

##### **NIT6150**

##### **Advanced Project**

##### System Design and Approach

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

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# Introduction

Falls are a leading cause of injury among children, prompting thousands of emergency visits daily in the U.S. due to accidents involving stairs and windows. This issue highlights the need for enhanced supervision in environments like kindergartens, where constant vigilance is challenging. Leveraging advancements in service mobile robotics, particularly 2D Simultaneous Localization and Mapping (SLAM) technology, presents a viable solution. Our project proposes using 2D SLAM robots equipped with LiDAR sensors for real-time navigation and monitoring within indoor settings such as schools and childcare centers. This approach aims to enhance child safety by identifying and mitigating hazards without compromising privacy, eschewing cameras in favor of non-intrusive sensors.

# System Development Approach

# Functional Requirements

For the project involving the development and deployment of a 2D SLAM-based mobile robot aimed at enhancing safety and operational efficiency in childcare centers, the functional requirements define specific behaviours or functions the system must fulfill. Here’s a detailed breakdown of these requirements:

**1. Navigation and Mobility**

* The robot must autonomously navigate within various indoor environments using its SLAM (Simultaneous Localization and Mapping) capabilities.
* The robot should be able to avoid obstacles and safely maneuver around people, furniture, and other objects without human intervention.
* The robot must return to navigate to and stop at the specified point in space.

**2. Child Monitoring and Safety**

* The robot should be able to guide the child from point A to B without hitting any obstacle, leading the child to safety.

**4. Data Collection and Reporting**

* The robot must collect data on its operational performance for continuous improvement.
* The robot must securely store and transmit data in compliance with applicable privacy regulations.

**5. Maintenance and Updates**

* The robot must be easy to maintain with capabilities for remote diagnostics and software updates.
* The robot must allow for manual override or shutdown by authorized personnel in case of emergencies.

**6. Security and Privacy**

* The robot should ensure that all data collection and monitoring activities comply with child privacy laws and ethical standards.

# Use Case

# Non-Functional Requirements

# System Navigation and Interface

## System navigation

Figure 2: System Navigation

## Interface

A screenshot of a computer

Description automatically generated

Figure 3: Virtual Machine

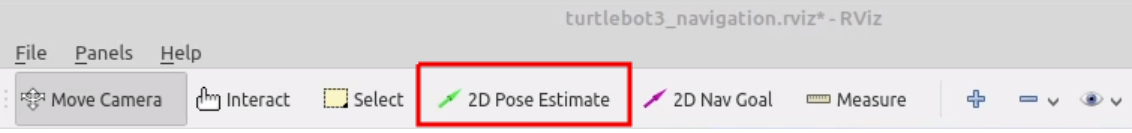
Oracle VM VirtualBox Manager is utilized to host the Ubuntu machine on laptops, enabling the operation and management of the robot's software via a virtual environment.

A screen shot of a computer program

Description automatically generated

Figure 4: Controls for Navigation

The robot can be easily controlled after it is setup properly. The commands above are used to control its movement.



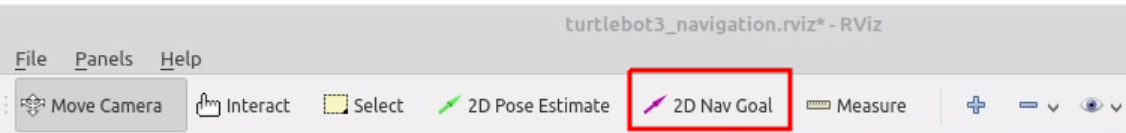


Figure 5: Rviz Controls

These two buttons in Rviz allow us to setup the Robot for navigation/guiding the child. The first one estimates the position of the robot and the second specifies the desired location it wants the robot to navigate to.

A screenshot of a computer program

Description automatically generated

Figure 6: Interface for Running Commands

The commands needed to run the nodes are almost always the same and require very few adjustments.

# Cost Estimate

Our estimated cost for the development services outlined above is $84,194.

