



**TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS**

**A
MAJOR PROJECT PROPOSAL
ON
AUTOMOBILE AND ADVANCED CONTROL SYSTEMS THAT USE
MULTIPLE SENSORS, CLOSED FEEDBACK LOOPS AND MACHINE
LEARNING FOR ADAPTIVE BEHAVIOR(FIRST HALF OF
AUTONOMOUS VEHICLE PROJECT)**

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Abstract

The recent trends and advancements in the field of artificial intelligence and autonomous systems has motivated us to work on a similar project of our own. The project required much considerations and effort in both hardware and software aspect due to which this project is separated into first half and second half. The first half deals with the physical system of the vehicle which involves all the hardware and the control system for those hardware. The second half primarily focuses on the implementation of autonomy, i.e. computer vision and model training.

This half of the project involves building a system that integrates all the sensors and actuators along with processing units to provide a platform for the model to control the vehicle. The physical system uses a stereo camera to observe the surrounding and also uses other sensors which communicates to the core system and each other using the CAN bus protocol. The vehicle is a large model capable of driving a single person which also utilizes a hardwired switch to take over the controls to manual mode in case of emergency.

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List of Abbreviations

CAN Controller Area Network	2
ML Machine Learning	2
SLAM Simultaneous Localization and Mapping	14
IMU Inertial Measurement Unit	14
SBC Single Board Computer	18
SDK Software Development Kit	13
API Application Protocol Interface	13
PCB Printed Circuit Boards	13
SCI Serial Communications Interface	6
LIN Local Interconnect Network	6
I2C Inter Integrated Circuit	6
MOST Media Oriented Systems Transport	6
TSN Time-Sensitive Networking	7

SOF Start-of-frame	8
RTR Remote Transmission Request	9
CRC Cyclic Redundancy Check	9
RTOS Real Time Operating System	4
PMI Project Management Institute	12
PMBOK Project Management Body of Knowledge	12
QA Quality Assurance	12

1. INTRODUCTION

1.1 Background

The recent trend in robotics has encouraged a class of vehicles which are autonomous and controllable to an extent by the user. Such intelligent system are able to identify their surroundings and react to different conditions that can occur in the surrounding when they are assigned to a task. These class of vehicle need a robust, reliable and highly reactive system to control them. Such systems are capable of processing loads of data in real time and adjusting to the required state in real time which requires a sophisticated set of devices within the system. Currently these systems are not that easy to find and are based on proprietary solutions. In context of Nepal, the vehicle industry has not taken off, there has not been any significant efforts in this industry to make it happen either. The environment is not predictive and previously employed and tuned controlled system may not be able to adapt to changing conditions. With advancement in edge AI it has allowed the device to compute sophisticated task real time on device which are up to the task of computing the changing environment around them. These mobile autonomous vehicle are able to explore and perform tasks that are not possible for normal human being.

1.2 Problem Statements

The problem statements we tackle for our half of the two-team collaboration are as follows:

- Can the system adapt to changes in the environment around it?
- How can we develop multiple feedback loops within a network?
- How can the system be reliable as to work on its own?
- Does the interface encounter all the exceptions and errors that can occur?
- Can we change the response of the system on demand?

These questions are integral to the challenge of building this project. The first two question relate on how we should implement the system and the third part reflects on what consideration needs to be taken while building such systems. The last two questions are based on how the communication system should react based on the input to the system.

1.3 Objectives

1.3.1 Collaboration Objectives

The collaboration objectives state the goals of the two-team collaboration, covering the entire project including the hardware, electronics, control systems and software. They can be stated as follows:

- To build an autonomous vehicle capable of driving a passive passenger from one location to another given the locations.
- To have the vehicle deal with obstacles, stay on route, and make decisions about changing routes both on a small and large scale in order to cause least damage to itself and discomfort to the passenger.
- To create a modular, layered and abstracted system that on principle opens possibilities of the modules' usage in a much wider variety of applications in the field of robotics and AI agents.
- To demonstrate an appropriate project management scheme covering all the important aspects of project management and work record keeping.

Further specifics from this point on can be found in the respective project objective sections for either half of the collaboration.

1.3.2 Objectives of This Project

An autonomous system includes a network of devices working in conjunction to achieve a system level goal.

1. System level design of every system nodes
2. Controller Area Network (CAN) protocol design and communication standard
3. Implementing on device Machine Learning (ML) on micro-controller and embedded systems
4. Established a defined error reporting and error handling sequences
5. Higher Level abstracting command and hierarchy of command signals
6. Building a vehicle that can accommodate all the components of the system
7. Takeover constraints to discard the higher level automation commands

8. Tuning the system to different reactive circumstances
9. Simulation of braking power of system and defining parameters for software control
10. Simulation of acceleration power of system and defining parameters for software control
11. Arbitration in command structure and command type in the system
12. Designing circuits to incorporate all the design parameters for different nodes in the system
13. Team collaboration and task division

1.4 Scope

1.4.1 Collaboration Scope

The collective scope of the entire project refers to both the problem statements and the objectives to define the coverage and limits set for our goals in order to make the project well defined and achievable. They can be stated as follows:

- Regarding the transportation of a passenger from one location to another
 - The number of passengers will be limited to one
 - The area for which the locations may be defined will be confined within Pulchowk Campus
 - Obstacles will be within the context of the campus (hence, some common elements present in the usual context of vehicles may not be considered, such as traffic lights)
 - The speed of the vehicle will be limited to 20 km per hour
- Regarding layering and modularity
 - The number of layers and modules will be kept low to accommodate the workflow for our small team and low resources

1.4.2 Scope of This Project

For this half of the two-team collaboration, the following scope will be considered:

- Regarding the capabilities of the system
 - The system will have knowledge about localization and layout of campus

- The system will be able to cope up with failure in any part of the system
- User can override the control of the system
- All the sub systems are isolated and have specific contracts with each other
- The system will be based on deadline and use Real Time Operating System (RTOS)
- Regarding the information provided by the AI agent
 - Defined commands will be provide to a middleware
 - Middleware translates those information to required data packets

2. Literature Review

The autonomous vehicle was once thought of as a dream but it is closer and closer to become a reality. The consequences of vehicle automation are already being outlined on global mobility, on traffic efficiency, on competitiveness, etc [1]. This requires advances in many aspects of vehicle autonomy, ranging from vehicle design to control, perception, planning, coordination, and human interaction. Autonomous vehicles, which operates in complex dynamic environments, require methods that generalize to unpredictable situations and reason in a timely manner in order to reach human-level reliability and react safely even in complex urban situations [2].

The SAE International (Society of Automotive Engineers) has define various levels of autonomy ranging from level 0 up to level 5. The daily utility vehicles belongs to level 0 and vehicles where no human interaction is required belongs to level 5. Level 5 automation is yet to be achieved due to limitations in understanding and decision making. Continuous industry and academic effort can facilitate the achievement of level 5 automation system in the near future [3].

Overview of Autonomous Vehicle Technology

Autonomous vehicle technology combines sensors, perception algorithms and advanced control systems to enable vehicles to navigate and make decisions without human intervention. With the integration of artificial intelligence and mapping technologies, these vehicles can perceive their environment, plan routes and execute actions with precision. Safety features and redundant measures ensure reliable and secure autonomous operations.

- **Sensor Integration:** Autonomous vehicles utilize a range of sensors, such as cameras, LIDAR, RADAR, and ultrasonic sensors, to gather comprehensive data about their surroundings.
- **Perception Algorithms:** Cutting-edge perception algorithms process sensor data to understand the environment and identify objects. For instance, computer vision and machine learning techniques are employed to classify pedestrians and detect obstacles.
- **Advanced Control Systems:** Autonomous vehicles employ sophisticated control systems to execute actions in real-time. These systems integrate sensor data and vehicle dynamics to make decisions such as acceleration, braking, steering, and lane

changes. Examples include adaptive cruise control, lane-keeping assist, and collision avoidance.

