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##### **NIT6150**

##### **Advanced Project**

##### System Design and Approach

##### **2D SLAM-based Childcare Robot**

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# Overview

Falls stand as the foremost contributor to injuries to children in their home. In fact, the Centres for Disease Control and Prevention (CDC) has highlighted that an estimated 8,000 children receive medical treatment for injuries stemming from falls in United States emergency departments each day [1]. Most common fall exposures include stairs, and windows. Providing 24/7 supervision to children has become challenging to parents or legal guardians, and even kindergartens.

Moreover, the field of technology, specifically in service mobile robotics has been quickly evolving. These service mobile robots offer a range of benefits across various industries and applications such as environmental monitoring. People have started to incorporate them more in their household through vacuuming, gardening and so on. The potential for mobile robots to take over additional household tasks is substantial. With the rise of indoor situations where the Global Positioning System (GPS) can't work for finding a robot's location, having a dependable way to identify the robot’s location is crucial. This is where Simultaneous Localization and Mapping (SLAM) comes in.

Simultaneous localization and mapping (SLAM) system allows a robot to build a map of the surrounding environment it is in while identifying its current position without any previous knowledge, which is vital when GPS doesn’t work indoors. SLAM technology comes in two primary forms: 2D and 3D where height information is less critical. On the other hand, 3D SLAM operates in a three-dimensional space, including height and depth information. This is valuable for scenarios where vertical information matters, such as outdoor navigation or environments with multiple levels. This research paper focuses on 2D SLAM for indoor navigation.

SLAM has been a focus of continuous investigation in the fields of indoor mobile robot applications. For example, it can be found in homes through robotic vacuum cleaners such as Samsung POWERbot R9+ which creates virtual maps of the household environments and finds best routes for efficient coverage. Moreover, another method proposed by Veronika includes a mobile robot detecting humans and following them using SLAM [2]. Another application for SLAM based mobile robots is a guide for blind people [3].

The main objectives of this research can be divided into three categories: developing a map of the environment using SLAM, navigating the environment, and maintaining privacy. This research will be done in small environments.

This study specifically addresses the challenge of developing a SLAM-based mobile robot for childcare, focusing on navigating indoor environments with accuracy and preserving privacy without the use of cameras. Motivated by the growing trend of dual-income households and the consequent challenge in continuous child supervision, our research explores a technological solution that aligns with modern family structures and their needs. Several challenges are confronted, including ensuring the accuracy and reliability of 2D SLAM in complex home environments, addressing privacy concerns with non-camera-based systems, and the practicality of deploying these robots in diverse household settings. This research contributes to the field by enhancing child safety through innovative use of 2D SLAM technology, developing privacy-respecting navigation algorithms, and providing new insights into the use of robotics in a childcare context.

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# Project Progress Documentation

# Strengths and Limitations

## **Strengths of the Product**

1. **Effective 2D Mapping**: The use of a 2D LiDAR sensor with ROS Gmapping has proven effective in generating accurate maps of indoor environments, which is critical for reliable navigation.
2. **Accurate Localization**: The implementation of the Adaptive Monte Carlo Localization (AMCL) algorithm ensures precise self-localization within the mapped environment, which is essential for accurate navigation and obstacle avoidance.
3. **Real-time Navigation and Obstacle Avoidance**: The integration of global and local planners, such as NavfnROS and DWA, allows the robot to navigate in real-time while effectively avoiding obstacles, ensuring safe movement through dynamic environments.
4. **Simulated and Real-world Testing**: The combination of Gazebo simulations with real-world experiments provides a robust validation of the robot’s performance, enhancing the reliability of the results and ensuring the system is well-tested before deployment.
5. **User-friendly Setup**: The use of ROS and tools like Rviz for visualization makes the system accessible to developers, allowing for easier setup, control, and customization of the robot's operations.
6. **Cost-effectiveness**: Utilizing a 2D LiDAR sensor instead of more complex 3D sensors reduces costs while still providing sufficient data for effective navigation and mapping in indoor environments.

## **Limitations of the Product**

1. **Limited Environmental Awareness**: The reliance on 2D LiDAR sensors limits the robot's ability to perceive and navigate complex 3D environments, potentially reducing its effectiveness in areas with varying floor levels or overhead obstacles.
2. **Inconsistent Mapping in Real-world Conditions**: The accuracy of the mapping can be compromised by factors such as inconsistent speeds, wheel slippage, or inadequate traversal of certain areas, leading to potential errors in navigation.
3. **Restricted Obstacle Detection**: The current system’s ability to detect and avoid smaller or moving obstacles, particularly in real-time, may be insufficient in dynamic environments where quick adjustments are necessary.
4. **Limited Interaction Capabilities**: The robot’s interaction with users, particularly children, is limited to navigation and obstacle avoidance, lacking more advanced human-robot interaction features such as voice recognition or gesture commands.
5. **Energy Efficiency Concerns**: The system's operational time may be limited by battery life, necessitating frequent recharging, which could reduce its practicality for continuous monitoring or guidance tasks.
6. **Complex Setup and Maintenance**: While the system is user-friendly for developers, the initial setup and ongoing maintenance, particularly in real-world environments, can be complex and time-consuming.

