Final Project Report

Class Name:

CSE 486: Capstone Project II

Team Name:

Astro Seed - Botanical Cyborg: Robotic Arm for Terra Pod's Plant Maintenance

Project description:

For our project, we need to have a robotic arm be able to prune, harvest, and provide general plant care.

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Description of the overall project

Motivation

The primary motivation behind the AstroSeed project is to revolutionize how we approach agriculture in environments that are traditionally unsuitable for crop cultivation, such as deserts, polar regions, and extraterrestrial bodies. The project seeks to reduce human labor costs, enhance plant care efficiency, and make food production sustainable in adverse conditions. By automating critical agricultural tasks, the project aims to enable year-round cultivation without the ecological footprint associated with traditional farming methods.

Requirements

The project's requirements are driven by the need to integrate seamlessly within the existing Terra Pod systems. These include:

- High Precision and Reliability: The robotic arm must perform tasks such as pruning, harvesting, and general maintenance with high precision to avoid damaging plants.
- Integration with Aeroponic Systems: Compatibility with the Terra Pod's aeroponic technology is crucial, requiring the robotic arm to operate without interfering with the delicate mist environment that nourishes the plants.
- Autonomous Operation: The arm should function autonomously, with minimal human oversight, using sensors and cameras to navigate and perform tasks.
- Safety and Compliance: Ensuring the robotic arm operates safely in the proximity of human operators and delicate plant life is paramount.
- Scalability: The design should be scalable, allowing for adjustments and upgrades as the Terra Pod technology evolves.

Work Completed

To date, the project has successfully reached several milestones:

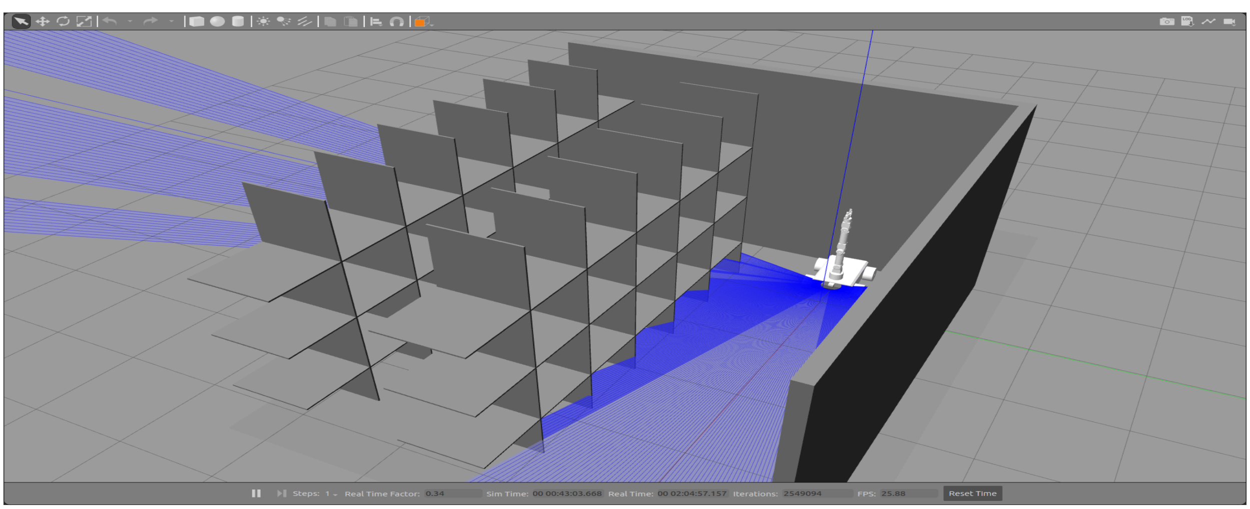
- Design and Simulation: Initial designs of the robotic arm were completed using CAD software, followed by rigorous simulations in Gazebo and RVIZ to ensure functionality and identify potential issues.
- Prototype Development: A working prototype of the robotic arm has not been made due to electrical and mechanical teams breaking off from the company.
- Integration Testing: The prototype has been tested within a mock-up of the Terra Pod environment to ensure it meets operational requirements.
- Software Development: Control software using ROS has been developed, allowing for basic autonomous functionality and manual override when necessary.