- **Artificial Intelligence (AI):** AI plays a crucial role in autonomous vehicle technology, allowing vehicles to learn from data and improve performance. Machine learning and deep learning algorithms enable tasks such as object recognition, behavior prediction, path planning, and decision-making in complex environments.
- **Mapping and Localization :** High-definition mapping and precise localization are essential for autonomous navigation. Mapping involves creating detailed maps of the environment, while localization techniques like GPS and SLAM algorithms help vehicles determine their position accurately.
- **Safety Features :** Autonomous vehicles prioritize safety and safety features like automatic emergency braking and blind-spot detection provide additional protection for passengers and pedestrians.

Node-to-Node Communication Protocol

The Controller Area Network (CAN) has become the standard communication protocol in autonomous node-based systems. It facilitates reliable and efficient data exchange between electronic control units (ECUs), enabling seamless coordination among subsystems. CAN's widespread adoption has made it a key component in the development of advanced autonomous capabilities.

Before the widespread adoption of the CAN, several communication protocol advances shaped the automotive industry. Serial Communications Interface Serial Communications Interface (SCI) provided a simple asynchronous serial communication interface, while Local Interconnect Network (LIN) offered a cost-effective alternative for less critical systems. Media Oriented Systems Transport (MOST) focused on high-speed multimedia and infotainment communication, utilizing fiber optics. Inter Integrated Circuit (I2C) facilitated short-range communication within electronic systems, and SAE J1850 served diagnostic and data communication purposes. Although these protocols were not as prevalent as CAN, they paved the way for advancements in automotive communication, contributing to the evolution of more sophisticated and standardized protocols.

Recent achievements in the CAN protocol include the introduction of CAN FD, enabling higher data rates and larger payload sizes for faster and more efficient communication. Enhanced security features, such as Secure CAN (CANcrypt), have been developed to ensure authentication and data integrity within CAN-based systems. Integration with

Time-Sensitive Networking (TSN) enables real-time and synchronized communication, while integration with Automotive Ethernet enhances compatibility with modern vehicle architectures. Additionally, improvements in fault tolerance and robustness have bolstered the reliability and resilience of CAN-based systems.

Practical Challenges

Advancements in vehicle technology and traffic administration have led to a decrease in road deaths in developed countries, while developing countries like India are experiencing the opposite trend. Globally, the number of traffic-related deaths remains high. Autonomous driving can significantly reduce accidents, with a high penetration rate of fully autonomous vehicles and effective traffic management strategies being crucial. However, the increase in vehicle-kilometers traveled may offset the decrease in accidents. Other risks include passenger overconfidence and reckless pedestrian behavior.

2.1 Related work

Robotics and Artificial Intelligence Laboratory researchers at the Tongji University of China have published an article on the architecture design and implementation of autonomous vehicle [4]. The article discussed a practical framework of hardware and software. It describes three typical sensor plans and introduces a general autopilot for the vehicle. The final report contains autonomous driving test implemented using the proposed architecture.

2.2 Related theory

Stereo vision

Stereo vision, also known as stereo vision or binocular vision, is a technique used in computer vision and robotics to extract depth information from a pair of images captured by two cameras, commonly referred to as a stereo vision camera setup. The basic principle behind stereo vision is triangulation, which involves using the displacement or disparity between corresponding points in the two images to estimate the depth or distance of objects in the scene. The stereo vision processing pipeline is as follows:

- **Stereo vision Camera Setup:** Two cameras are positioned horizontally or slightly diverged from each other, mimicking the separation of human eyes. These cameras capture two slightly different views of the same scene simultaneously.
- **Image Acquisition:** Both cameras capture the scene, resulting in a pair of images called the left image and the right image. These images represent the scene from two different viewpoints.

- **Correspondence Matching:** Correspondence matching is performed to find corresponding pixels or features in the left and right images. This process involves comparing the intensity or feature descriptors of pixels in one image with the corresponding pixels in the other image.
- **Disparity Calculation:** Once the corresponding pixels are identified, the disparity or the horizontal displacement between the pixels in the left and right images is calculated. Disparity represents the apparent shift of an object between the two views due to the cameras' baseline separation.
- **Triangulation:** Using the disparity information and known camera parameters (such as the baseline distance and focal length), triangulation is performed to estimate the depth or 3D coordinates of the scene points. Triangulation involves finding the intersection point of two rays originating from the camera centers and passing through the corresponding image points.
- **Depth Map Generation:** By applying triangulation to all the corresponding points in the stereo image pair, a depth map or a disparity map is created. The depth map represents the scene's 3D structure, where each pixel corresponds to the estimated distance or depth of the corresponding object point in the scene.
- **3D Reconstruction and Applications:** With the depth map or the 3D information, it becomes possible to reconstruct the scene in three dimensions. This information can be used for various applications such as object detection, tracking, obstacle avoidance, 3D mapping, and robot navigation.

The accuracy of stereovision-based depth estimation depends on factors like camera calibration, image rectification, the quality of correspondence matching, and the baseline distance between the cameras. Disparity maps can provide valuable information about the scene's depth structure and help in perceiving the 3D environment, enabling more advanced and precise analysis in computer vision and robotics applications.

CAN frames

A CAN frame consists of several fields that together form the message being transmitted or received. The most common type of CAN frame is the Standard Frame, which has the following components:

- **Start-of-frame (SOF):** This is a single dominant (logic 0) bit indicating the beginning of a CAN frame.

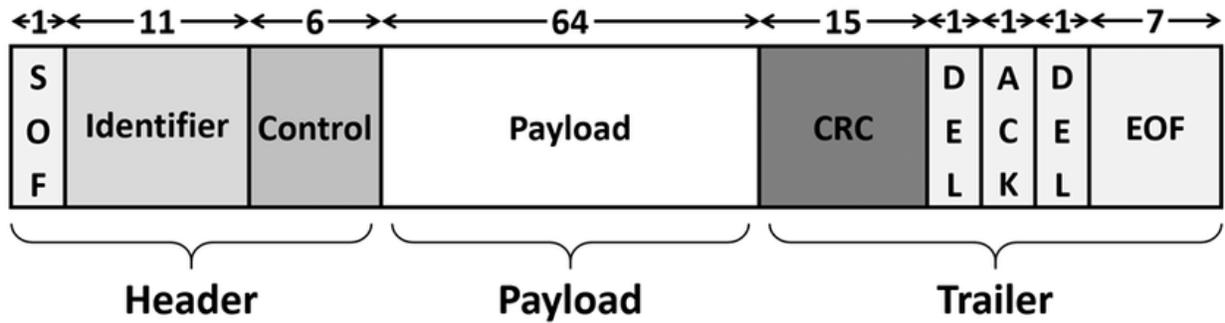


Figure 2.1: Standard CAN Frame Layout

- **Arbitration field:** It contains the identifier or message priority, which is used for determining message precedence when multiple nodes attempt to transmit simultaneously. The arbitration field consists of the identifier (11 bits for standard CAN) and the Remote Transmission Request (RTR) bit.
- **Control field:** This field includes bits for specifying the frame type, such as data frame or remote frame, as well as additional control information.
- **Data field:** This field carries the actual data being transmitted, ranging from 0 to 8 bytes in length. The data field is optional for remote frames.
- **Cyclic Redundancy Check (CRC):** It is a 15-bit or 17-bit field used for error detection. The transmitting node calculates the CRC based on the data and appends it to the frame, while the receiving node performs the same calculation to verify the integrity of the received data.
- **Acknowledge field:** It consists of an acknowledge delimiter and an acknowledge slot. The acknowledge field serves to acknowledge successful receipt of a frame by other nodes.
- **End-of-frame (EOF):** A sequence of seven recessive (logic 1) bits that mark the end of the frame.