# **Future Scope**

In future expansions of this research on autonomous navigation using the TurtleBot3 Burger, several advancements can be considered to enhance its efficacy and applicability, particularly in the context of child safety. One critical application is guiding children safely from one location to another, mitigating the risk of falls. To achieve this, integrating more sophisticated sensors, such as depth cameras or advanced LiDAR, could significantly improve obstacle detection and environment mapping. Exploring 3D SLAM algorithms would also offer a more comprehensive spatial understanding, crucial in complex and dynamic home environments where children move and play.

Furthermore, incorporating machine learning, especially reinforcement learning, could optimize path planning in real-time, adapting to changing environments and ensuring safer navigation. Enhancing human-robot interaction capabilities, such as voice or gesture recognition, would make the robot more intuitive and interactive for children, potentially increasing their compliance with the robot’s guidance.

The potential for deploying multiple robots in a coordinated effort could be explored for more extensive coverage, ensuring continuous supervision. Improvements in energy efficiency are also vital for long-term operation, ensuring the robot remains operational without frequent recharging, especially in scenarios where constant monitoring is necessary.

Additionally, adapting the robot's capabilities for specific real-world applications, such as preventing child falls in homes or daycares, would involve tailoring its navigation and safety features to these particular settings. This would include enhancing its ability to navigate around moving obstacles like pets and people, a common challenge in household environments.

Finally, developing a user-friendly interface would be imperative for allowing caregivers or parents to interact with the robot effectively, setting navigation paths, monitoring activity, or receiving alerts. This research, with its focus on child safety and fall prevention, has the potential to make significant contributions to the practical use of autonomous robots in everyday life, offering peace of mind and enhanced safety for families.

# **Challenges and Problems During Project Implementation**

#### 1. SLAM Algorithm Instability in Dynamic Environments

* **Challenge:** SLAM algorithms, particularly those based on 2D LiDAR sensors, may struggle in dynamic environments where objects or people move frequently. This can lead to inaccuracies in the generated map and hinder navigation.
* **Solution:** Implement more advanced SLAM algorithms such as Hector SLAM or Cartographer, which are designed to be more robust in dynamic environments. Additionally, incorporating 3D LiDAR or depth cameras can improve environmental mapping accuracy by providing richer spatial data.
* **Justification:** Studies show that advanced SLAM algorithms and 3D sensors can enhance map accuracy and robot localization in complex environments.

#### 2. Localization Errors Leading to Navigation Failures

* **Challenge:** Errors in robot localization can cause significant navigation failures, particularly in cluttered environments where the robot may struggle to recognize its position accurately.
* **Solution:** Utilize the Adaptive Monte Carlo Localization (AMCL) algorithm with an increased number of particles to improve accuracy. Additionally, implementing a sensor fusion approach that combines data from LiDAR, IMU, and cameras can enhance localization precision.
* **Justification:** Sensor fusion techniques have been proven to improve localization accuracy in robotics by integrating multiple data sources, reducing the likelihood of navigation errors.

#### 3. Inadequate Handling of Real-Time Obstacle Avoidance

* **Challenge:** The robot may encounter difficulties in avoiding obstacles in real-time, especially when using a local planner that doesn't adequately account for dynamic changes in the environment.
* **Solution:** Integrate a more sophisticated local planning algorithm such as the Dynamic Window Approach (DWA) combined with machine learning techniques for adaptive obstacle avoidance. This approach allows the robot to learn from previous experiences and improve its obstacle avoidance capabilities over time.
* **Justification:** Machine learning-enhanced planners can adapt to new obstacles and optimize paths in real-time, offering significant improvements over traditional planning methods.

#### 4. Limited Mapping Accuracy in Confined Spaces

* **Challenge:** In small, confined spaces, the SLAM-generated maps may lack accuracy, particularly in representing narrow passages or small objects.
* **Solution:** Fine-tune the SLAM parameters, such as reducing the robot's speed during mapping and ensuring uniform coverage of the area. Consider using high-resolution LiDAR sensors or enhancing the robot's mapping capabilities with a 3D SLAM approach.
* **Justification:** High-resolution sensors and 3D SLAM are particularly effective in improving mapping accuracy in confined or complex environments, ensuring better navigation performance.