Defining the Best of the Work

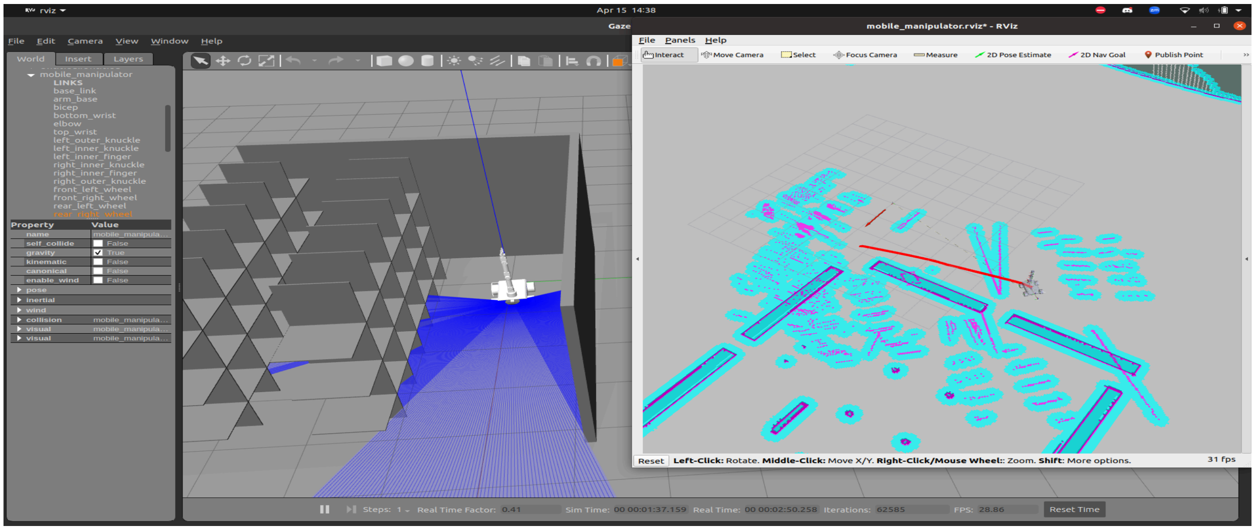
What sets the AstroSeed project apart from other agricultural automation efforts is its specific focus on extreme environment adaptability. The robotic arm's integration into an aeroponic system represents a novel approach to indoor farming technology. Furthermore, the use of advanced machine learning algorithms enables the robotic arm to improve its efficiency and effectiveness over time through reinforcement learning, a feature that enhances its decision-making capabilities in real-time plant care.

Project Multimedia

The diagram outlines the integration of the robotic arm with the Terra Pod's existing systems, detailing the communication flow between the sensors, control units, and the arm's actuators.



Robotic arm placed in terrapod environment



2D SLAM performing path planning for autonomous navigation

Summary of overall contributions

Presentations

I took on significant responsibilities in preparing for various presentations related to our project. I managed the registration and preparation of the showcase presentation, ensuring all details were meticulously planned and executed. I was responsible for creating a video demonstration of our simulation. Additionally, I was responsible for creating three slides for the final presentation of Capstone 1, focusing on delivering clear and impactful content.

Currently, I am involved in developing the final presentation for the showcase day. This task includes incorporating essential elements such as video demonstrations and detailed explanations to effectively convey the project's scope and results to the audience.

Reports

In my role as Scrum Master, I led multiple sprints, during which I was responsible for drafting and compiling comprehensive sprint reports. As part of my duties, I consistently communicated with all team members to ensure the timely completion and submission of these reports. Additionally, I took on the responsibility of creating the test report presentation, which involved synthesizing testing outcomes and presenting these findings in a clear and structured manner. I was also tasked with obtaining the necessary signature from our sponsor, ensuring all documentation was fully authorized and compliant with project requirements.

