The Path Planning of Mobile Robot by Hierarchical Reinforcement Learning

Interim report

submitted in partial fulfilment

of the requirements for the degree

of

Bachelor of Science

in Engineering

in Electronics and Telecommunication

at

Sri Lanka Technological Campus

by

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2023

Abstract

In the context of infectious epidemic diseases, such as the Corona pandemic, the safety of healthcare workers is of paramount importance. The risk of infection increases when doctors and nursing staff have to physically interact with patients during treatment. To address this concern, we propose the development of a robot utilizing hierarchical reinforcement learning to navigate obstacles and autonomously deliver food and medicine to patients without requiring direct interaction with nursing staff.

The robot is designed to operate in healthcare settings and its primary objective is to efficiently and safely reach patients' beds while avoiding any obstacles in its path. Hierarchical reinforcement learning enables the robot to learn a hierarchy of actions and decisions, allowing it to handle complex tasks in a step-by-step manner. By using this approach, the robot can effectively navigate through the environment, identify the patient's bed, and deliver the required items without human intervention.

The development of such a robot has the potential to significantly reduce the risk of infection transmission to healthcare workers, as it eliminates the need for direct physical contact with patients. Moreover, it can enhance the efficiency of healthcare delivery by automating the process of delivering food and medicine to patients, thereby freeing up nursing staff to focus on other critical tasks [1][2][3][4].

To evaluate the effectiveness of the proposed robot, we conducted experiments in simulated healthcare environments. The results demonstrate the robot's ability to successfully navigate obstacles and reach the targeted patient's bed with a high degree of accuracy. Additionally, the robot's performance was comparable to or exceeded that of human counterparts in terms of speed and precision.

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Acronyms and Abbreviations

HRL	Hierarchical Reinforcement Learning
AI	Artificial Intelligence
ML	Machine Learning
NN	Neural Network
A*	A-star algorithm
ANN	Artificial Neural Network
OMPL	Open Motion Planning Library
ROS	Robot Operating System
A3C	Asynchronous Advantage Actor-Critic
DQN	Deep Q-Network

Chapter 1

The Path Planning of Mobile Robot by Hierarchical Reinforcement Learning

1.1 Scope

The proposed robot aims to mitigate the risk of infection transmission during infectious epidemic diseases by utilizing hierarchical reinforcement learning. Its scope involves developing a robot capable of autonomously navigating obstacles and delivering food and medicine to patients' beds without direct interaction with nursing staff. The focus is on automating the delivery process and ensuring the robot can identify patient beds, handle objects, and maneuver safely in healthcare environments. Through experiments and evaluations, the robot's effectiveness, accuracy, and performance will be assessed compared to human counterparts. However, the scope is limited to the specific task of delivering essential items, and does not encompass other medical procedures or patient monitoring, assuming compatibility with the healthcare environment and infrastructure. [1].

1.2 Background and Motivation

Infectious epidemic diseases like the Corona pandemic pose a significant risk of infection to healthcare workers who must interact closely with infected patients. To address this issue, the development of a robot using hierarchical reinforcement learning to autonomously navigate healthcare environments and deliver essential items to patients' beds without direct interaction with nursing staff is motivated. By reducing the need for human contact, this technology can effectively mitigate the risk of infection transmission, ensuring the safety of healthcare workers while maintaining efficient patient care delivery. The integration of advanced learning algorithms and robotics in healthcare systems has the potential to revolutionize disease management during epidemics, prioritizing the well-being of both medical personnel and patients. [2][3][4]. [5].

1.3 Objectives

- **Develop a robot using hierarchical reinforcement learning (HRL) to autonomously navigate healthcare environments**: The primary objective is to design and implement a robot capable of navigating through healthcare settings, avoiding obstacles, and reaching patients' beds without direct interaction with nursing staff. The robot will utilize HRL techniques to learn a hierarchy of actions and decisions, enabling it to handle complex navigation tasks effectively.

