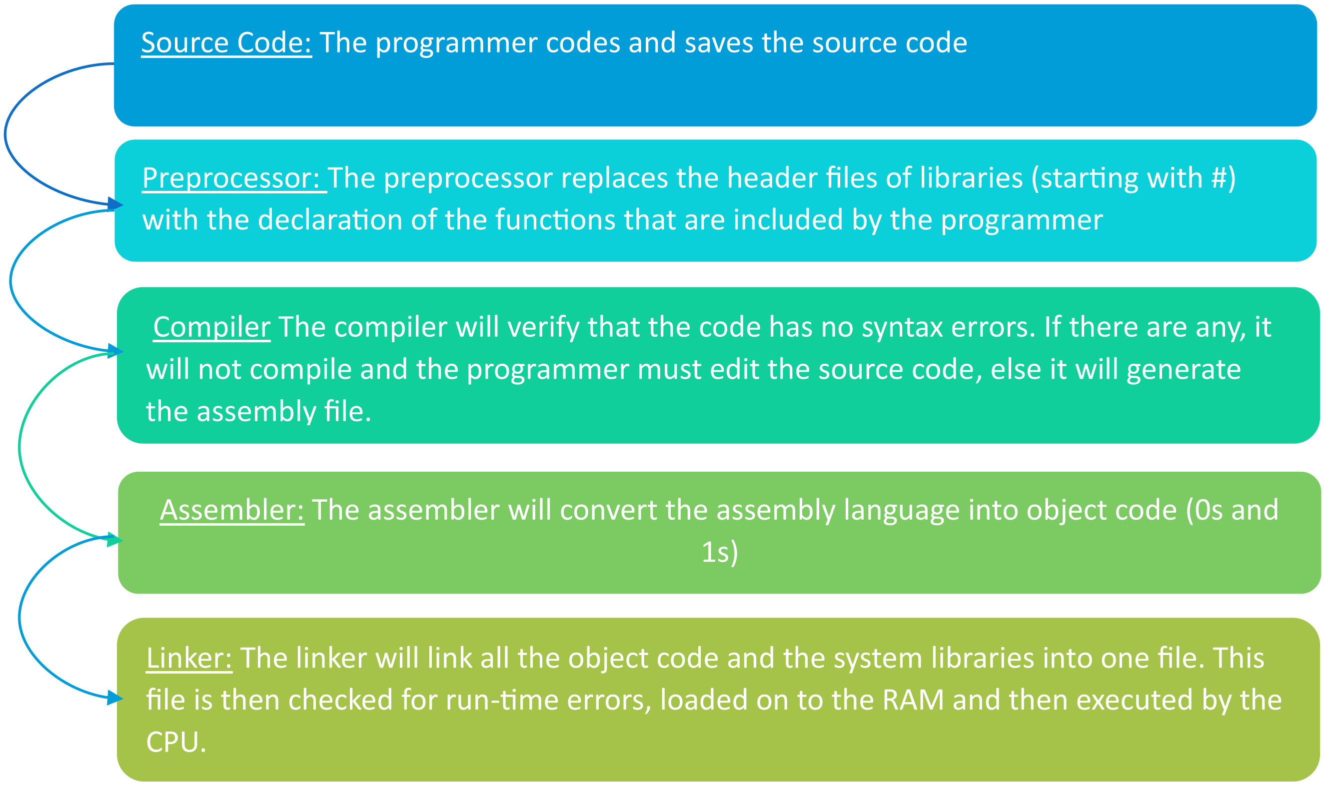
Fig. 10: The internal components of ChefMate

Computer Programming

The computer programming in a robot gives it the instructions to be carried out as well gives the ability of automation, including the robot's movements, responses to stimuli and interactions with the environment.

Programming is also necessary to integrate sensor data into the decision-making process.

How the Program Executes?



The code for ChefMate uses Blynk, an IoT platform for iOS or Android smartphones that is used to control Arduino, Raspberry Pi and NodeMCU via the Internet, to allow for tele-operated control and uses its LIDAR for sensing to map the environment for autonomous movements.

The flow for the code:

Defining the blynk template, auth_token

Including the required libraries

Setting up ssid and pwd for connecting to WiFi

Definition of the servos and then variables required: starting position, previous position, storing position, speed

Blynk connected function

In the void setup:

- Serial monitor w baud rate
- pinMode of different motors
- blynk.begin
- Attaching the servos to the required pins
- Setting up initial position of the arm

In the void loop:

- Call blynk.run function

Different functions for state changes in different virtual pins

Each function will have the same logic controlling the respective servos

END OF REPORT

Credits

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