|  |  |  |
| --- | --- | --- |
| **Category** | **Item** | **Cost** |
| **Hardware Costs** | TurtleBot3 Burger Robot | $500 |
|  | LiDAR Sensor (LDS-02) | $200 |
|  | Raspberry Pi | $50 |
|  | OpenCR (Microcontroller Unit) | $70 |
|  | IMU (Inertial Measurement Unit) | $30 |
|  | 12V Li-Po Battery | $40 |
|  | Miscellaneous Components | $100 |
|  | Spare Parts and Maintenance | $100 |
| *Total Hardware Costs* |  | **$1090** |
| **Software Costs** | Robot Operating System (ROS) | Free |
|  | Gazebo (simulation software) | Free |
|  | Additional Software Libraries and Tools | $100 |
| *Total Software Costs* |  | **$100** |
| **Personnel Costs** | Researchers (3 people, 20 hours/week each for 9 months at $30/hour) | $64,800 |
|  | Supervisor (1 person, 5 hours/week for 9 months at $50/hour) | $9,000 |
|  | Consultant (10 hours total at $100/hour) | $1,000 |
| *Total Personnel Costs* |  | **$74,800** |
| **Miscellaneous Costs** | Data Collection Expenses | $200 |
|  | Travel Expenses | $300 |
|  | Printing and Documentation | $50 |
| *Total Miscellaneous Costs* |  | **$550** |
| *Contingency* | Buffer for Unexpected Costs | **10% of Budget ($76,540) = $7,654** |
| *Total Project Budget* |  | **$84,194** |

Table 1: Cost and Budget

# Schedule

|  |  |  |  |
| --- | --- | --- | --- |
| **WBS Level** | **WBS Code** | **WBS Name** | **WBS Description** |
| **1** | **1** | **Childcare Robot Project** | Development and deployment of a 2D SLAM-based robot for enhancing safety and efficiency in childcare centers. |
| **2** | **1.1** | **Initiation** |  |
| 3 | 1.1.1 | Charter | Development of a charter that defines project goals, major stakeholders, and the approval process. |
| 3 | 1.1.2 | Stakeholder Setup | Identify stakeholders and establish communication protocols. |
| 3 | 1.1.3 | Feasibility & Risk | |  | | --- | |  |  |  | | --- | | Conduct feasibility study and risk assessment. | |
| 3 | 1.1.4 | Funding & Resources | Secure necessary funding and resources. |
| **2** | **1.2** | **Planning** |  |
| 3 | 1.2.1 | Project Plan | Develop detailed project plan with timelines, resources, and budget. |
| 3 | 1.2.2 | Requirements Spec | Finalize technical requirements for hardware and software. |
| 3 | 1.2.3 | Procurement Planning | Organize procurement of hardware and software. |
| 3 | 1.2.4 | Standards & Compliance | Establish protocols for quality, privacy, risk management, and safety. |
| **2** | **1.3** | **Execution** |  |
| 3 | 1.3.1 | Hardware & Software Setup | Assemble hardware and install software. |
| 3 | 1.3.2 | Testing & Integration | Conduct preliminary testing and system integration. |
| 3 | 1.3.3 | |  | | --- | |  |  |  | | --- | | Software Dev & Simulation | | Develop and simulate software functionalities. |
| 3 | 1.3.4 | Deployment & Evaluation | Deploy system in real-world settings and evaluate performance. |
| **2** | **1.4** | **Control** |  |
| 3 | 1.4.1 | Performance Reviews | Regularly review project performance and progress. |
| 3 | 1.4.2 | Quality & Risk Management | Manage project risks and maintain quality standards. |
| **2** | **1.5** | **Closure** |  |
| 3 | 1.5.1 | Feedback & Adjustments | Incorporate feedback and make final project adjustments. |
| 3 | 1.5.2 | Marketing & Outreach | Prepare and execute marketing materials. |
| 3 | 1.5.3 | Close | Document project outcomes and close the project. |

Table 2: Word Breakdown Structure

1.Childcare Robot Project

Figure 7: WBS Diagram

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Task ID** | **Task Name** | **Duration** | **Start** | **Finish** | **Predecessors** |
| **1** | **Initiation Phase** | **28d** | **07 Aug '24** | **13 Sep '24** |  |
| 2 | Define project scope and goals. | 7d | 07 Aug '24 | 15 Aug '24 |  |
| 3 | Identify project stakeholders and establish communication protocols. | 7d | 16 Aug '24 | 26 Aug '24 | 2 |
| 4 | Conduct feasibility study and initial risk assessment. | 7d | 27 Aug '24 | 04 Sep '24 | 3 |
| 5 | Secure initial funding and resources. | 7d | 05 Sep '24 | 13 Sep '24 | 4 |
| **6** | **Planning Phase** | **42d** | **16 Sep '24** | **12 Nov '24** |  |
| 7 | Develop detailed project plan | 14d | 16 Sep '24 | 03 Oct '24 | 5 |
| 8 | Finalize requirements for hardware and software components | 7d | 04 Oct '24 | 14 Oct '24 | 7 |
| 9 | Plan procurement processes for hardware and software | 7d | 15 Oct '24 | 23 Oct '24 | 8 |
| 10 | Establish quality control, privacy standards, risk management and safety certification protocols | 14d | 24 Oct '24 | 12 Nov '24 | 9 |
| **11** | **Execution Phase** | **98d** | **24 Oct '24** | **20 May '25** |  |
| 12 | Hardware Setup and Software Configuration | 21d | 24 Oct '24 | 21 Nov '24 | 9 |
| 13 | Preliminary Testing and Integration | 7d | 22 Nov '24 | 02 Dec '24 | 12 |
| 14 | Software Development and Simulation | 42d | 03 Dec '24 | 10 Apr '25 | 13 |
| 15 | Real-World Deployment and Evaluation | 28d | 11 Apr '25 | 20 May '25 | 14 |
| **16** | **Control Phase** | **126d** | **16 Sep '24** | **10 Mar '25** |  |
| 17 | Regular Performance and Progress Reviews | 126d | 16 Sep '24 | 10 Mar '25 | 5 |
| 18 | Quality Control and Risk Management | 77d | 22 Nov '24 | 10 Mar '25 | 12 |
| **19** | **Closing Phase** | **28d** | **21 May '25** | **27 Jun '25** |  |
| 20 | Final adjustments based on feedback and compliance results | 7d | 21 May '25 | 29 May '25 | 15 |
| 21 | Preparation and execution of marketing and outreach materials | 14d | 30 May '25 | 18 Jun '25 | 20 |
| 22 | Project review and closure documentation | 7d | 19 Jun '25 | 27 Jun '25 | 21 |