CAN frames can be transmitted either in a "broadcast" mode, where all nodes on the bus receive the frame, or in a "point-to-point" mode, where the frame is specifically addressed to a single node.

In addition to the Standard Frame, there is also an Extended Frame format that allows for longer identifiers (29 bits) and more data payload (up to 64 bytes).

CAN frames enable reliable and efficient communication between various electronic control units within a system, facilitating tasks such as sensor data exchange, control signal transmission, and fault diagnosis.

SLAM

Simultaneous Localization and Mapping (SLAM) is a technique used by robots to build a map of an unknown environment while simultaneously estimating their own position within that map. The main goal of SLAM is to allow a robot to navigate autonomously in an unknown environment by constructing a map of the surroundings and estimating its own pose (position and orientation) relative to that map. This process involves several key steps:

- **Data Acquisition:** Robots collect sensor data from range sensors like lidar or depth cameras.
- **Feature Extraction:** Distinctive features are extracted from the sensor data.
- **Data Association:** Features are matched across frames to establish correspondences.
- **Mapping:** Robots incrementally build a map by incorporating observed features.
- **Localization:** Robots estimate their pose (position and orientation) relative to the map.
- **Loop Closure:** Revisited areas are detected, allowing for error correction and map refinement.
- **Optimization:** Global optimization improves the map and pose estimates by minimizing inconsistencies.

SLAM is used in various applications such as robotic navigation, autonomous vehicles, augmented reality, virtual reality, and 3D mapping. It enables robots to explore and understand unknown environments, performing tasks autonomously.

Isolated Redundant Network

An isolated redundant network, also known as a redundant network architecture or a redundant network design, is a system configuration that incorporates redundancy and isolation to enhance reliability and fault tolerance. It is commonly employed in critical infrastructure, industrial control systems, and mission-critical applications where system failures can have severe consequences.

The primary objective of an isolated redundant network is to ensure continuous operation even in the presence of failures or disruptions. This is achieved through the following key features:

- **Redundant Components:** Duplicate components and alternative paths are used to provide backup and redundancy.
- **Isolation:** The network is physically or logically separated from other systems to prevent failures from spreading.
- **Failover Mechanism:** Automatic switching to redundant components or alternate paths ensures uninterrupted operation in case of failures.
- **Network Monitoring:** Robust monitoring tools detect issues early and facilitate proactive measures.
- **Load Balancing:** Traffic distribution optimizes network utilization and prevents congestion.

An isolated redundant network provides increased reliability, fault tolerance, improved performance, enhanced security, and scalability. It ensures continuous operations, minimizes downtime, optimizes resource utilization, reduces the risk of unauthorized access, and accommodates future growth.

3. Proposed Methodology

3.1 Project Management

This project is expected to be on a scale large enough to require quick and efficient task division, work tracking, careful planning in all time scales, etc. As a result we have decided to build a robust project management scheme for our two-team collaboration, giving the role of Project Manager to one of the six members. The project manager shall be conducting all of the aforementioned tasks as well all levels of integration, planning, controlling and monitoring, etc. as mentioned in and in accordance with **Project Management Institute (PMI)'s Project Management Body of Knowledge (PMBOK)**. The team member with the project manager role assigned has drafted a Project Management Plan laying out the planning, controlling and monitoring schemes that will be used during the development and progress of the project. The Project Management Plan document has been attached to this proposal. The project management aspect of the project will be made as official and as close to the actual industry as possible in order to provide legitimate project managing and team-work experience holding proper weight for applications in the industry.

3.1.1 Quality Assurance

With a robust project management scheme, a robust Quality Assurance (QA) scheme is also required. The purpose of this scheme will be to estimate, enforce and monitor the quality of entities and modules built, having a well defined plan for measuring and tracking the quality. This information will be used to alter the plan for the project to keep expectations realistic as well as the workflow to keep quality acceptable. For example, a 3D map of the campus will be required for building the virtual environment for early training and testing (see below), the workflow for which is for the most part unique and improvisational. QA will be responsible for defining the quality of the 3D mapping required, and will monitor the work efficiency, noting successes and failures, to help in the future. Since a large portion of the project is defining layers, modules, their abstraction, their interfacing etc. their quality will be defined as how flexible they are with their abstraction, how universal their inputs and outputs are, etc. All these definitions will be managed by QA.

QA will be integrated with the project management activities, and the role of *Quality Assurance Manager* will be given to one of the six team members. This role (not necessarily the assignment) has been separated from the project manager role to stress its importance

and build a separate abstracted scheme. Common practice is to have a dedicated team for QA, however, since our team is small, this will be limited to one of the roles of a single member, with flexible coordination with other members for any problem solving and information gathering involved.

3.2 Scale of the Project

Now it is necessary to define our project assumptions. We have planned to create a go-cart sized(around 78" long, 25" tall and 52" wide) vehicle which will be controlled by the use of Brushless Hub motors like those found on electric scooters. The rear of the vehicle will the two of these motor and the front wheel will be coupled for steering action. The steering will be a drive by wire concept utilizing a system to decouple the steering from the user. Battery Packs will be stored in the vehicle. The vehicle will also have an infotainment system to provide a real time feedback of what the system is doing.

When we are behind a vehicle we have a perspective of the environment around the vehicle and can adapt to changes within the environment instantly. This is difficult to achieve in a autonomous system and all of the system and environment perception should be calculated and handled by the system itself. The system would be able to counteract the changes instantly by itself. A vehicle design takes a lot of research and work. The difficult aspect before any mass production is creating the vehicle itself. We are not looking for mass producing this vehicle and neither we want to spend time on any aesthetics of the system. So taking that out of the equation, still the main aspect of any vehicle is the chassis. The chassis needs to designed from scratch which adds about 1 month of work hours for a team of six like ours.

As listing our working domain, we have to complete the task from Printed Circuit Boards (PCB) designing, circuit layout, sensor placement, communication design, protocol interface, embedded firmware development, real time operating systems, linux socketCAN, CAN protocols, system errors and exceptions, Software Development Kit (SDK) design or Application Protocol Interface (API) design, mapping, slam, mechanical gears and tools, welding, CAD, simulations, machine learning, multi layer model deployment and much more to be expected. It is sure that this is a very engaging project and will populate most of our effort in it.

The system design requires a thorough introduction to how each component would play a role in the system. Since this is an node based isolated system each node is system by itself. This contributes to a lot of work to the team but brings a trade-off.The system is modular and can be replaced at node if any error occurs. Also about the system level exception and reporting protocol that needs to defined. For a team like ours we are estimating this alone

could take around 2-3 months of active work. And we are not even in the tuning part of the system yet, as each nodes needs to be tuned to the sensor, motors, or transducers they are connected to. This alone could take 2 months of active work for optimizing the system.

Now the system can be controlled but we need a way to send command to the system and show its status on a dashboard. Some UI design, control tweaking would take some more amount of our time. After this is the main part of the system, making is autonomous and providing a abstracting SDK to build on top of our hardware or creating an API to which the higher level software can connect and send commands. We need to expose all of our real-time data to the upper layers of Machine Learning models. This is the part to combine the work of the Machine Learning part of the system. So both of the team needs to run in parallel to make sure that they achieve the goals on time and none of them act as throttling each others job. The collaboration alone can take 3 months to complete. Therefore the hardware team can expect active work of around 8 months for the system to be complete. Of course many task can run in parallel and multiple task can make it easy for other tasks to be complete.

3.3 Autonomous Region and Environment

The world for the vehicle is where it is able to provide its services. Mapping a large area requires a lot of time and effort. For this vehicle we have chosen the world to be Pulchowk Campus CIT block. We will be utilizing all the roads present in there, where the vehicle is free to roam about provided that instructions are given to it. With human supervision the vehicle can be taken anywhere the user wishes. A mapping needs to be done of Pulchowk Campus to provide a digital environment to the vehicle.

