Project Title: ***AUTONOMOUS TRAM SYSTEM***
Team ID: **20**

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Introduction

Problem Statement

Tram systems have long served as an efficient mode of urban connectivity, effectively reducing traffic congestion and enhancing public transit accessibility. However, the deployment of urban rail transit projects like these is frequently hampered by the high upfront costs and inflexibility of fixed-track infrastructure. These limitations delay deployment and restrict scalability, particularly in rapidly growing urban areas.

Proposed Solution

To address this, our project proposes an autonomous, line-following tram system that eliminates the need for physical tracks, leveraging IoT-enabled stations and cloud-based decision-making. The tram navigates using infrared (IR) sensors along a predefined path, while the tram stations employ IR and ultrasonic sensors to monitor passenger occupancy. Real-time data from these stations is uploaded to the ThingSpeak cloud platform, enabling the tram to dynamically adjust its stopping duration based on passenger demand and its current capacity. This trackless approach not only reduces infrastructure costs but also optimizes passenger wait times and resource utilization. Due to its autonomous nature, it also reduces labour costs significantly when compared to more traditional forms of urban public transportation.

Objectives

This project is divided into three stages. In Stage 1, we focus on developing a functional prototype: a line-following tram with IR navigation, IoT-enabled tram stations that monitor occupancy, and cloud integration for real-time data exchange. Stage 2 will focus on polishing and enhancing the system with additional features like tram capacity checks, and Stage 3 is for the stretch goals; the features to be implemented if there's enough time, such as obstacle detection, and switching to a PCB model. The objectives for each stage are listed below.

Stage 1: Basic Features

- ➢ *Develop a line-following tram model that uses IR sensors to navigate predefined routes.*
- ➢ *Deploy IoT-enabled tram stations with IR and ultrasonic sensors to count passenger occupancy at each station.*
- ➢ *Collect real-time occupancy data and upload (publish) it to the ThingSpeak cloud platform.*
- ➢ *Enable the tram to subscribe to the station occupancy data on ThingSpeak and dynamically adjust stopping duration at each station.*

Stage 2: Polishing

- ➢ *Ensure sensors placed at stations can distinguish humans from animals, so as to prevent false triggers (for example, one way to achieve this can be to place the sensors at shoulder-height).*
- ➢ *Integrate a capacity check for the tram, so that it only stops for passengers if it is not full to capacity.*

Stage 3: Additional Features

- ➢ *If possible, we will try to incorporate additional functionality for detecting obstacles on the path (e.g. using ultrasonic sensors) and stopping the tram accordingly, to prevent accidents.*
- ➢ *Convert the final prototype into a PCB-based hardware model to increase robustness and stability.*

Deliverables

- ➔ *Functional line-following tabletop tram prototype (scale model) equipped with IR sensors for path detection, DC motors and a motor driver for movement and navigation, and a microcontroller (ESP32) for real-time decision making.*
- ➔ *Deployment of IoT-enabled tram stations at a minimum of three locations on campus (for data collection and publishing purposes), using ultrasonic and IR sensors to measure occupancy data. The tabletop model will dynamically adjust stopping duration based on the data collected in real-time from the deployed stations, implementing a kind of **real-time hybrid scale model**.*
- ➔ *Cloud dashboard on ThingSpeak for monitoring station occupancy and tram status. This real-time display of data from the project would help provide a comprehensive overview of its working.*

Hardware Requirements

Components:

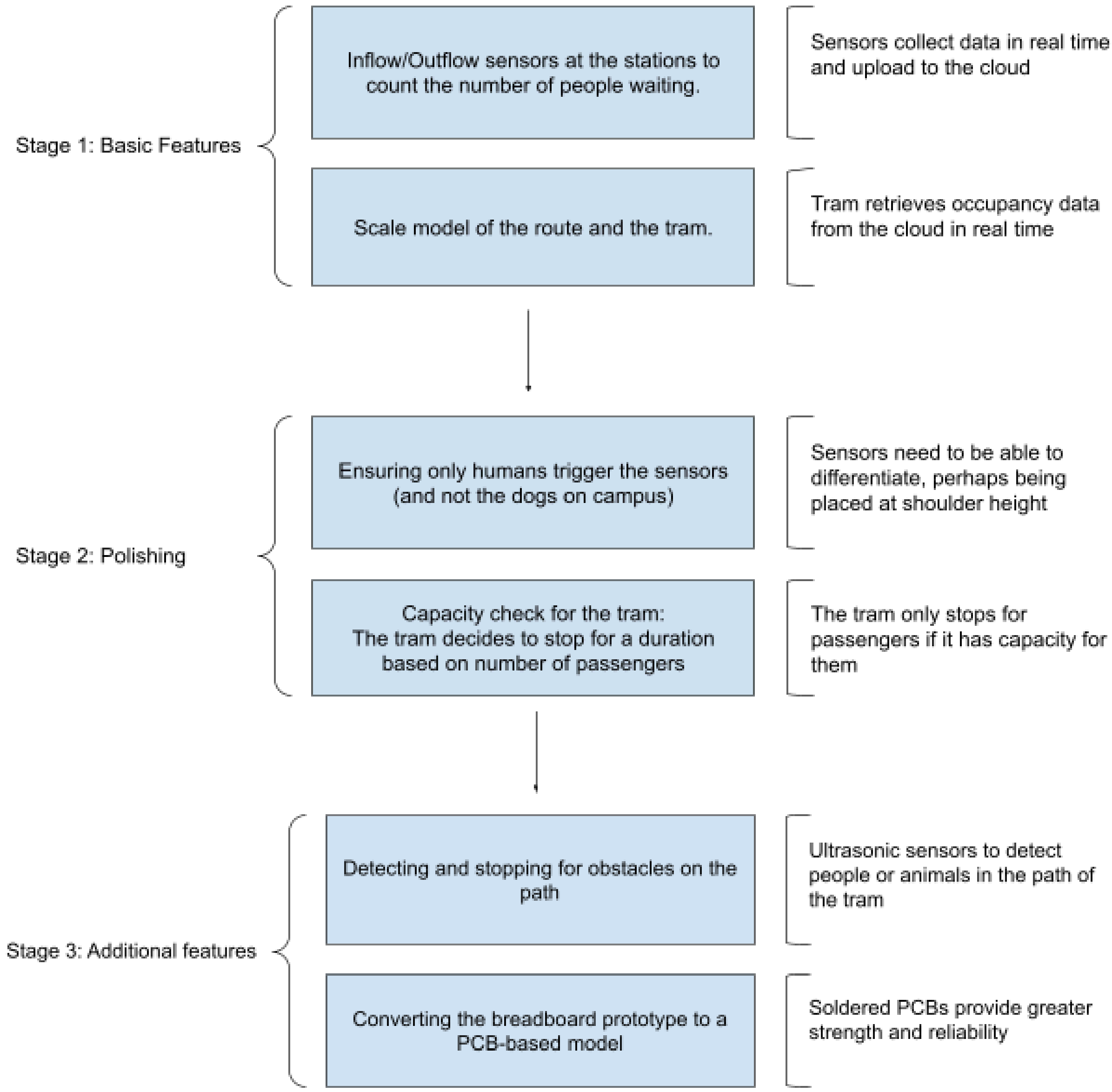
1. ***Sensors***
   - 1.1. *For the Tram*
     - 1.1.1. *HW201 IR sensor (x3)*
   - 1.2. *For the Stations*
     - 1.2.1. *HC-SR04 Ultrasonic sensor (x10)*
     - 1.2.2. *HW201 IR sensor (x5)*
2. ***Actuators***
   - 2.1. *For the Tram*
     - 2.1.1. *DC BO Motor (x2)*
3. ***Controllers***
   - 3.1. *For the Tram*
     - 3.1.1. *TB6612 Motor Driver (x1)*
4. ***Miscellaneous Hardware***
   - 4.1. *ESP32 (x5)*
   - 4.2. *Chassis and wheels*
   - 4.3. *AA Battery (x4)*
   - 4.4. *Jumper Wires*