- **Train the robot to deliver food and medicine to patients' beds**: The research aims to teach the robot the necessary skills to identify patient beds, handle objects like food and medicine, and deliver them to the targeted locations autonomously. By using HRL, the robot will learn the optimal strategies for successful delivery while considering any constraints or objectives specific to the task.

- **Evaluate the effectiveness and performance of the robot in simulated healthcare environments**: Experimental evaluations will be conducted to assess the robot's navigation capabilities, obstacle avoidance skills, accuracy in reaching patients' beds, and overall performance compared to human counterparts. The objective is to demonstrate that the robot can operate efficiently and safely in healthcare settings, minimizing the risk of infection transmission.

- **Enhance the adaptability and versatility of the robot through machine learning**: The research aims to leverage machine learning techniques, particularly neural networks, to enhance the robot's adaptability and effectiveness in handling complex scenarios. By enabling the robot to learn from its interactions with the environment, it can improve its decision-making capabilities and adapt to different situations encountered during navigation and item delivery.

- **Contribute to the advancement of healthcare robotics for infectious epidemic diseases**: The overall objective is to contribute to the development of healthcare robots that can assist in infectious epidemic situations. By minimizing the risk of infection transmission to healthcare workers and improving the efficiency of patient care delivery, the research aims to make a significant impact on managing infectious diseases and safeguarding the well-being of both patients and medical personnel.

1.4 Problem

The problem at hand is the need for effective path planning, task allocation, resource management, and multi-agent coordination in the context of robotics and autonomous systems. These challenges arise in various scenarios where robots are required to navigate complex environments, allocate tasks efficiently, manage limited resources effectively, and coordinate their actions with other agents to achieve common objectives.

Path planning is a critical problem where robots need to find optimal paths while avoiding obstacles and considering multiple objectives and constraints. Task allocation involves assigning tasks to robots in a way that maximizes efficiency and minimizes risks, ensuring optimal utilization of available resources. Resource management is crucial for robots to effectively allocate and utilize resources such as energy, time, and computational capabilities to optimize their performance. Multi-agent coordination is essential in scenarios involving multiple robots, where they must coordinate their actions and decision-making processes to achieve collective goals. These challenges require advanced techniques, such as Hierarchical Reinforcement Learning (HRL), to develop solutions that can address the complexity and dynamic nature of these problems. By effectively addressing path planning, task allocation, resource management, and multi-agent coordination using HRL, it is possible to enhance the capabilities of robots and improve their overall performance in a wide range of applications, from navigation in complex environments to efficient task execution in collaborative scenarios.

1.3.1 Requirements

The resource requirements for a path planning algorithm for an autonomous mobile robot in a dynamic environment will depend on the complexity of the environment and the algorithm used. Here are some general resource requirements that may be needed for this task,

Hardware

- A computer or embedded system for running the path planning algorithm.
- Mobile robot hardware equipped with sensors such as lidar, camera, or sonar [11].

Software

- A programming language such as Python or C++ for implementing the algorithms.
- Path planning libraries such as OMPL (Open Motion Planning Library) or ROS (Robot Operating System).
- Real-time processing libraries such as ROS, ROS 2 or Fast-RTPS.
- A simulation environment such as Gazebo or Unity for testing and evaluation of the algorithms [12].

Data

- A dataset of the environment where the mobile robot will operate.
- Real-time sensor data from the robot's sensors.

Time

- The path planning algorithm must be designed to operate in real-time.
- The training of machine learning-based algorithms for path planning can take significant time.

Chapter 2

Literature review

Mobile robotics has become a significant area of research, with applications in various fields, including healthcare, logistics, manufacturing, and surveillance. The ability of mobile robots to navigate and perform tasks autonomously is a crucial factor in their success in these applications [5][6]. One of the critical tasks of mobile robots is path planning, which involves generating a collision-free path from an initial position to a target position. Several path planning algorithms have been proposed in the literature, including graphical methods such as visibility graph, the potential field, and the cell decomposition. These methods are designed for static environments, where the obstacles are stationary. However, in dynamic environments, where the obstacles are moving, these methods may not be effective. In addition, the motion planning task for mobile robots can be highly complex because it requires complete knowledge of the robot's environment [7][8].