Product

- **Initial Setup and Testing:**
  - Connected a standard laptop webcam to the robotic arm to facilitate initial 2D vision capabilities.
  - Conducted preliminary tests to ensure basic operational functionality with the robotic arm's control system.
- **Integration of 3D Depth Camera:**
  - Integrated a simulated 3D depth camera developed by OpenNI Kinect to enhance the robotic arm's vision capabilities.
  - Configured and verified the proper functioning of the camera by setting up ROS (Robot Operating System) publishers and subscribers, ensuring seamless data flow.
- **Edge Detection Implementation:**
  - Implemented an edge detection algorithm, specifically the Canny Edge Detection, within the 3D depth camera's data stream.
  - Utilized this algorithm to detect and visualize edges in the environment, facilitating better spatial understanding and object interaction.
  - Employed NumPy to analyze and quantify the number of detected edges, enhancing the analytical capabilities of the system.
- **Object Detection via YOLO Algorithm:**
  - Integrated the YOLO (You Only Look Once) object detection algorithm to identify and classify objects based on a pre-trained dataset.
  - This integration allowed for real-time object detection and classification, crucial for complex task execution by the robotic arm.
- **Distance and Size Calculation Script:**

    - Developed a custom script that utilizes the camera parameters from the 3D depth camera.
    - The script calculates the distance of detected objects from the camera, as well as their height, which is vital for accurate manipulation and interaction by the robotic arm.

Team management

- We held weekly in-person meetings at Noble Library to review the achievements of each team member and plan the next steps. These sessions were crucial for discussing challenges and collaboratively debugging issues. While our meetings typically lasted about an hour, unresolved issues were often carried over to extended discussions via Discord calls.
- In addition to these group interactions, I also had personal meetings with the project sponsor to discuss my individual progress. The sponsor provided substantial support during the initial stages of the project, offering guidance and sharing helpful resources to address specific challenges.

Reflection on your work

Critical evaluation of the quality of your work on the project

In critically evaluating my work on the project, I recognize several key areas of strength and opportunities for improvement. My effectiveness in leveraging essential technologies like ROS, Gazebo, and OpenCV contributed positively to project outcomes, though a deeper mastery of some ROS functionalities could have expedited problem resolution. Efficiency in task management was generally good, yet proactive planning could enhance my timeliness further. Adaptability and responsiveness to project changes were strong, especially in learning new tools such as Taiga and Notion, yet quicker adjustment to technical challenges remains a goal. My collaboration and communication as Scrum Master were proactive, but inviting more feedback could strengthen team dynamics. Overall, my contributions significantly advanced project goals, and the experience substantially enriched my professional skills, laying a robust foundation for future challenges in robotics and AI.

Technologies and skills learned

- Robot Operating System (ROS): I gained extensive knowledge of ROS, learning its core functionality which includes managing topics and nodes, essential for orchestrating complex robotic tasks.
- Linux Terminal Proficiency: Improved my command line skills in Linux, enhancing my ability to navigate and manipulate the system effectively for software development.
- Programming Skills: Advanced my proficiency in Python3 and mastered OpenCV, leveraging these tools to implement sophisticated image processing and computer vision algorithms.
- 3D Simulation Tools: Acquired skills in using Gazebo and RVIZ for 3D simulation, critical for visualizing and testing robot models and environments in a virtual space.
- File Management and Configuration: Learned to create and manage URDF, launch, and XML files, crucial for configuring and deploying robotic applications.
- Project Management Software: Became proficient in using Taiga and Notion, both vital tools for supporting agile methodologies and enhancing team collaboration. Taiga was instrumental in tracking project progress and facilitating agile processes, while Notion served as an essential platform for organizing project documentation, managing tasks, and centralizing team communication.

Lessons learned

- Team Collaboration: Developed a strong capability to work collaboratively in a team, effectively solving problems and sharing insights, which was fundamental to our project's success.
- Scrum and Agile Practices: I appreciated the importance of the scrum process in project management, understanding how agile practices can streamline project timelines and enhance output quality.