Table 3: Activities List

A screenshot of a computer

Description automatically generated

Figure 8: Gantt Chart

**Schedule Overview**

* **Initiation Phase (28 days):** This phase sets the foundation for the project. Tasks include defining the project scope, identifying stakeholders, conducting a feasibility study, and securing necessary funding and resources. This phase is crucial as it establishes the project's parameters and ensures that all necessary support and approvals are in place before moving forward.
* **Planning Phase (42 days):** Detailed planning involves developing the project plan, finalizing hardware and software requirements, planning procurement, and establishing standards for quality control, privacy, risk management, and safety. This phase prepares the project for successful execution by laying down a detailed roadmap and guidelines that will govern project activities.
* **Execution Phase (98 days):** The core phase where actual product development happens, including hardware setup and software configuration, preliminary testing and integration, software development and simulation, and real-world deployment and evaluation. This phase is critical as it transforms theoretical plans and designs into a tangible, operational system.
* **Control Phase (126 days):** This phase overlaps substantially with others due to its nature, focusing on monitoring the project's progress and maintaining standards through regular performance reviews and risk management activities. It ensures the project remains on track and meets set quality standards.
* **Closing Phase (28 days):** The final phase involves making adjustments based on feedback, preparing and executing marketing and outreach materials, and completing project documentation for closure. This phase wraps up the project by ensuring all objectives have been met and the product is ready for wider deployment and use.

**How These Relate to the Project**

1. **Sequential and Overlapping Tasks:** The schedule shows dependencies where certain tasks cannot begin until previous ones are completed, such as "Hardware Setup and Software Configuration" that can't start until procurement plans are finalized. Meanwhile, the control activities like "Regular Performance and Progress Reviews" span multiple phases, emphasizing continuous oversight.
2. **Critical Path:** Identifying tasks that directly affect the project timeline helps in prioritizing efforts and resources. For instance, delays in "Software Development and Simulation" would directly delay "Real-World Deployment and Evaluation," impacting the project's finish date.
3. **Resource Allocation:** Knowing the duration of each phase helps in planning resource allocation efficiently, ensuring that manpower and financial resources are available when needed without idling or bottlenecks.
4. **Risk Management:** Scheduling long durations for tasks like risk management and quality control highlights the project’s commitment to adhering to standards and addressing potential issues proactively.
5. **Stakeholder Engagement:** Scheduled reviews and documentation phases ensure continuous engagement with stakeholders, keeping them informed and involved throughout the project lifecycle, which is crucial for maintaining alignment and support.