In the paper" The Path Planning of Mobile Robot by Neural Networks and Hierarchical Reinforcement Learning" by Jinglun Yu, Yuancheng Su, and Yifan Liao, the authors propose a path planning algorithm that uses neural networks and HRL to enable mobile robots to navigate in dynamic environments. The approach is validated in simulation and experimental environments and shows promising results in terms of path planning quality and generalization effects [9][10][11]. Similarly, in the paper" Hierarchical Reinforcement Learning Approach for Motion Planning in Mobile Robotics" by Andrea Buitrago-Mart´ınez, R. Fernando la Rosa, and Fernando Lozano-Mart´ınez, the authors propose an option-based hierarchical learning approach to the motion planning task. The robot learns basic behaviors independently during the learning phase and then learns to coordinate these behaviors to resolve the motion planning task. In the paper" Path Planning Algorithm for Autonomous Mobile Robot in Dynamic Environment" by M.S. Ganeshmurthy and Dr. G.R. Suresh, the authors propose a heuristic-based method for efficient initial path search, which is then combined with the simulated annealing-based approach for dynamic robot path planning. The approach shows improvements in the quality of the solution in terms of the length of the planned path for both runtime and offline path planning [12].

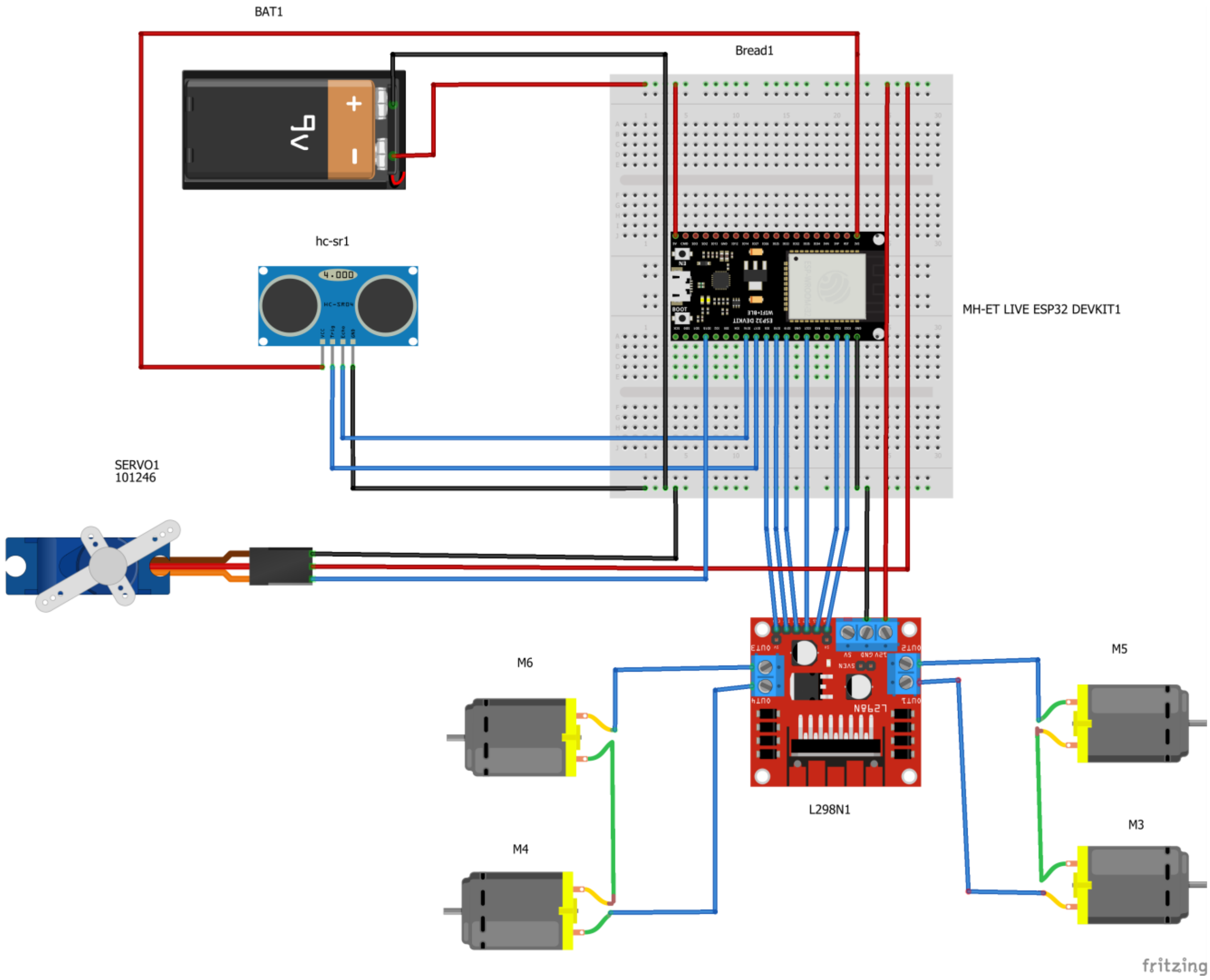
Chapter 3

Methodology

The first step of the methodology would be to set up the required hardware and software for the project. This would involve gathering all the necessary components, such as the ultrasonic sensor, Zigbee modules, and 5MP camera, and ensuring they are properly connected to the robot. Additionally, software tools such as MATLAB and VREP would need to be installed and configured for simulation purposes. Once the hardware and software are properly set up, the project can move forward to the development and implementation of the different phases.