#### 5. Communication Latency Between Robot and Remote PC

* **Challenge:** Latency issues in communication between the robot’s SBC and the remote PC can lead to delayed responses, affecting real-time control and monitoring.
* **Solution:** Implement a more efficient communication protocol, such as ROS 2, which offers lower latency and improved real-time performance. Additionally, optimizing the network configuration and ensuring a high-speed, stable connection can reduce communication delays.
* **Justification:** ROS 2 has been developed with enhanced real-time capabilities and lower latency, making it more suitable for applications requiring prompt robot responses.

# **Potential Solutions and Justifications**

#### 1. Improved Sensor Integration for Enhanced Mapping

* **Problem:** Limited sensor integration may result in suboptimal mapping and localization.
* **Solution:** Introduce a sensor fusion framework that combines data from multiple sensors (LiDAR, IMU, and cameras) to enhance environmental perception.
* **Justification:** Research indicates that sensor fusion significantly enhances the robot’s ability to perceive and navigate its environment accurately.

#### 2. Enhanced Algorithmic Approaches for Dynamic Environments

* **Problem:** Traditional SLAM algorithms may not perform well in dynamic settings.
* **Solution:** Transition to more advanced algorithms like Cartographer, which can handle dynamic elements in the environment better than basic 2D SLAM approaches.
* **Justification:** Advanced SLAM algorithms are essential in dynamic environments where conventional SLAM may fail to maintain accurate maps.

#### 3. Adoption of Reinforcement Learning for Adaptive Navigation

* **Problem:** Static path planning methods may fail in unpredictable or changing environments.
* **Solution:** Incorporate reinforcement learning to enable the robot to adapt its navigation strategy in real-time, learning from the environment as it navigates.
* **Justification:** Reinforcement learning has been shown to be effective in enabling robots to adapt to dynamic environments, improving navigation performance.

# Human Factors and Privacy Preserving

When developing the 2D SLAM-based childcare robot, it’s crucial that the system is easy for daycare staff to use with minimal training. Our goal is a user-friendly design that fits smoothly into daily routines.

A key challenge is ensuring the robot’s interface isn’t too complex, which could lead to frustration and mistakes. To avoid this, we’re focusing on a simple, clear design with easy-to-recognize icons and prompts, making the robot intuitive to use. While the design will be straightforward, some training will still be provided, including tutorials and hands-on sessions to ensure everyone is comfortable with the robot. We’ll also set up a feedback system so staff can share their experiences, helping us make improvements based on real-world use. Prototyping and user testing will help catch any usability issues early, and simplified controls will make the robot easy for all staff to operate. After deployment, ongoing feedback will guide further refinements to keep the system responsive to daycare needs.

Privacy is also a top priority. The robot uses LiDAR sensors instead of cameras to avoid capturing personal images, greatly reducing privacy risks. We’ll implement strong data protection measures, like encryption, to ensure that any collected data is securely stored and only accessible to authorized personnel.

By prioritizing ease of use, intuitive design, and privacy protection, we aim to develop a childcare robot that seamlessly integrates into daycare operations, is easy to adopt, effective in its role, and trusted by all users.

# Ethical Issues

Creating a childcare robot is exciting, but it comes with important ethical questions. First, we need to protect privacy. The robot will collect some data, so we’ll make sure it’s encrypted and let parents and staff know how it’s used and stored. Being open about this builds trust.

It’s also important that everyone understands and agrees to the robot being in the daycare. We’ll clearly explain what the robot does and how it helps keep kids safe, so everyone feels comfortable with it. We need to be honest about what the robot does and how it benefits the children. Transparency builds trust and reassures everyone that the robot is there to help, not to replace caregivers. If something goes wrong, like a malfunction, we’ll have clear roles and responsibilities to address issues quickly. And while some might worry about job security, the robot is designed to assist, not replace, human caregivers.

# Conclusion

In conclusion, providing 24/7 supervision to children can be challenging. This leads to accidental falls and injuries, and some can be very harmful to children. Incorporating assistive robots in households has been widely evolving, from vacuums to lawn mowers. Very little to almost no research has been done on how to incorporate assistive robots in childcare scenarios. This research proposal outlines the development of a mobile robot equipped exclusively with LiDAR sensors, designed to offer a novel solution to child monitoring in confined spaces. The robot employs SLAM technology for environmental navigation and LiDAR data collection. Its primary functions include precise self-localization and efficient navigation to designated locations while adeptly circumventing obstacles. The core objective of this research is to safely guide a child to a specified area, ensuring they do not encounter falls or obstructions. A notable aspect of this project is its emphasis on privacy. By relying solely on LiDAR data, the privacy of the household is safeguarded. The results from a series of both simulated and real-life experiments have been promising, demonstrating the feasibility and effectiveness of this approach. Nevertheless, there is scope for further enhancements, particularly in refining the navigation capabilities. This system holds potential for future application in larger settings such as kindergartens and daycare centers, where child safety and privacy are vital. I acknowledge the limitations of our study, particularly regarding the scalability of our solution to varied home layouts and dynamics, and clarify the scope within which our findings are most applicable.

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