3.4 Absolute and Relative Positioning of the Device

We need to keep in track where the vehicle is so that we can direct the vehicle towards where its needs to go. For this we need to know the position of the vehicle. We are going to use a GPS based system with Simultaneous Localization and Mapping (SLAM) to pin point its exact location. The directive constraint is provided via an Inertial Measurement Unit (IMU) that is on the device.

3.5 Team and Work Division

We are a team of three individual with a diverse set of skills. The work will be divided on the basis of our individual skill set. With this classification we have divided our work under multiple categories so that it is easy to evaluate each work.

1. Mechanical Work

One of our team member has some experiece in mechanical work and with the assisted tools in the Pulchowk Robotics Club all of our mechanical work will be completed under supervision of that team member. The mechanical parts include the frame and all the actuator that we need to build on our own.

2. **Electronics and Embedded Systems**

We are a students of on this very domain and are quite familiar with the system we need to develop so this work will be divided equally if not based the amount of work each team member has.

3. **Programming Based Work**

This is similar to that of the before as it will be divided among all of the members.

4. **Protocol and Contract Defining Work** This lays a foundation on how the system should collaborate so all of need to be there to lay the groundwork for this work.

5. **CAD Based Work**

One of our member has previous experience in CAD based work using Fusion 360, Solid Works and Free Cad and another member has experience in Blender. So the CAD based work will be divided among these individuals.

6. **PCB Design and Fabrication Based Work**

One of our member has an excellent record of PCB design during their time in Pulchowk Campus so this work will be issued to them.

3.5.1 Collaboration Team

The hardware and software part of the system are vague by itself and requires a lot of work in each aspects. Two teams are present which represent each of the hardware and software part of the system. Here hardware refers to the controllable system design and software refers to the controlling system design. Both teams are not only to complete each of their task but collaborate throughout the process about each and every decision that are to be made throughout the development, as every single changes will effect both the teams. So a collaborative effort is to be made between the team defining what they are doing and pitching in the necessary developments to the other team so that they can bring those changes in their domain. Both teams will work independently with a timely update from each side. The integration part of the system may start as early as the project initiation and will be active throughout the development. This is why we have chosen a project management based approach so that each system is documented and each members are aware of what is going on in the system.

3.6 Equipment, Tools and Devices

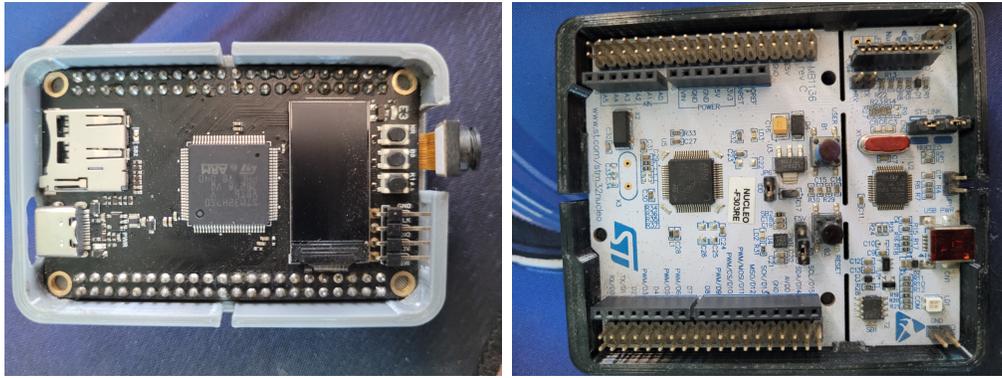
These are the devices that we will be using in the system or will be used to design the system.

- **3D Printer** One of our team member has access to a 3D Printer, so all of our CAD based work will be brought to life using this machine. This enables us to create parts that are unimaginable with handwork.



Figure 3.1: A bed slinger 3D printer

- **Micro controller** We have a range of micro-controllers from STM32 like F4,F3,M0,H7 series. With a total of 10 micro-controller we have an ability to create isolated redundant systems.



(a) Master Controller

(b) Node Controller A



(c) Node Controller B

Figure 3.2: Micro-controllers

- **CAN Transceivers** These form the physical layer of our CAN Bus protocol.

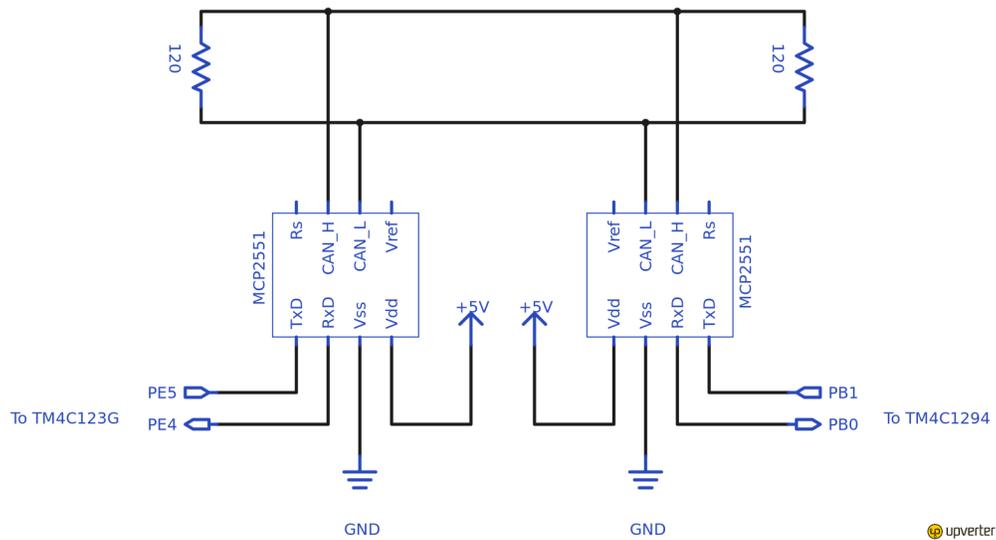
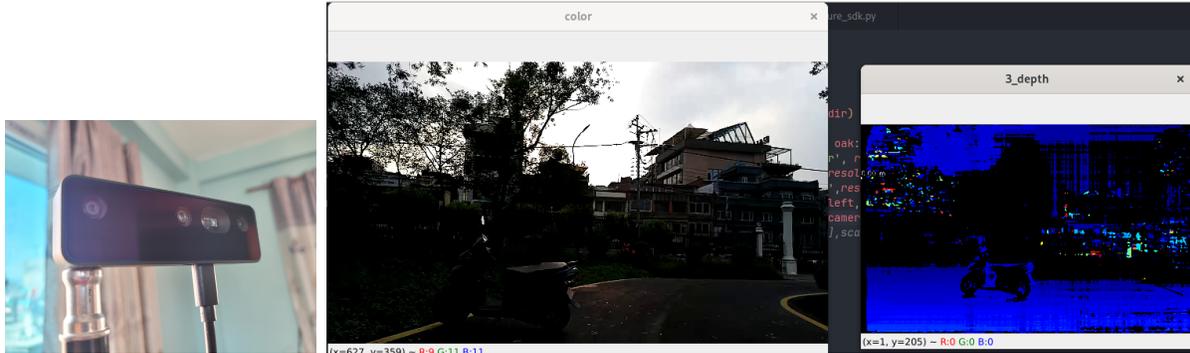


Figure 3.3: CAN Transceiver

- **Stereo-Vision Camera** A stereo-vision camera works on the basis disparity and triangulation to produce depth feedback from the environment. We are utilizing the depth sensor to provide a feedback to the system about the path, roadways and obstacle that are present in front of the vehicle.



(a) Camera

(b) StereoVision of Camera

- **Main Board (Logic Board)** A real-time mapping should be provided to the vehicle using the sensor in the vehicle. There is requirement to process multiple camera feed and data from the sensors in the vehicle to provide feedback to the vehicle. These enormous processing requires a lot calculation and needs to process multiple ML models. With this in mind we have got a hold of a board that is capable to process these information in real time. The board is based on ARM architecture and is one of the fastest Single Board Computer (SBC) available till date. It is a Rockchip RK3588 based SBC. We will be using linux with SocketCAN to communicate with our low level CAN BUS. This will have a contract with the CAN Master Controller and can provide instruction to the the vehicle.