In the first phase of the project, the main focus is on training the robot to identify and avoid obstacles using an ultrasonic sensor. The robot is programmed to detect obstacles in its path and develop a strategy to overcome them by adjusting the angle of the axle of the front two wheels and changing direction. This technique will enable the robot to avoid any obstacles that come in its way while navigating towards a specified location. The robot will be trained to develop its own path planning algorithm, which will be used to determine the best route to the specified location while avoiding any obstacles detected by the ultrasonic sensor. By successfully completing this phase, the robot will have the necessary skills to navigate through a static environment while avoiding obstacles.

In the second phase of the project, the focus is on enabling the robot to find the shortest path to its destination using Zigbee signals [13]. To achieve this, Zigbee modules are integrated with the robot, which allows it to communicate with other Zigbee devices and receive signals that help it navigate [14]. The robot still uses its ultrasonic sensor to detect obstacles in its path, but now it also uses the Zigbee signals to calculate the shortest path to its destination while avoiding the obstacles. The development of an algorithm that combines obstacle avoidance with shortest path planning is critical to the success of this phase. The algorithm should be able to identify obstacles, calculate the shortest path to the destination, and modify the path accordingly to avoid obstacles in real-time. This phase will build upon the skills learned in the first phase, with the added complexity of integrating Zigbee modules and developing a more sophisticated algorithm for obstacle avoidance and path planning.



