How do sensor-based navigation systems in simple autonomous robots respond to manipulated or incorrect sensor input, and how can we improve their reliability?

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Proposal Study Planner - Collaboration

1 Executive Summary

Autonomous robots rely on sensor-based navigation systems to move safely and make decisions in real-world environments. These systems use sensors such as LiDAR, ultrasonic sensors, and cameras to detect obstacles, estimate distance, and determine movement paths. However, incorrect, delayed, or even a manipulated sensor input can negatively affect robotic behavior and reduce system reliability. Autonomous robotic systems are becoming more common in homes, warehouses, transportation, healthcare environments, etc - so understanding how these systems respond to unreliable sensor data becomes increasingly important.

This research project will investigate how sensor-based navigation systems in simple autonomous robots respond to manipulated or incorrect sensor input and how their reliability can be improved. The project will focus on evaluating the behavior of a ROS-based mobile robotic platform (used for prototyping) under different sensor conditions, including delayed readings, false obstacle detection, noisy sensor data, and inconsistent sensor measurements. The robot's navigation performance, obstacle avoidance behavior, and overall stability will be analyzed during these experiments.

The project will also explore methods for improving robotic reliability through simple validation and filtering techniques. Hardware-in-the-loop experimentation and simulation resources available through the ICARUS Lab will support the testing process and allow controlled experimentation in cyber-physical environments.

The anticipated outcome of this work is a better understanding of how autonomous robots behave under unreliable sensor conditions and what methods can improve resilience and navigation reliability. This research may contribute to the development of safer and more dependable robotic systems while also preparing this research for future graduate-level work in robotics and cyber-physical systems.

2 Survey of Background Literature

2.1 Overview

Autonomous robots are becoming increasingly common in areas such as healthcare, warehouses, transportation, and even homes. Many of these systems rely on sensor-based navigation to safely move through their environment and make decisions with minimal human intervention to improve efficiency, reduce repetitive labor, and assist with everyday tasks. Sensors such as LiDAR, ultrasonic sensors, and radars allow robots to detect obstacles, estimate movement, and navigate independently [1]. However, these systems may become unreliable when sensor input is incorrect, delayed, noisy, or intentionally manipulated.

This research proposes to investigate how simple autonomous robots respond to manipulated or incorrect sensor input and how their reliability can be improved. Using a ROS-based mobile robotic platform along with cyber-physical system resources available through the ICARUS Lab, this project will evaluate how unreliable sensor data affects navigation performance, obstacle avoidance behavior, and overall system stability.

The broader goal of this work is to better understand vulnerabilities in autonomous robotic systems and explore methods for improving their resilience and dependability. Autonomous systems will continue to expand into real-world environments where safety and reliability are critical. Improving the robustness of sensor-based navigation systems may help support safer assistive robotics, more reliable autonomous technologies, and stronger cyber-physical system security practices.

2.2 Background

Modern robotic systems depend on environmental awareness to safely operate without constant human control. To achieve this, robots use light detection/ranging, ultrasonic/sonar sensors, computer vision, and even cameras to gather information about their surroundings and support navigation decisions. Using a combination of these systems, it allow robots to avoid obstacles, estimate movement, and adjust their behavior in real time.

Because autonomous robots combine physical hardware with software-driven decision-making, they are often categorized as cyber-physical systems. In these environments, robotic performance is heavily influenced by the quality and consistency of incoming data. Delayed measurements, noisy readings, communication interruptions, or manipulated information may influence how a robot interprets its surroundings and responds to changing conditions.

Existing research in robotics and cybersecurity has shown that disruptions in sensing and communication can reduce navigation accuracy, destabilize movement, or interfere with obstacle avoidance behavior. As robotic platforms become more connected and intelligent, understanding these weaknesses becomes increasingly important for maintaining safe and dependable operation.

The TurtleBot3 platform provides a programmable and practical environment for studying these challenges because it supports Robot Operating System (ROS/ROS2) integration, LiDAR-based navigation, and real-time robotic experimentation. In addition to physical testing, this project will utilize the Opal-RT real-time simulator to support hardware-in-the-loop experimentation and controlled testing scenarios.

By combining physical robotics experiments with real-time simulation tools, this research aims to better understand how autonomous robots behave under unreliable sensing conditions and identify methods that may improve overall system dependability.

2.3 Relevance/Impact

As autonomous systems become more advanced and interconnected, concerns surrounding reliability and security continue to grow. Robots that rely on automated decision-making and environmental sensing are expected to operate with minimal human intervention, which also means small sensing failures may lead to larger behavioral or safety issues due the amount of trust given.

Modern cyber-physical systems are increasingly connected through wireless communication, networking, cloud infrastructure, and artificial intelligence integration. Because of this, robotic systems may become vulnerable to unreliable data, communication failures, or manipulated sensor information that can influence navigation and decision-making behavior.