Figure 3.4: Main System Board

4. Proposed Experimental Setup

4.1 Node Level Isolated System

Each node of the CAN bus, such as the acceleration node or braking node, is carefully isolated from one another to ensure optimal performance. This isolation is achieved by assigning each node its own micro-controller, allowing operations specific to that node to be carried out independently. By operating in isolation, the functions of one node do not interfere with the operations of other nodes, thereby enhancing the speed and efficiency of the entire system. Each node is capable of receiving message packets from other nodes or the master controller, and based on the content of these messages, it performs the necessary tasks. The isolation of nodes not only contributes to reliable and robust communication but also necessitates the use of a custom CAN protocol. Designing this custom message communication protocol involves the meticulous debugging of packets using tools such as oscilloscopes and signal analyzers, ensuring the smooth and accurate transmission of data across the CAN bus.

4.2 Communication Protocol Design

Designing a custom CAN bus communication protocol requires careful consideration and adherence to certain principles. Here are some steps to design a custom CAN bus protocol:

1. **Define Communication Requirements:** We start by clearly defining the communication requirements for our specific application. We identify the types of data to be transmitted, their priorities, message formats, and any specific timing constraints. We consider the desired network topology and the number of devices that will be connected to the bus.
2. **Identify Message Structure:** We determine the structure of the messages that will be transmitted over the bus. This includes the identification of message IDs, data fields, and any additional control or status information that needs to be included. Decide on the data formats, such as binary, hexadecimal, or ASCII.
3. **Define Message Arbitration:** CAN bus uses a priority-based message arbitration scheme to determine which message gets transmitted when multiple devices attempt to send data simultaneously. We then define our custom arbitration scheme, considering

factors such as message priorities, message IDs, and the algorithm for resolving bus contention.

4. **Error Handling and Recovery:** We plan how your custom protocol will handle errors and recover from them. We define the error detection and error handling mechanisms, such as checksums, CRCs (Cyclic Redundancy Checks), and acknowledgments. Then, we determine the actions to be taken when errors occur, such as re-transmission or error notification.
5. **Frame and Bit Timing:** We then specify the frame format and bit timing parameters for your custom protocol. The length of the data frame, the number of bits for the message ID, and any additional fields required are determined. Then, the bit timing parameters, such as bit rate, sample point, and synchronization requirements are also determined.
6. **Protocol Implementation:** We then implement our custom CAN bus protocol in software or hardware, depending on the needs. Then the necessary firmware or drivers to handle the protocol on the transmitting and receiving devices are developed. We then test the implementation thoroughly to ensure its correctness and compliance with the desired specifications.
7. **Verification and Validation:** We need to perform rigorous testing and validation of our custom CAN bus protocol. we have to test it under different scenarios, including normal operation, high-load conditions, and error conditions. we need to verify its performance, reliability, and adherence to the defined specifications.

4.3 PID Tuning and System Calibration

The system may have errors, you may not achieve the required output in the system due to mechanical deformities and environmental factors. This variations in the required output of the system and actual output of the system can be minimized and system can be calibrated using the technique called PID(Proportional, Integration, Derivative) tuning. PID tuning uses PID controller which has three constants(K_p , K_i and K_d) that can be manipulated.

PID controller is one of the most popular closed-loop controllers which is used in the automation industry. By fine-tuning 3 constants, you are able to achieve a system which is almost free from any errors. [5]

In a PID controller, we calculate an error $e(t)$ as the difference between the desired set-point and the current value(process variable) and pass it as a feedback signal. The error $e(t)$ is then corrected based on the proportional(p),integral(i) and derivative(d) terms.

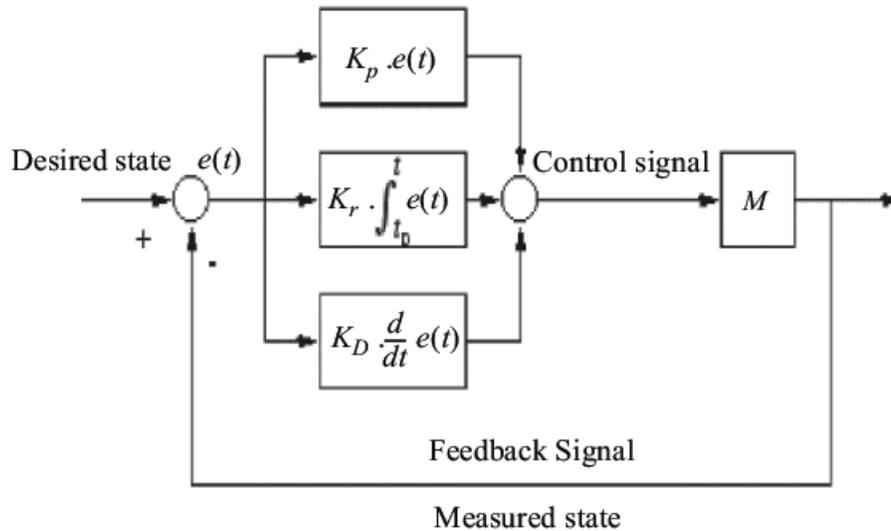


Figure 4.1: PID Controller

We'll use a genetic algorithm to find the 3 constant values (K_p , K_i and K_d).

As the name implies, the PID controller provides three separate actions on the error signal to produce the controller output, proportional, integral, and derivative. The proportional action produces an output proportional to the error signal $y(t) = K_p * e(t)$. Thus, no proportional action will result when the plant output is equal to the set point, since the error is zero. As the proportional gain K_p is increased the controller will produce a larger signal in response to an error. This amplification of the error signal will result in a faster response to errors, but may also add instability. These effects are quantified by the response having a shorter rise time, and an increase in the percent overshoot. Conversely, reducing the proportional gain will reduce overshoot but will increase the steady state error.

The derivative action provides a control signal proportional to the time rate of change of the error signal. $y(t) = K_d * de(t)/dt$. The derivative term provides an anticipatory element to the controller, providing larger controller response to rapidly changing error signals, and smaller response to slower changes. This permits a faster system transient response without increasing the percent overshoot. The derivative action alone has little effect on the steady state behavior of the system. It cannot remove a fixed error (constant steady state error) since the derivative of a constant is zero. Therefore, the derivative element of the PID controller would produce zero output to a non-changing error.

The integral action produces an output proportional to the accumulated (integral) of the error signal, allowing the controller to zero the steady state error between setpoint and system output. $y(t) = k_i \int e(t)$. From a control system theory perspective the integrator term improves the steady state performance because it increases the "system type" by one by adding a zero at the origin. Intuitively, the integral element insures that even small errors

will eventually amass to produce significant controller output. The combination of the three actions is summarized as

$$y(t) = K_p * e(t) + K_d * de(t)/dt + k_i \int e(t) \quad (4.1)$$

In equation 4.1, $y(t)$ is the system output, $e(t)$ is the error signal, K_p , K_i , and K_d are the proportional, integral, and derivative gain constants. The selection of the three constants K_p , K_i , and K_d , to achieve a specific response is known as tuning. Manual tuning consists of adjusting the three gain factors in a systematic manner using multiple trials.

After obtaining the mathematical model of our system, we can use MATLAB software to obtain the best possible value of K_p , K_i , and K_d . Using these values our system shall be calibrated.

4.4 Exposed System Parameter For Varied System Response

Our system offers the flexibility to tune various parameters of the vehicles according to specific preferences and requirements. Parameters such as brake bias, acceleration gain, battery current limit, throttle gain, speed limit, acceleration curve, motor sync parameters, steering motor gain, steering motor curve, and steering motor limits can all be adjusted.