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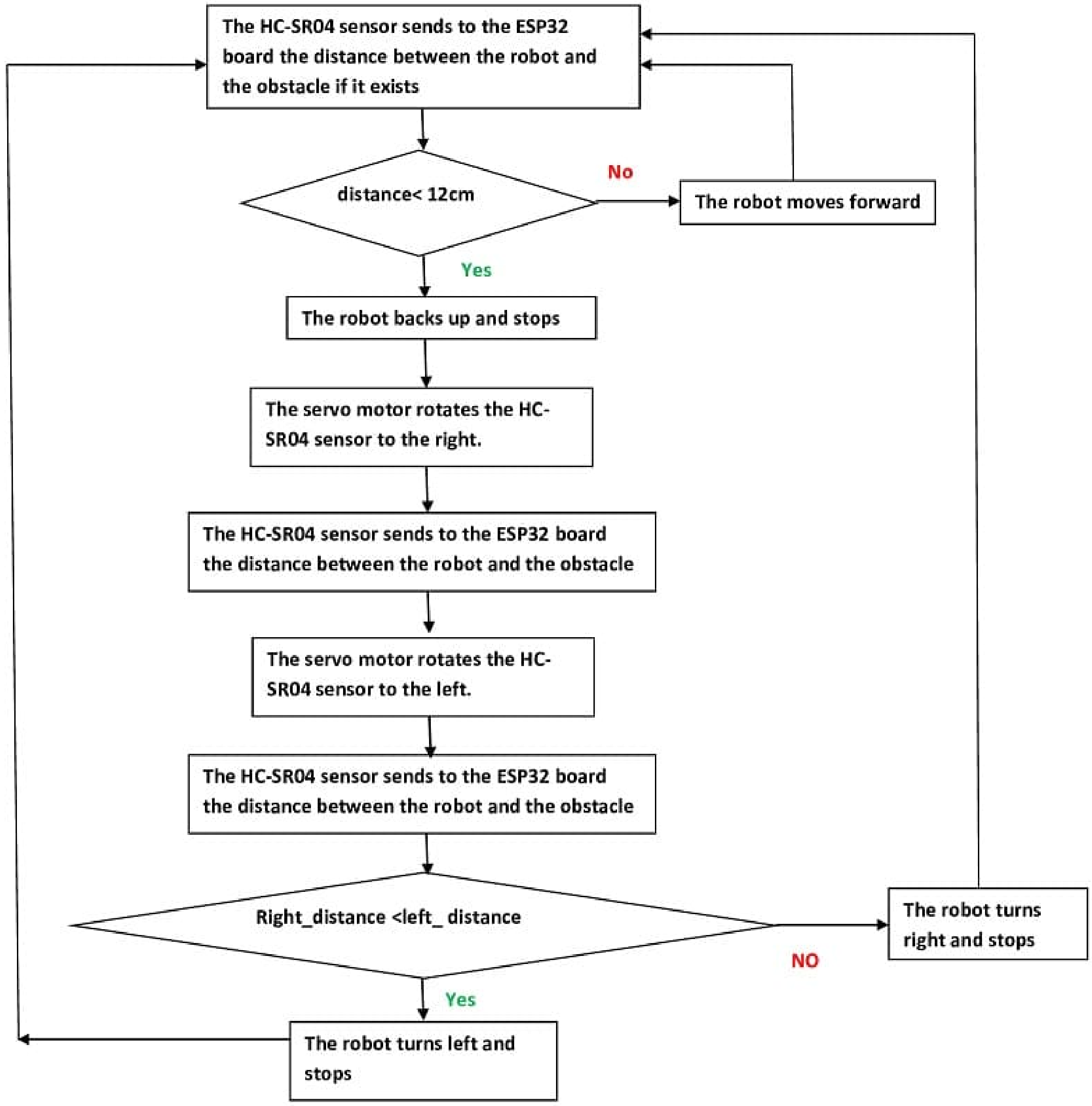
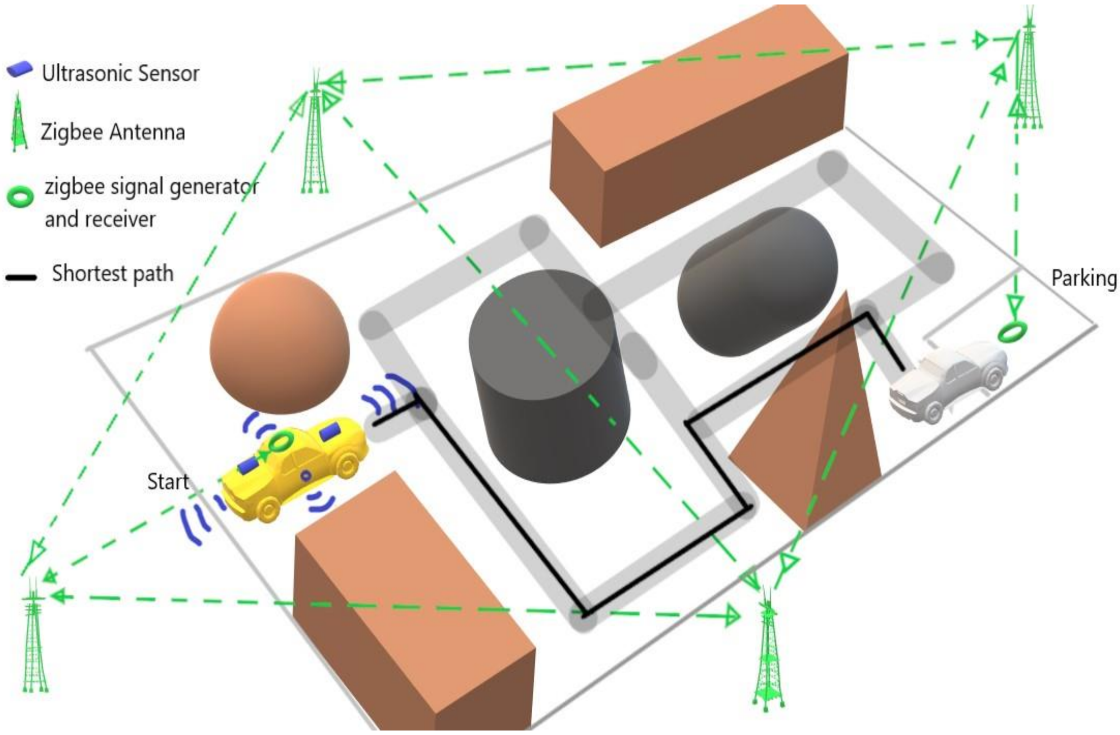
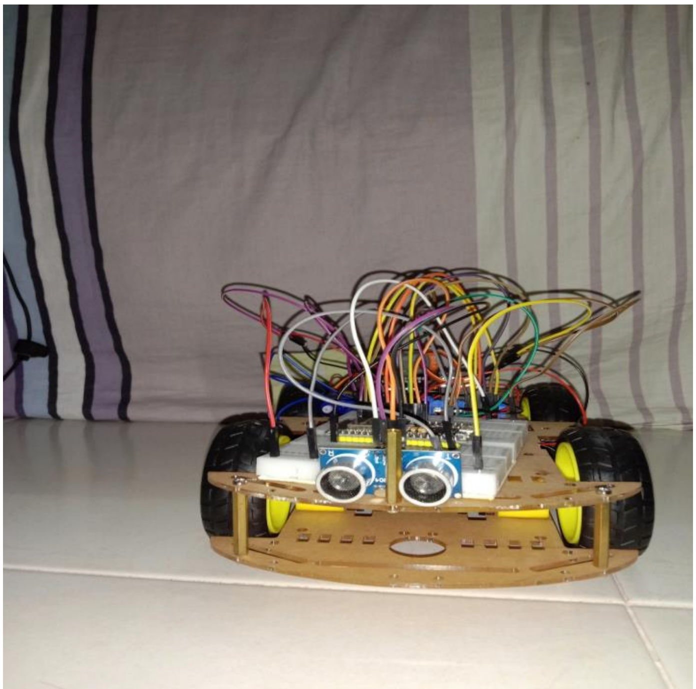
In the third phase, the project aims to develop the ability of the robot to navigate in a dynamic environment using the simulated annealing algorithm. To achieve this, a 5MP camera will be integrated with the robot to detect any obstacles that suddenly appear on the road. The simulated annealing algorithm will then be implemented to determine the optimal path for the robot to reach its destination while avoiding the detected obstacles. Through this approach, the robot will be trained to efficiently navigate around the dynamic environment and reach its destination in the shortest time possible. By using the simulated annealing algorithm, the robot will be able to quickly determine the optimal path in a dynamic environment with moving obstacles. The aim is to develop a robot that is capable of navigating in real-world scenarios with high accuracy and efficiency.

