Autonomous Navigation System For Indoor Delivery Robots

Kaavish Project Proposal

By

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1 Abstract

This interdisciplinary project aims to develop an autonomous delivery system inspired by the Industry 4.0 paradigm, with a focus on SLAM (Simultaneous Localization and Mapping), Navigation, and Voice Bot technology. The project envisions a future where society functions with minimal human intervention, enhancing operational efficiency and safety. The project seeks to create a versatile autonomous mobile robot platform adaptable to various sectors, including industrial logistics, healthcare, unmanned missions, and security operations. For its final year milestone, the project focuses on the development of a self-driving delivery robot for indoor environments, notably the Habib University cafeteria. The robot will integrate SLAM to create a map of its surroundings and localize itself within the map. This will allow the robot to navigate safely and efficiently, even in dynamic and cluttered environments. The robot will also use navigation algorithms to plan and execute paths to its destination, avoiding obstacles and other hazards. An interactive food ordering system with a voice bot interface will enhance the user experience and streamline the ordering process. The voice bot will allow users to place orders using natural language, making the system more accessible and user-friendly.

2 Problem definition

The problem addressed by this project is the need for an autonomous navigation system tailored to indoor delivery robots. Indoor environments, such as warehouses, hospitals, office buildings, and fulfillment centers, pose unique challenges for robots tasked with transporting goods and completing various tasks independently. The absence of GPS signals indoors, dynamic and cluttered surroundings, human interactions, and the need for efficient path planning all present significant hurdles that must be overcome to enable the seamless operation of indoor delivery robots.

Background

The rise of indoor delivery robots has gained significant attention across industries due to their potential to streamline logistics, enhance operational efficiency, and reduce costs. These robots have the capacity to operate in settings where precision and speed are paramount, revolutionizing tasks ranging from inventory management to healthcare services. However, their effective deployment hinges on the development of an advanced autonomous navigation system capable of addressing the intricate challenges unique to indoor environments.

Current Challenges

1. **Mapping and Localization:** Indoor spaces lack the omnipresent GPS signals found outdoors, necessitating the use of alternative technologies such as LiDAR, cameras, and sensor fusion to create detailed maps and accurately determine the robot's position [1].
2. **Obstacle Avoidance:** Indoor environments are characterized by cluttered and dynamic spaces filled with shelves, equipment, furniture, and human presence. A robust obstacle detection and avoidance system is essential to ensure the robot's safe and efficient navigation [2].

3. **Dynamic Environments:** The unpredictable movement of objects and people within indoor spaces demands real-time adaptability. The navigation system must be capable of responding promptly to changes, avoiding collisions, and re-routing as necessary [3].

4. **Human Interactions:** Indoor delivery robots frequently interact closely with humans, including employees, customers, or patients. The navigation system must be designed to handle these interactions with tact, respecting personal space and ensuring safe coexistence [4].

5. **Path Planning:** Efficient path planning is paramount for optimizing routes, minimizing delivery times, and avoiding congestion within confined indoor spaces [5].

6. **System Integration:** Building a comprehensive and seamless integration of various components is critical. This includes ensuring that sensors, processing units, mapping algorithms, and control systems work together cohesively. Effective system integration is essential for the overall reliability and performance of the autonomous navigation system. It involves not only hardware but also software components that need to communicate and coordinate effectively to address the challenges of indoor navigation.

Stackholders

Stakeholder Name/Role	Description	Interest	Primary Benefits	Primary Detriments	Net Impact
Habib University	The application is directed towards making a delivery system within the premises of the university	High	Increased efficiency, marketing, source of attraction, and research opportunity	None	Positive
Industries and Hospitals	Since the primary focus is on industry 4.0, they are the utmost stakeholders	High	Increased efficiency, safety, less monetary overhead, precise and better operations	High Investment	Positive
Hotels and Supermarkets	Serving robots can be deployed to aid general operations within the premises of such areas	High	Robots can provide easier management, better production, and can be attract public towards them	Might need constant supervision as these are public areas	Positive
Work Force and Labor	Less labor will be required after implementing this framework	High	Labor would be trained to operate high end equipment and would be relaxed	Work force responsible for physical work and deliveries would lose their jobs	Neutral
R&D Departments	Technical novel aspects do open up various research opportunities	High	Newer platform to test out their research and would be able to explore newer ideas	None	Positive
Disabled personnel's	The idea is to serve those who cant help themselves, in terms of self service	High	it will be more feasible for them to get things delivered to them without them making an effort	None	Positive.