All these parameters are exposed and can be updated via the controller with a set of administrative commands in the upper layer of the system in real-time, allowing for adaptive tuning. which means that the lower layer of the system can have a simpler design, as the complex calculations and feedback can be handled by the upper layer. By providing a mechanism to update these parameters, the system becomes more manageable, eliminating the need for firmware modifications on individual nodes. This indeed means calibration of the system is essential before use but we can store these parameters permanently in the memory of the main controller so when it wakes up it updates all of these parameters to a default state.

4.5 RC Based Initial Design

Our end system will pose different challenges when it comes to modifications, as each change becomes increasingly expensive as we scale up. We do not have the option to completely abandon the current idea or design if it doesn't work out, especially since we are working on the end product. This situation carries a huge amount of risk. Therefore, to adopt a more manageable approach is followed. We have decided to create a small-scale 1:1 Remote controlled vehicle which will be representative of the final product. This approach allows us the flexibility to make changes as we progress in our project. While it may not be possible

to achieve a perfect replica of the end system, this strategy will effectively eliminates most of the design issues that arise in the early stages, thus preventing wastage of the time and resources

4.6 Mechanical Based System Design

In order to achieve our desired outcome, we must carefully design the individual mechanical components that will facilitate the translation of motion from various actuators or motors to trigger the mechanical system. Each aspect of the system will be given individually designed ensuring that we establish a clear understanding of how the electrical feedback can be effectively translated into mechanical feedback.

5. Proposed System Design

5.1 How does the system work?

The system works with the combination of different nodes and controller that can be divided into functional layers. Various data packets, messages, control signals are passed between the different layers for proper functioning of the system. The different layers are:

5.1.1 Layer 1: Actuator Sensor Transducer Layer

This layer acts as a physical foundation to connect the mechanical system of the vehicle to the electronically controlled systems. A sensor acts in reporting the current state of the mechanical system, a transducer acts in bidirectional communication to the mechanical parts, an actuator acts in helping the system achieve a given command.

5.1.2 Layer 2: Node Control Layer

A node represents an isolated system that can react on its own in the universe that is the vehicle. A node contains a range of sensors, actuator or transducer. A node consists of the following components, micro-controller(CPU), CAN controller, and CAN transceiver that is able to read the current status of the system and report its information to the higher layer. Making an independent node allows the system to be robust to include multiple nodes if required as a redundant system. A node is also able to receive commands from the upper layer to perform a given set of tasks. A ML network will be initiated within the micro-controller which will be able to identify anomalies of the system or update its parameter on the fly. A simple example would be correcting the power level fed to the motor by the battery management system in a range of voltage fluctuation as per the road conditions or the type of the road terrain.

5.1.3 Layer 3: CAN Layer

A Controller Area Network is what we will be using for the communication within the nodes. A CAN Bus is a multi-master bus that runs parallel to each other in real time. The Bus is shared and all the nodes are not able to send data at the same time to other nodes. The Shared Bus allows the system to communicate with only two wires throughout the system. CAN itself has multiple layers which define things like cable type, electrical signal, node requirement, cable impedance e.t.c. Multiple types of CAN Bus are available, the one we

will be implementing is a High Speed CAN which has a bandwidth of 1 Mbits/s. The CAN Bus as two layers. They are:

- **Physical Layer of CAN:** CAN layer offers two wire communication, the wires are twisted and are a differential pair represented as CAN_H (can high) and CAN_L (can low). Termination resistors are present at each end which matches the nominal impedance of the wire.
- **Controller Layer of CAN:** A controller layer is responsible for the transmission and reception of messages between nodes. It performs activities like arbitration of messages and the error detection and handling.

Advantages of CAN bus

The advantages of a CAN bus system are as follows:

- **Low Latency:** CAN bus utilizes message prioritization based on its arbitration rules, enabling critical messages to take precedence over less critical ones. This ensures that time-sensitive or safety-critical data can be transmitted without delays or interruptions.
- **Reliability:** The CAN bus wiring system is less vulnerable to electromagnetic interference and electrical noise due to the use of twisted-pair cables. It decreases system complexity by employing a pair of wires for each Electronic Control Unit (ECU).
- **High Data Rate:** The CAN bus offers data rates ranging from 1 kbps to 1 Mbps, depending on the implementation. It is defined by two physical layers: High-Speed CAN (CAN-H) and Low-Speed CAN (CAN-L).
- **Scalability:** The network architecture of a CAN bus is easily scalable, allowing for the integration of additional nodes or components. New nodes can be added or removed, and the network can be expanded as needed.
- **Error Detection and Fault Tolerance:** CAN bus utilizes several mechanisms for error detection, including bit stuffing, bit monitoring, frame check, acknowledgment check, and cyclic redundancy check (CRC). These mechanisms ensure data integrity and detect transmission errors. The protocol also supports error handling and fault recovery, ensuring reliable data transmission.
- **Cost-Effective:** The hardware required for implementing a CAN bus network is relatively affordable. Additionally, CAN bus has minimal signal processing requirements,

making it cost-effective. It is considered an ideal solution for embedded applications requiring multi-processor communication on a budget.

- **Wide Industry Adoption:** CAN bus has gained widespread acceptance in industries such as automotive, industrial automation, aerospace, and more. This broad adoption has led to a wide range of compatible devices, tools, and software, making it easier to integrate and develop systems utilizing the CAN bus.

5.1.4 Layer 4: System Control and Master Initiator Layer

Node Status are read by this control layer, it can control the other nodes in the network, handle system exceptions, reset the system to the default state, handle system errors and compensate for the errors, and translate the user interaction to the system. The system runs a higher level ML network which will be able to identify the current system status and adjust to various environmental factors in real time. This is the controller that provides all the information on how the nodes should react.

5.1.5 Layer 5: Environment Data Collection Layer

Multiple cameras will be employed within the system to understand the environment the system is in. The cameras we will be using are stereoscopic cameras which will understand the depth of the objects around it. Also the lower layer sensor information from the depth sensors will be accessed and transformed. A SLAM based environment will be employed to locate the system. The system will also employ a GPS for real time location mapping.

5.1.6 Layer 6: Computing and Processing Layer

This layers runs application which takes all the feedback from the layers below and provides a general procedure on what the system need to do next.

5.2 Nodes of the Vehicle

Humans can take over the control of the vehicle whenever required, so every node of the vehicle can take inputs from both humans and AI. Both input mechanisms will be different and separated from one another. Every node shall be designed in such a way that switching between human control and AI control can be achieved by clicking a button.

Following are the nodes of the vehicle:

5.2.1 Master Controller

Master Controller is the master of the CAN Bus system, attached with all the nodes, it initiates the communication, sends the message packets for operations in nodes and receive

the information regarding state, operation and health of the node. It takes input from the AI computation, and transducers that generates signals on the basis of human input.

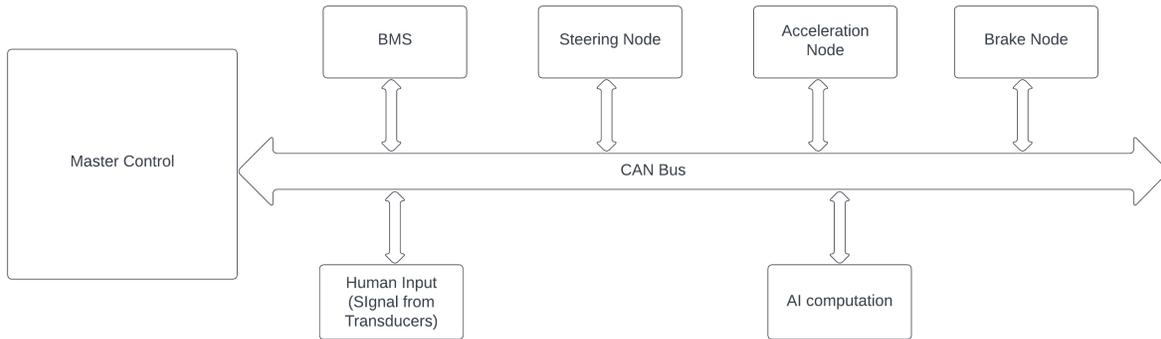


Figure 5.1: Master Controller of CAN BUS

5.2.2 Acceleration Node

This node is responsible for acceleration and de-acceleration of the vehicle. it operates when the master controller sends the message packets requesting for acceleration or de-acceleration of the vehicle. When it receives the signal from the master controller, it then sends signals(PWM signal) to the motor controller. This node sends the message packets to the master controller which includes the acceleration value of the vehicle and other operations of node.