Recent progression in AI-assisted automation have also shown how connected systems and devices may be targeted or exploited in ways that were previously difficult to achieve. While autonomous technologies are designed to reduce repetitive labor, improve efficiency, and support human tasks, these benefits may also introduce new security and reliability challenges if these systems are not carefully evaluated.

This research aims to better understand how manipulated or unreliable sensing conditions influence robotic behavior and system stability. By studying these weaknesses early, this work may contribute to the development of safer, more dependable autonomous systems and support future efforts in robotics reliability, cyber-physical security, and intelligent system design.

3 Proposed Methodology

This project will combine physical robotics experimentation with simulation-based testing to study how unreliable sensor input influences robotic navigation and system behavior. The primary platform used for this research will be the

TurtleBot3 Burger, which was selected because it supports autonomous navigation, ROS/ROS2 integration, and real-time prototyping capabilities commonly used in robotics research.

The project will begin by establishing a baseline understanding of how the robot performs under normal operating conditions during navigation and obstacle avoidance tasks. Once this behavior is observed, different sensing disruptions and unreliable input conditions will be introduced to evaluate how the robot responds when environmental information becomes inconsistent and/or inaccurate.

To support this process, the research will also utilize the Opal-RT real-time simulator and hardware-in-the-loop experimentation environment provided by the ICARUS Lab. These tools were chosen because they allow more controlled testing conditions while providing a safer and more flexible way to observe robotic behavior in cyber-physical environments.

After analyzing the robot's response under different conditions, the project will explore general approaches for improving system dependability and navigation consistency. The overall goal of the methodology is to better understand how autonomous robotic systems react to unreliable sensing conditions and identify ways to improve reliability in future robotic applications.

4 Research Plan

Phase 1 — Preliminary Research and System Training

The first stage of this project will focus on reviewing existing research related to autonomous robotic navigation, sensing systems, and cyber-physical reliability. During this phase, I will also become familiar with the TurtleBot3 Burger platform, ROS/ROS2 tools, and the Opal-RT real-time simulation environment in order to build a stronger understanding of the systems being used throughout the project.

Phase 2 — Baseline Navigation Experiments

After becoming familiar with the platform and software environment, the next phase will involve configuring the robot for basic navigation and obstacle avoidance tasks. Initial testing will be conducted under normal conditions to observe movement behavior, navigation performance, and general system stability.

Phase 3 — Sensor Reliability Testing

Once baseline behavior is established, the project will begin exploring how unreliable or manipulated sensing conditions affect robotic behavior. Different testing scenarios will be introduced to observe how the robot responds when environmental information becomes inconsistent, delayed, or inaccurate.

Phase 4 — Reliability Improvement Analysis

After analyzing the results from the testing phase, the project will explore general approaches that may improve navigation consistency and overall system dependability. The goal of this stage is to evaluate whether certain adjustments or validation methods can reduce instability caused by unreliable sensor input.

Phase 5 — Documentation and Presentation

The final stage of the project will focus on organizing research findings, analyzing results, and preparing presentation materials for publishing. This phase will include technical documentation, visualizations, and preparation for research presentations through the McNair Scholars Program and potential conference opportunities throughout the research.

5 Resources

This project will utilize the TurtleBot3 Burger robotic platform as the primary experimental system for navigation and sensor reliability testing [2]. The platform includes integrated components such as a Raspberry Pi single-board computer, OpenCR control board, LiDAR sensor, wheel actuators, battery system, and supporting communication hardware required for autonomous navigation experiments.

The research will also utilize the Opal-RT real-time simulator available through Professor Zografopoulos's laboratory for simulation, cyber-physical experimentation, and hardware-in-the-loop testing [3]. Access to the simulator will allow the project to explore robotic control behavior and evaluate navigation reliability under different sensing conditions.

Software resources will include Robot Operating System (ROS/ROS2), Python, Linux-based development tools, and data visualization tools used for robotics experimentation and analysis.

Additional materials may include replacement sensors, mounting hardware, communication modules, or auxiliary testing equipment depending on experimental needs throughout the project.

Human resources for the project primarily consist of the student researcher and faculty mentor, along with guidance from graduate researchers within the laboratory environment.

Primary Resources and Equipment

- TurtleBot3 Burger robotic platform [2]
- Raspberry Pi camera module [4]
- LiDAR distance sensor
- OpenCR embedded control board

- Opal-RT real-time simulator
- ROS/ROS2 robotics framework
- Python programming environment

References

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[3] Ioannis Zografopoulos, "ICARUS Lab Capabilities," https://zografop.github.io/lab.html.

[4] Digikey, "RaspberryPi SC0024," https://www.digikey.com/en/products/detail/raspberry-pi/SC0024/6152811?s=N4IgTCBcDaIEoEMDOAHARgUwE5YJ4AIAFAS3wGUBhABirABYQBdAXyA.

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