Figure 1: Stackholders

The successful development of an adaptive autonomous navigation system capable of addressing these challenges has the potential to transform various industries, enhancing operational efficiency, reducing costs, and advancing the capabilities of indoor delivery robots.

3 Social relevance

The relevance of autonomous service robots is increasing medical industries, especially in hospitals. In times of pandemics such as COVID-19, it has been observed that influx of patients, often critical patients, was very high. This high influx resulted in the shortage of staff and hence not every patient was not given the care they required. The use of service robots can greatly help with the under staff problem in hospitals. These service robots can do menial task such as delivering equipment, taking survey from patients and can monitor patients vitals. Furthermore, these service robot can help patients who are in nursing and recovery. These robot can be with these patients and give them a good company which is important for a patient's mental well being and their overall recovery. Service robots can also be used in at-home care settings and can also assist and provide company to elderly people at old age homes.

The supply chain industry is adopting robotics to automate a number of processes, including organization, transportation, warehousing and inventory management, and delivery. A recent analysis predicts that the global market for logistics robots would increase to $21,01 billion over the next seven years at a CAGR of 16.7%[6]. Robots capable of indoor autonomous navigation are essential for streamlining and improving logistics processes. They are relevant because they can increase productivity, cut costs, increase safety, and give useful information for making decisions. The logistics sector is anticipated to use technology more frequently as it develops, which will influence how warehousing and distribution are done in the future.

In recent times, the Fast Food industry, especially restaurants are slowly moving towards self-service model for ordering food in a restaurant. Essentially in self-service model, the customer places his or her order at the cash counter and also picks up his or her meal from the same counter, essentially eliminating the need of a waiter service. Two of the biggest food chains in the world; KFC and Mcdonalds, have been using this service model and since then many more have either already adopted this model or are transitioning to this model. In Pakistan, almost all the restaurants in a shopping Malls operate on this service model. However, the self-service model has it own set of disadvantages.

With the increase of service robots in hospitality industries in recent times, the use of a robot to function as a waiter brings the best elements of both self-service model and tradition service models. Professional and personal use of service robots is reported to be growing at 30% percent a year, and it is expected that the robotic market will reach USD 55.72 B in 2026 as the demand for service robots continues to increase [7]. This will make service robots more cheaper and hence a more viable option for restaurants in the long run. The use of such robots will improves customer service experiences and provides a number of advantageous outcomes, such as consistent service improvement, waiting time reduction, client welcomes, or increased productivity that hospitality industries want[7]. Many restaurants around the world have recently replaced human waiters with service robots, such as the FOODOM Tianjiang Food Kingdom in China, Mad for Garlic in Korea, and Royal Palace Renesse in Netherland (Funk, 2020, Lyons, 2020, Teller Report, 2020), as service robots can help reduce the risk of human-to-human transmission and create a safer dining environment[8]. According to research, solo diners react more favorably to restaurants with non-humanoid service robots than they do to those with humanoid ones[9].

4 Originality/Novelty

The primary objective is to build an automated delivery system based on the industry 4.0 paradigm, with the motivation of helping small businesses and societies. Our long-term goal is to not only use this framework for food delivery in indoor spaces but to also serve society such as helping autistic patients, and in hospitals for indoor delivery of medicine. In a nutshell, The robot is meant to function as an autonomous mobile robot platform for a variety of applications, including transportation in industrial sectors, food and medication delivery in hospitals, unmanned missions, and security. Our goal for this final year project is to create a self-driving delivery mobile robot that can deliver food items as part of the indoor service from point A (cashier's counter) to point B (any of the serving tables) in the Habib University cafeteria. Considering the existing solutions, we have highlighted their weaknesses in the Fig. 2 below.

Robot Name	Weaknesses
Locus Robotics	Specific to warehouse management Available to limited countries Very expensive
Keenon Robot	Very expensive and hard to procure in Pakistan High maintenance cost - requires experienced labor
Robotnik	Very expensive for small businesses Hard to maintain and operate on
SwiftBot	Only LiDAR based/Unreliable obstacle detection Utilizes Raspberry Pi so unable to avoid sudden obstacles 2 wheeled differential drive thus slower speed Limited flexibility. (Not flexible for multiple applications)
Starship Delivery Robot	Specific to deliveries for themselves Highly overloaded with sensor devices thus costly Only available in San Francisco
R2 Autonomous Robot	Operating in limited countries Not flexible for different applications Huge design and very expensive Limited flexibility. (Not flexible for multiple applications)
Zhen Robotics	High cost Limited to China Low flexibility (only delivery based)

Figure 2: Existing Robots.