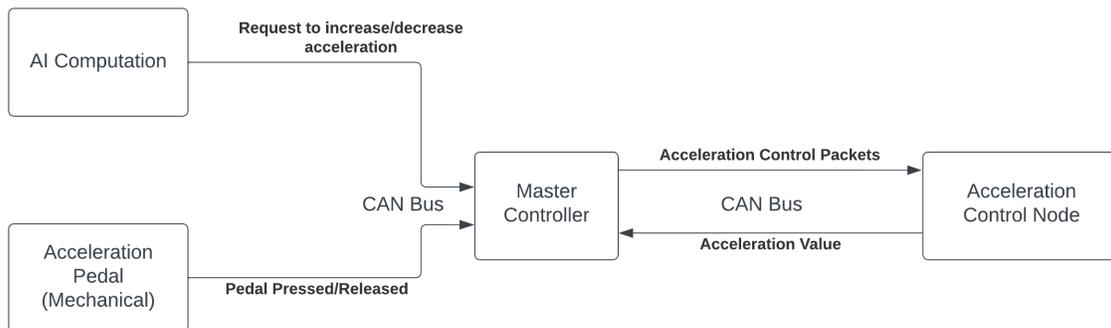


Figure 5.2: Acceleration Node connected to CAN Bus

5.2.3 Brake Node

This node is responsible for applying the brake of the vehicle. it operates when the master controller sends the message packets requesting to apply brake or release the brake. When it receives the signal from the master controller, it then sends signal to the actuator which applies physical brake. This node sends the feedback message packets to the master controller which includes the amount of brake pressed and other health of the node. When the vehicle is turned off, the brake is applied.

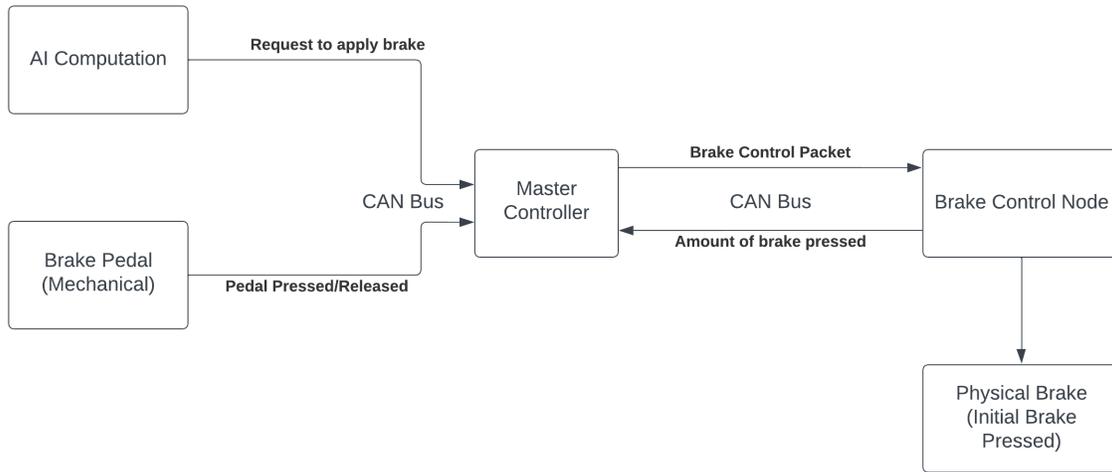


Figure 5.3: Brake Node connected to CAN Bus

5.2.4 Steering Node

This node controls the steering of the vehicle. It operates when master controller sends the packets requesting to change the steering angle of the vehicle. It then sends the signal to the actuator (Power Steering Motor) of the vehicle. This node sends the feedback message packets to the master controller which includes the current steering angle of the vehicle.

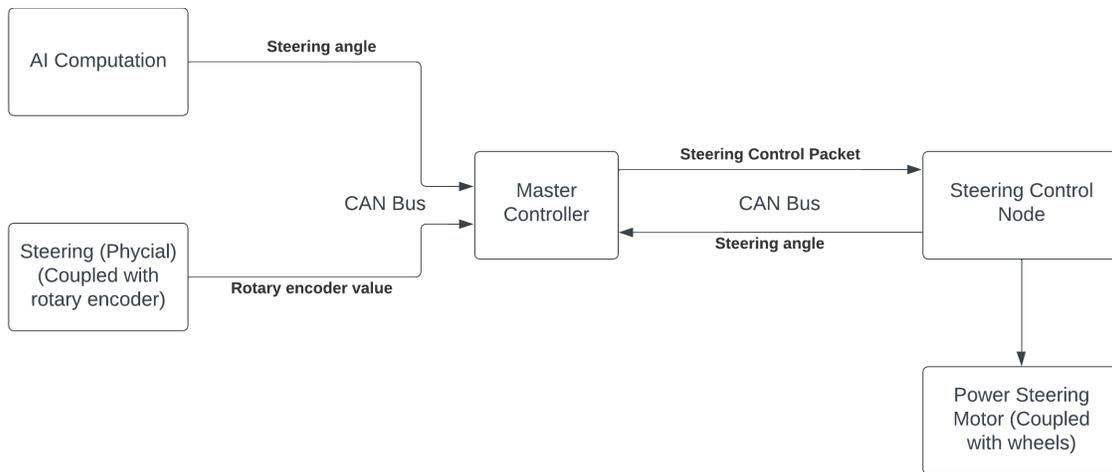


Figure 5.4: Steering Node connected to CAN Bus

5.2.5 Battery Management Sytem(BMS) Node

This node is responsible for charging and discharging of the battery packs of the vehicle. During charging of the vehicle this nodes balances the charge among the each cell of the packs avoiding any hazardous situation. It discharges the battery packs according to the need as requested by the master controller. This node sends the feedback message packets which

includes the State of Health(SOH), State of Current(SOC) and State of Temperature(SOT) of the cells to the master controller.