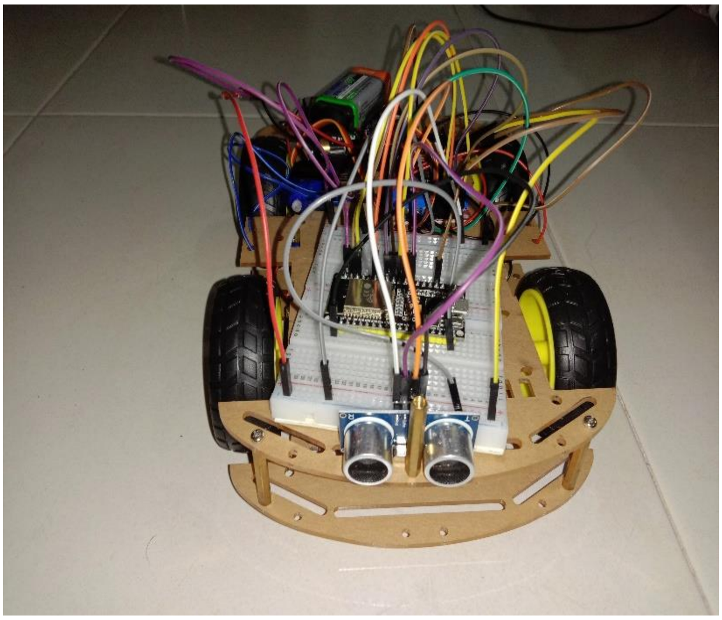


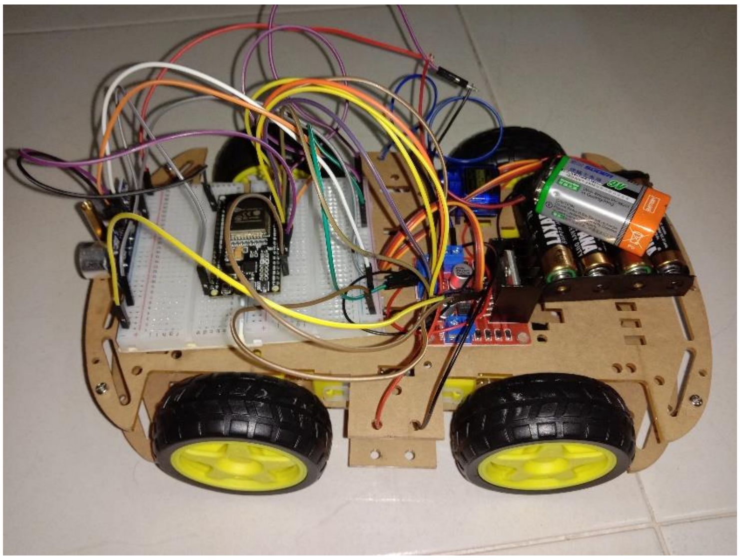
The developed robot in this project has the potential to be a valuable tool in various industries and fields. Through the use of different techniques such as obstacle identification and avoidance with arbitrary trajectory movements, shortest path planning with Zigbee signals, and dynamic environment navigation with the simulated annealing algorithm, the robot can navigate through complex environments with ease and efficiency. The application of reinforcement learning further enhances the robot's accuracy and decision-making abilities in each of these areas. The evaluation and testing of the robot in different scenarios and environments ensures its reliability and suitability for various tasks. The continuous refinement of algorithms and techniques based on evaluation and testing results can further improve the robot's performance and potential applications. Overall, this project demonstrates the potential of advanced robotics and AI techniques in creating intelligent and efficient machines capable of performing complex tasks in dynamic environments.