Novelty Aspects:

1. **Sensor Fusion with RGB-D or LiDAR SLAM::** Our project leverages sensor fusion, combining LiDAR and Computer Vision data, to excel in object detection within unstructured and dynamic environments. This innovative approach enhances the robot's ability to perceive and navigate its surroundings with precision and adaptability.

2. **ROS Simulation:** To analyze and optimize navigation and path planning tasks, we employ the Robot Operating System (ROS) for simulation. This enables us to test different algorithms and scenarios in a virtual environment, ensuring the robot's readiness for real-world challenges.

3. **Interactive Food Ordering System with VoiceBot:** In addition to robot development, we introduce an interactive website for food ordering. This system streamlines the ordering process, enhancing user experience and ensuring efficient coordination between customers and the delivery robot.

4. **End-to-End Delivery Robot Prototype with Jetson Nano:** At the heart of our project lies the creation of a complete end-to-end delivery robot prototype. This prototype embodies all the integrated features we've discussed, from advanced sensor fusion to object detection, SLAM and ROS simulation. What sets it apart is the use of the Jetson Nano platform, a testament to our commitment to cutting-edge technology. By integrating Jetson Nano, we provide our robot with a powerful GPU computing platform, enabling it to process data efficiently, make real-time decisions, and navigate indoor environments with utmost precision.

5 CS contribution

The CS component of the project is divided into 4 parts:

1. **Computer Vision**: The Computer Vision (CV) is used robot perception. Here courses like EE-452 (Computer Vision) and CS-316 (Intro to Deep Learning), coupled with some research and literature survey will help us develop Perception system of the robot with greater accuracy and versatility. A better Perception System will improve the global and local planning system of the robot and hence better robot performance.

2. **Chatbot/Voicebot**: The Chatbot/Voicebot will be used to mimic human like behaviour with customer. This will allow customers to have a more natural, personalized and professional experience with the robot. The chatbot/voicebot will operate in Urdu language. Courses like CS-316 (Intro to Deep Learning), Human-Computer Interaction(CS/DES 333/327), and CS-458 (Natural Language Processing) will be relevant here.

3. **Application interface**: The Application interface(Website) will be a vibrant and aesthetically designed application, incorporating front-end and back-end technologies, that will allow the customers to interact with the robot systems like menus, promotional material, order placement, POS, etc. The relevant courses that will help us in implementing an application interface are; CS-370 (Web and Mobile Development), CS-353 (Software Engineering), CS-232 (Operating Systems) and CS-355 (Database Systems) and CS-224 (OOP & Design Methodologies).

4. **Robot Operating System**: The Robot Operating System (ROS) will used as a platform to connect the software elements of the robot with the hardware elements of the robot. The relevant courses that will help us in implementing ROS are; EE/CE-468 (Mobile Robotics), CS-380 (Intro to Robotics) and CS-232 (Operating Systems).

6 Scope and Deliverables

Robot Simulation on ROS (Gazebo, Rviz) Platform: For Kaavish 1

1. Development of a realistic simulation environment on the Robot Operating System (ROS) platform, incorporating Gazebo for physics-based simulation and Rviz for visualization.

2. Implementation of path planning algorithms to enable the robot to navigate dynamic indoor environments.

3. Integration of Simultaneous Localization and Mapping (SLAM) techniques to enable the robot to create maps of its surroundings.

Interactive Food Ordering Website: For Kaavish 2

1. Development of an interactive and user-friendly website for food ordering.

2. Implementation of a seamless ordering process, allowing customers to place orders conveniently.

3. Integration of communication and coordination features, enabling efficient interaction between customers and the autonomous delivery robot.

Integrated Voice Chat-Bot in Robotic Platform: For Kaavish 2

1. Development of a Food Chat-bot that would enhance the interaction between the customer and the Robot.

2. Tidio or Dialog-flow will be used to develop the chatbot.

3. The bot will be trained on Habib University's Tapal Cafeteria menu, which may include food items, prices, expected waiting time, etc.