# Considerations

|  |  |  |  |
| --- | --- | --- | --- |
| **Issue** | **Description** | **Possible Solution** | **Justification** |
| Technical Risk | Building and deploying the robot comes with some technical challenges, like making sure it can accurately map and move around different daycare environments. Problems could pop up with the robot’s sensors, software, or its ability to work in tricky spaces with complex layouts or shiny surfaces. | To avoid these issues, we’ll do thorough testing in a variety of real-world-like settings. This includes testing in different lighting, with obstacles, and on different floor types. Keeping the software modular also makes updates and fixes easier. | Catching and fixing these problems early during testing means we’re less likely to face major issues later, ensuring the robot works well in any daycare setting. |
| Privacy Risk | Even though we’re using LiDAR sensors instead of cameras to protect privacy, there’s still a chance that data could be mishandled or accessed by the wrong people. | We’ll use data encryption to make sure any data the robot collects is secure. | Protecting data privacy helps build trust with users, which is key to getting the robot widely accepted in sensitive places like daycare centers. |
| Transitioning to New System | Switching from traditional child supervision methods to a robotic system might be disruptive. Staff might struggle to adapt to the new technology, and there could be worries about job security or how reliable the robot is. | We’ll roll out the system gradually, starting with a pilot program in a few daycare centers. We’ll provide thorough training and support, including hands-on demos and easy-to-follow manuals. The rollout will expand based on feedback and any needed adjustments. | A phased rollout helps ensure a smooth transition, making it easier for staff to get comfortable with the robot. This reduces the risk of disruption and increases the chances of success. |
| Over Budget | The project might go over budget due to unexpected costs, like needing extra hardware, longer development time, or unforeseen technical issues. | We’ll keep a close eye on the budget and put strict controls in place. We’ll set aside a contingency fund for any surprises and focus spending on the most critical parts of the project. Regular budget reviews will help keep things on track. | By staying on top of the budget and having a backup plan, we can avoid running out of money and make sure we deliver the essential features without cutting corners. This also helps maintain trust with stakeholders. |

Table 4: Consideration and Issues

# 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.

# Risk and Issue mitigation

Our project involves a 2D SLAM-based robot designed for childcare, focusing on safety and navigation without cameras, using LiDAR sensors. Despite not capturing images, privacy risks arise from tracking movements, addressed by encrypting data and ensuring transparency about the robot's function to alleviate concerns of constant surveillance. Local data storage policies will emphasize secure deletion after specific periods, aligning with best privacy practices without seeking certifications. Key risks include moderate privacy concerns from data collection (Risk Level: 9), low risk of perceived surveillance (Risk Level: 4), high risk related to data management (Risk Level: 12), and compliance practices (Risk Level: 6).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Risk ID** | **Risk Factor** | **Likelihood (1-5)** | **Impact (1-5)** | **Risk Level (Likelihood x Impact)** | **Description** |
| 1 | Privacy Concerns from LiDAR Data Collection | 3 (Moderate) | 3 (Significant) | 9 (Moderate) | Privacy issues from data collection could arise, needing strong encryption and policies. |
| 2 | Perception of Constant Surveillance | 2 (Low) | 2 (Minor) | 4 (Low) | Staff or parents may feel overly monitored; transparency and demonstrations can mitigate this. |
| 3 | Data Management and Storage | 3 (Moderate) | 4 (Major) | 12 (High) | Improper data management could lead to significant privacy breaches; robust data policies required. |
| 4 | Compliance and Best Practices | 2 (Low) | 3 (Medium) | 6 (Low) | Ensuring adherence to privacy standards and best practices through regular review, even without specific certifications. |

Table 5: Risk Matrix

# 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.

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# Appendix

|  |  |  |  |
| --- | --- | --- | --- |
| **Date** | **Time** | **Items to be discussed** | **Attended** |
| 10/08/2024 | 3:00 PM | **Agree on Common Availability:** Establish a schedule that suits all team members for meetings and work sessions. | Everyone |
| 14/08/2024 | 3:00 PM | **Reach Consensus on Project Objectives:** Discuss and finalize mutual understanding and agreement on the key aspects of the project.  **Divide Responsibilities:** Allocate tasks among team members based on expertise and workload balance. | Everyone |
| 15/08/2024 | 2:30 PM | **Consult with the Supervisor:** Address any uncertainties or seek guidance on project directions by consulting with the project supervisor.  **Progress on Individual Tasks:** Ensure each member advances their respective parts of the project as planned. | Everyone |
| 18/08/2024 | 12:00 PM | **Assemble and Review the Final Document:** Combine individual contributions into a comprehensive final document and conduct a thorough review for consistency and completeness. | Everyone |

|  |  |  |
| --- | --- | --- |
| **Members Name** | **Sections Written** | **Tasks Undertaken** |
| Mary | - Functional Requirements  - Meeting Minutes  - System navigation and UI  - Project Schedule  - Risks | - Distribution of work  - Writeup for the mentioned sections  -Setup meeting & maintain group register  - Helping and guiding team members with the topics |
| Meghna | - System Development Approach  - Use Case Diagram  - Member Contribution Table  - Non- Functional Requirements  - Risks | - Distribution of work  - Writeup for the mentioned sections  - Research case study |
| John | - Project Cost Estimate  - Issues and Solutions  - Human Factors  - Ethical Issues  - Risks | - Writeup for the mentioned sections  - Distribution of work  - Research case study |

Github Repository:

https://github.com/maryyaz/NIT6150