Component	***Purpose***	***Implementation***
HW201 IR Sensors (Tram)	Detect and follow predefined line path for navigation	Mounted at the front of tram chassis; calibrated to distinguish line from background based on amount of IR light reflected
HC-SR04 Ultrasonic Sensor (Tram, optional)	Obstacle detection to prevent collisions	Installed on tram front; triggers emergency stop if obstacles are detected
HW201 IR Sensors (Stations)	Detect passengers entering/exiting the station	Mounted at station entrance/doorway; placed at shoulder height (1.5–1.8m) to avoid animal triggers
HC-SR04 Ultrasonic Sensor (Stations)	Detect passengers entering/exiting the station	Mounted at station entrance/doorway; placed at shoulder height (1.5–1.8m) to avoid animal triggers
DC BO Motor	Drive tram wheels for movement	Paired with TB6612 motor driver for speed/direction control via PWM
TB6612 Motor Driver	Control motor speed, direction, and torque	Connected to tram's ESP32; configured to receive PWM signals for precise motor control
ESP32 (Tram)	Process navigation logic, sensor data, and cloud communication	Hosts code for line-following, obstacle detection (optional), and subscribing to ThingSpeak data
ESP32 (Stations)	Collect, process, and upload station occupancy data to ThingSpeak	Wired to IR/ultrasonic sensors; runs edge computations and transmits data to ThingSpeak
Chassis & Wheels	Provide structural support and mobility for the tram	Lightweight, modular design with 6.5 cm wheels; accommodates sensors, motors, and battery placement
AA Batteries	Portable and reliable power supply for tram electronics	Ensures untethered operation during testing.

Pricing:

Component	***Quantity***	***Cost Per Unit***
HW201 IR Sensor	8	₹308
HC-SR04 Ultrasonic Sensor	10	₹50-60
DC BO Motor	2	₹60-90
TB6612 Motor Driver	1	₹160-190
ESP32	5	₹300-330
Chassis	1	₹470-530 (total kit cost)
Wheels (6.5 cm diameter)	2	
Universal Wheel	1	
AA Batteries	4	₹20

Hardware Features:



The above flowchart illustrates the hardware features we intend to implement in our project.

Data Collection

Overview

Data collection is central to the tram's decision-making process. The tram stations deployed act as IoT nodes, gathering occupancy metrics to inform the tram's actions. This data is then transmitted to the cloud, where it is processed and made accessible to the tram in real-time, allowing it to dynamically adjust stopping duration at each station.

Collection Methodologies

- To simulate realistic tram station dynamics, we currently plan to deploy IoT sensor modules for the tram stations in at least three locations on the IIIT-H campus. Since the locations chosen would need to have sufficient footfall to simulate an actual tram station, we have selected the following deployment points for our sensor modules: the Vindhya A6 entrance, the Nilgiri entrance and the OBH entrance.
- We plan to use a combination of IR and ultrasonic sensors to measure inflow/outflow data of passengers into or out of the stations, thereby allowing us to calculate station occupancy. This would give us an idea of the number of passengers waiting to take the tram. The sensors will be mounted near the main doorway/entrance and will be connected to an ESP32, which can process the sensor data locally, perform edge computations to derive real-time station occupancy metrics, and publish this data to the ThingSpeak cloud platform.
- This data collected and published in real-time would provide live data that is integral for the hybrid model. The tabletop tram prototype subscribes to the ThingSpeak channels, enabling it to dynamically adjust its stopping duration based on live occupancy insights from each station.

Outcomes

- ➢ **Dynamic Scheduling:** The tram dynamically adjusts stopping duration so that it stops for longer at more crowded stations (allowing ample time for people to embark and disembark).
- ➢ **Efficiency:** Reduced passenger wait times through demand-responsive stop times.
- ➢ **Scalability:** The cloud-based framework allows easy expansion to additional stations.

Conclusion

This project proposes a trackless solution for urban transit systems — an autonomous tram system designed to overcome the limitations of traditional rail transit by eliminating costly fixed-track infrastructure and prioritizing dynamic, data-driven operations. By integrating IoT-enabled stations, cloud-based analytics, and autonomous navigation, the system addresses urban mobility challenges through scalability, cost-efficiency, and real-time adaptability.

Key Achievements:

1. **Trackless Autonomy**: The line-following tram navigates predefined routes using IR sensors (without the need for physical tracks), significantly reducing infrastructure costs.
2. **Data Collection for Cloud Analytics**: Tram stations deploy IR and ultrasonic sensors to monitor passenger occupancy, with real-time data transmitted to the ThingSpeak cloud platform.
3. **Efficiency**: The tram adjusts stopping duration based on live station occupancy and its own capacity, minimizing wait times and optimizing resource use.
4. **Scalable Framework**: The modular design and cloud integration allow seamless expansion to additional stations or routes.

By merging IoT innovation with autonomous navigation, this project tries to offer a cost-effective, adaptable solution to modern transit challenges.