Delivery Robot Prototype: For Kaavish 1 and 2

1. Designing the robot structure

2. Interfacing and Integration of voice bot, website and sensor module in the Robot prototype platform.

Gantt Chart for Kaavish 1 and Kaavish 2 Deliverables and Milestones

You can access the Gantt chart for more details and updates at the following link:
`https://docs.google.com/spreadsheets/d/1TRYLb7lYOgMUk7PVofgamzo7w5hh2eDoUBj9Yw-dJXA/edit?usp=sharing`

7 Proof of Concept Demonstrations

In this heading, we present a summary of the Proof of Concept (POC) demonstrations that we have developed for our project. These POCs showcase the capabilities and integrations we have explored to demonstrate the versatility of our platform for various applications

7.1 VoiceBot

For our first POC, we developed a VoiceBot system. This demonstration highlights the integration of voice recognition and natural language processing into our platform. You can watch the VoiceBot POC video here: https://youtu.be/RQL43XBo7B0.

7.2 Autonomous Obstacle Avoidance on Simulation

The second POC involves autonomous obstacle avoidance in a simulated environment. Although we don't have a video for this demonstration, but have some pictures.

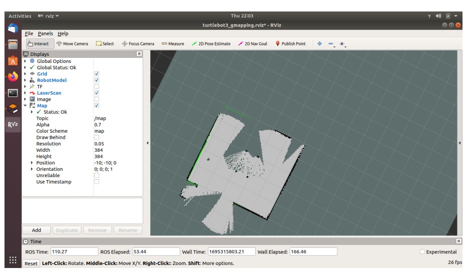

Figure 3: Rviz Simulator

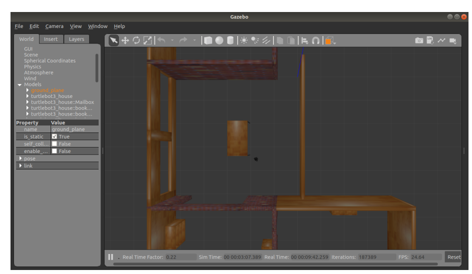

Figure 4: Gazebo Simulator

7.3 Object Distance Avoidance with Vision

Our third POC focuses on object distance avoidance using computer vision. The video for this POC can be found here: https://youtube.com/shorts/vl6PUmpPBDA?feature=share.

7.4 RP Lidar Integration on ROS

In the fourth POC, we integrated RP Lidar with the Robot Operating System (ROS). This video demonstrates our platform's compatibility with ROS: https://youtube.com/shorts/ztGst1BdD1g?feature=share.

8 Feasibility

Dataset for Object Detector Training:

1. **Resources:** Datasets like MS-COCO, CAMO, and other state-of-the-art datasets for object detection.
2. **Access and Utilization:** These datasets are publicly available and can be accessed through online repositories. They will be used to train and fine-tune the YOLO-based object detection model.

GPU for Object Detector Training:

1. **Resources:** Access to a GPU (Graphics Processing Unit) with sufficient computational power for training deep learning models.
2. **Access and Utilization:** Depending on availability, the GPU can be provided through local hardware or cloud-based GPU services. It will be used for training and optimizing the object detection model.

Lidar:

1. **Resources:** Procurement of a Lidar sensor for environmental perception and mapping.
2. **Access and Utilization:** The Lidar sensor will be an integral hardware component of the robot, utilized for mapping and obstacle detection. It will be physically integrated into the robot platform.

Jetson Nano and Raspberry Pi:

1. **Resources:** Jetson Nano and Raspberry Pi devices for onboard computing and control.
2. **Access and Utilization:** These devices will serve as the computational brains of the autonomous delivery robot, managing its decision-making and control processes. They will be integrated into the robot's hardware setup.

9 Team dynamics

9.1 Laiba Ahmed (Robotics Engineer)

Laiba has taken courses such as Introduction to Robotics (EE 366), Mobile Robotics (EE 468), Principles of Feedback Control (EE 361) which describe has background in Robotics and Control Systems. Along with this Laiba also Self Led a Project over the summers under the supervision of Dr Basit Memon, "Maximizing Coverage in Unknown Cluttered Environments using Deep Reinforcement Learning - A Comparative Study" where she explored and learnt ROS, Gazebo and Pytorch libraries to train autonomous robots.