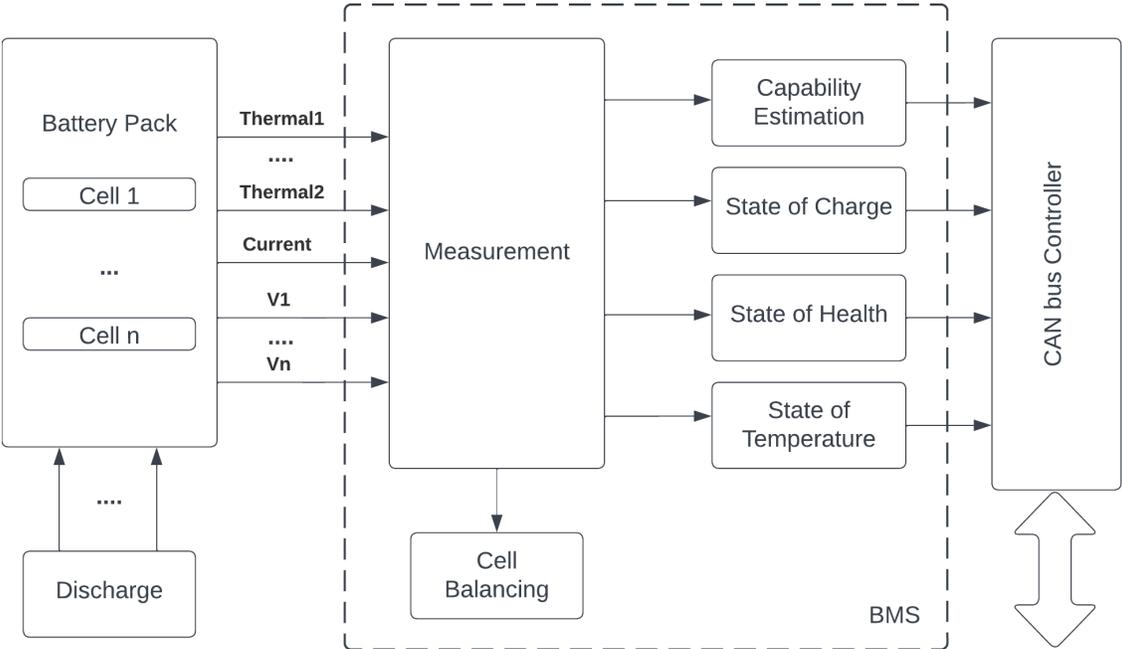


Figure 5.5: BMS Node connected to CAN Bus

6. Timeline

The various works needed to for the completion of this project are divided into 10 months duration starting from June of 2023. These tasks can be viewed in the Gantt Chart below:

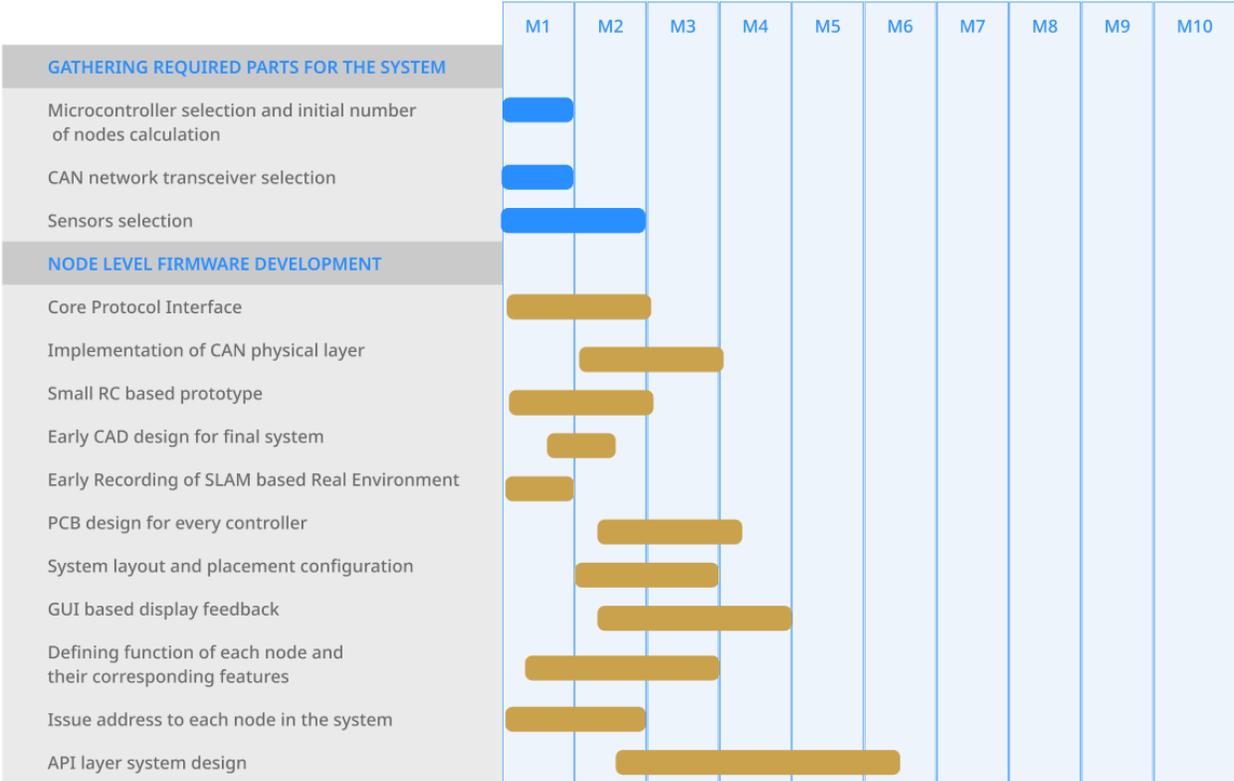


Figure 6.1: Gantt Chart (First Half)

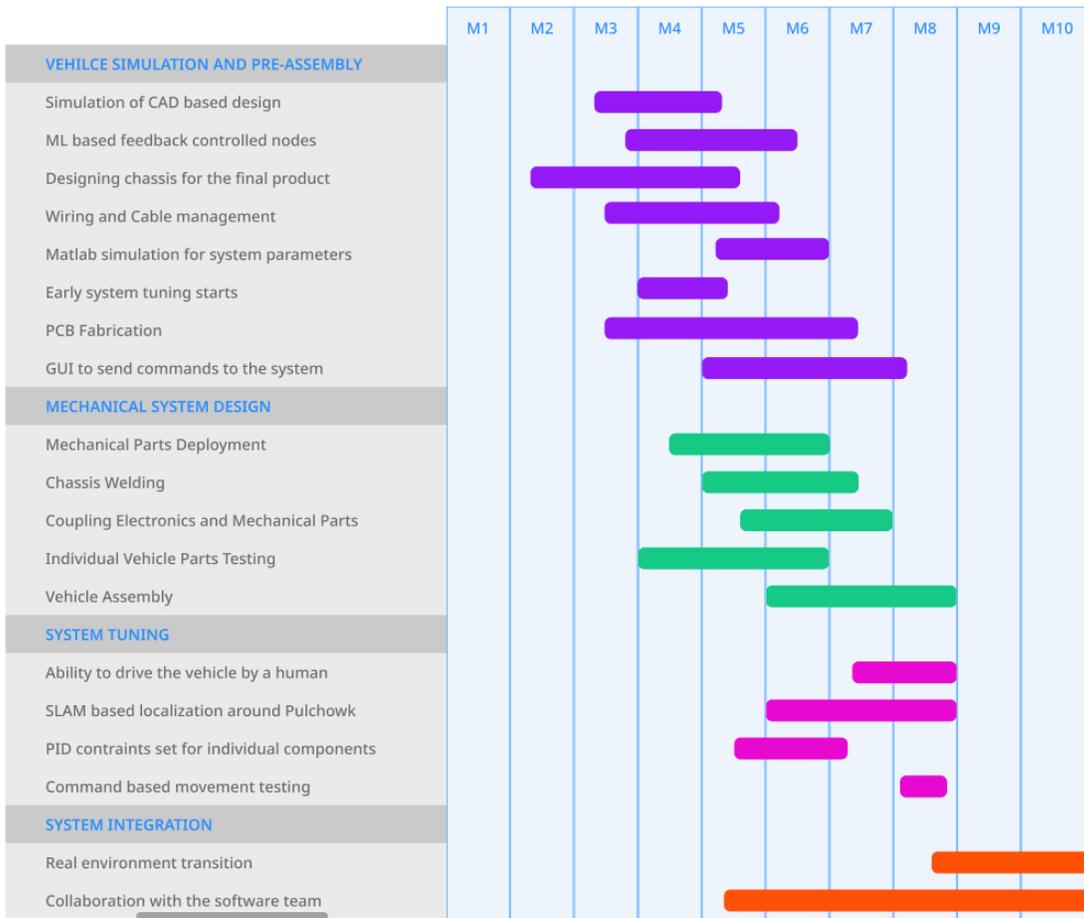


Figure 6.2: Gantt Chart (Second Half)

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