3.1 The system mode







Project timeline

Duration		Performer	January-23	February-23	March-23	April-23	May-23	June-23	July-23	August-23	September-23	October-23	November-23	December-23	January-24
initiation	Evaluation	Both													
	Charter	Both													
Planning	Curriculum Studies	Both													
	Analyzing	Thawfeek													
	Documentary	Shakhila													
	Presentation	Both													
Execution	Algorithms & Simulation	Both													
	Outline Design	Thawfeek													
	Coding	Shakhila													
	Testing	Both													
	Final Design	Both													
Control	Resource Management	Both													
	Cost Management	Both													
	Risk Management	Both													
Close out	Final Presentation	Both													
	Final Documentary	Both													
	Document Handover	Both													

4.1 Gantt chart

Chapter 6

Conclusions and Future Work

6.1 Summary and Conclusion

In the context of infectious epidemic diseases, ensuring the safety of healthcare workers is crucial. The risk of infection transmission increases when doctors and nursing staff have direct physical contact with patients during treatment. To address this concern, the development of a robot utilizing hierarchical reinforcement learning (HRL) has been proposed. This robot is designed to navigate healthcare environments, avoiding obstacles, and autonomously delivering food and medicine to patients' beds without requiring direct interaction with nursing staff. HRL enables the robot to learn a hierarchy of actions and decisions, allowing it to handle complex tasks step-by-step.

The implementation of such a robot has the potential to significantly reduce the risk of infection transmission to healthcare workers. By eliminating the need for direct physical contact with patients, the robot enhances safety in healthcare settings. Additionally, the automation of the delivery process frees up nursing staff to focus on other critical tasks, improving overall healthcare delivery efficiency.

Experiments conducted in simulated healthcare environments have shown promising results. The robot successfully navigated obstacles and accurately reached patients' beds. Its performance was comparable to or even exceeded that of human counterparts in terms of speed and precision.

The development of a robot utilizing hierarchical reinforcement learning offers a valuable solution to mitigate infection risk and improve healthcare delivery during infectious epidemic diseases. By implementing such a robot, we can prioritize the safety of healthcare workers while maintaining efficient and effective patient care. This technology has the potential to revolutionize healthcare systems and contribute to the overall well-being of both medical personnel and patients.

6.2 Future Work

Real-world Implementation: The next step would be to transition from simulated environments to real-world healthcare settings. Conducting experiments and evaluations in actual healthcare facilities would provide more realistic insights into the robot's performance and effectiveness. It would also allow for validation of the robot's ability to navigate real-world obstacles and interact with the healthcare environment.

Handling Dynamic Environments: Infectious epidemic scenarios are dynamic and can involve rapidly changing conditions. Future work could focus on enhancing the robot's ability to adapt to dynamic environments, such as crowded hospital corridors or rooms with moving objects or people. Dynamic obstacle avoidance and real-time decision-making strategies could be developed to ensure safe and efficient navigation.

Human-Robot Interaction: While the proposed robot minimizes direct interaction between healthcare workers and patients, there may still be a need for some level of communication and collaboration. Future work could explore ways to enable effective human-robot interaction, such as voice commands, gesture recognition, or remote monitoring and communication capabilities, to facilitate seamless collaboration between the robot and healthcare personnel.

Multi-Robot Systems: In large healthcare facilities or during widespread epidemic outbreaks, multiple robots working in coordination could enhance efficiency and coverage. Future work could focus on developing strategies for multi-robot coordination, task allocation, and communication protocols to optimize resource utilization and improve overall healthcare delivery.

Safety and Ethical Considerations: As robots become more integrated into healthcare environments, ensuring their safety and addressing ethical concerns becomes paramount. Future work could involve developing robust safety mechanisms, ethical guidelines, and protocols to handle potential issues related to robot behavior, data privacy, and patient confidentiality.

Continuous Learning and Improvement: HRL enables the robot to learn from interactions with the environment, but continuous learning and improvement are necessary for long-term effectiveness. Future work could focus on developing algorithms and methodologies for online learning, enabling the robot to adapt and improve its performance over time based on real-world experiences and feedback.

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