9.2 Syed Muhammad Hussain (Project Lead and CV Engineer)

Syed Muhammad Hussain possesses a strong educational background with a focus on Robotics and AI domains. His coursework includes a comprehensive set of subjects, which include "Intro to Robotics(EE/CS 366/380)," "Computer Vision(EE 452)," "Human-Computer Interaction(CS/DES 333/327)," "Deep Learning(CS 316)," and "Data Science(CS 457)." These courses have equipped him with the theoretical knowledge and practical skills necessary for contributing effectively to projects in the field. Furthermore, Syed Muhammad Hussain has gained valuable industry experience through internships at Folio3 and HBL, where he actively participated in the Engineering and Computer Vision departments. These internships have provided him with hands-on exposure to real-world applications of the concepts he learned in his coursework.

9.3 Syed Muhammad Daniyal Murtaza Zaidi (Software Engineer)

Daniyal Murtaza has built a strong foundation in software development through his education and practical experience. He has taken a range of courses covering important subjects such as Object-Oriented Programming (CS-224), Software Engineering (CS/CE 353/374), Software Security (CS 371), database systems (CS/CE 355/373) and Website and Mobile Development (CS 370). These courses have given him both the theoretical understanding and practical skills needed for success in software development. In addition to his studies, Daniyal has worked part-time as a Software Engineer at Digi-Creations for seven months. This hands-on experience has given him valuable insights into real-world software development projects, allowing him to apply his academic knowledge effectively. As part of this project, he plans to use his in-depth experience of software development to develop a full-fledge interactive food ordering website and chatbot with comprehensive user experience and interface.

9.4 Muhammad Ahmed Atif (DL and RL Engineer)

Muhammad Ahmed Atif has a solid educational background with a specialty in the field of Artificial Intelligence. His coursework covers a wide range of topics, including "Intro to Deep Learning (CS 316)," "Intro to Reinforcement Learning (CS 352)," "Applied Stochastic Processes (MATH 402)," "Statistical Inferencing (CE/MATH 362/322)," and "Mobile Robotics (EE/CE 468)." He possesses both the theoretical knowledge and practical abilities needed to contribute effectively to projects in the area as a result of these courses. Muhammad Ahmed Atif has also designed an end-to-end ML/DL product while working as an intern at Folio3. Through this internship, he has gained practical experience with the real-world implementations of the concepts he learned in his coursework. Muhammad Ahmed Atif is also currently doing research on the topic of "Multiagent Reinforcement Learning" as part of Habib University's Internal Research Group, this research can greatly benefit future projects.

10 Tech Stack

We will be utilizing the MERN stack to develop an interactive food delivery website, aiming to enhance the interaction between humans and robot (HRI). The MERN stack includes following technologies that are pertinent to our project:

- **MongoDB:** This technology will serve as the foundation for our robust database. It will incorporate essential information such as order details, order items, table assignments, and customer profiles.
- **Express JS:** Express JS will act as a pivotal link connecting the front-end and back-end components of our website. It will efficiently handle incoming requests and responses.
- **React JS:** Leveraging the popular JavaScript library, React JS, we will craft the website's front-end. Our objective is to create an exceptionally user-friendly interface that provides a seamless and comprehensive ordering experience.
- **Node JS:** Node JS will take on the responsibility of managing real-time interactions between customers and our delivery system, all while ensuring the website's responsiveness.
- **Robot Operating System**
- **TensorFlow and Pytorch**

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Undertaking of Kaavish advisement as an External Supervisor

I hereby affirm that I have read the project details as described on the preceding pages and agree to undertake advisement of this Kaavish project as an External Supervisor. I understand that this role entails the following.

Meeting Meeting the project team regularly, at least once every two weeks, for the entire duration of the Kaavish. The meetings may be held remotely if required.

Advisement Providing supervision and advice to the team in order to ensure steady progress of the project toward its goals.

Liaison Liaising with the Internal Supervisor as required, e.g. to provide feedback or engage in grading.

Other Any other task, depending on availability and suitability, relevant to the Kaavish as communicated by the Internal Supervisor or Kaavish Working Group.

Name: ______________________________

Email: ______________________________

Phone: ______________________________

Designation: ______________________________

Affiliation: ______________________________

Signature: ______________________________