Impact of these new learning on your future development

- The skills and insights gained from this project have prepared me for advanced studies; I will be pursuing an MS in Artificial Intelligence and an MSE in Robotics Engineering.
- The foundational knowledge in ROS and related technologies has provided a strong base that will be instrumental in my future academic and professional endeavors in the field of robotics and AI. The hands-on experience with real-world applications and team dynamics will significantly benefit my capacity to lead and innovate in future projects.

Value

Economic Impact

The introduction of a robotic arm to perform tasks such as pruning, harvesting, and general plant care within the Terra Pod represents a substantial economic advantage. By automating these labor-intensive activities, the project is set to significantly reduce labor costs, which are often one of the largest expenses in agricultural operations. Moreover, the precision and efficiency provided by robotic automation could lead to higher yields and better quality produce, potentially increasing profitability. The robotic arm's ability to function autonomously or semi-autonomously also means that it can operate continuously without the need for breaks or shifts, maximizing productivity around the clock. This increased efficiency can make the Terra Pod system economically viable not only in remote and extreme environments but also in urban settings where space and labor costs are premium.

Environmental Impact

The Terra Pod system, enhanced by the robotic arm, also offers substantial environmental benefits. By utilizing aeroponic technology, which requires significantly less water and no soil compared to traditional farming methods, the system minimizes the ecological footprint of agricultural practices. The precision of the robotic arm ensures that resources like nutrients and water are distributed efficiently, reducing waste and further diminishing the environmental impact. Furthermore, the ability to deploy these systems in diverse and extreme environments such as deserts, polar areas, or even other planets can lead to a reduction in the need for transporting food over long distances, thus lowering greenhouse gas emissions associated with logistics. This aligns with global efforts to make agriculture more sustainable and can significantly contribute to food security without the extensive use of land and water resources typically required for traditional farming.

These impacts demonstrate the project's potential to revolutionize agricultural practices by merging advanced robotics with innovative farming techniques, making it a pioneering model for future agricultural solutions in challenging environments.

Team reflection

Evaluation of the team success

The AstroSeed team, tasked with integrating a robotic arm into the Terra Pod system, showcased resilience and adaptability amidst significant challenges, such as the split of the electrical and mechanical teams. Despite these obstacles, the team's strategic approach to communication and structured role allocation led to marked improvements in team dynamics and effective problem-solving capabilities. Notably, the team maintained consistent engagement with the project sponsor, which proved crucial in navigating project hurdles and aligning with the sponsor’s expectations. This aspect of sponsor interaction was highlighted by their satisfaction with the project outcomes, indicating successful alignment with their vision.

Technical execution focused on simulations in the absence of complete team resources, which, while limiting in terms of producing a tangible prototype, was essential in identifying potential flaws and testing solutions safely and efficiently. This foundational work in simulation is pivotal for future phases, suggesting a promising direction towards prototype development and further iterations. Overall, the team's ability to continue progressing under strained circumstances speaks volumes about their potential and lays a strong groundwork for future advancements within AstroSeed. The recommended strategic enhancements in communication, conflict resolution, and project planning are poised to further strengthen the team's effectiveness and project outcomes in upcoming endeavors.

Future Project Directions

Looking ahead, the project could benefit significantly from expanding the team to include new members who can offer fresh perspectives and replace the expertise lost with the departure of the electrical and mechanical teams. Additionally, exploring partnerships with other academic departments or external experts could compensate for the reduced team size and provide additional technical support.

Incorporating more advanced technologies such as machine learning algorithms for predictive maintenance and anomaly detection within the Terra Pod's operational parameters could also enhance the project's scope and functionality. Furthermore, initiating smaller, parallel projects that focus on specific components of the Terra Pod system could help in mitigating risks associated with the main project and foster innovation within the team.

Conclusion

In conclusion, the AstroSeed project represents a significant advancement in the field of agricultural technology, specifically tailored for extreme environments. By developing a robotic arm for the Terra Pod system, the project addresses key challenges in traditional agriculture by reducing labor costs, enhancing operational efficiency, and minimizing ecological impacts. Despite facing setbacks such as team splits and prototype development delays, the project has made substantial progress through detailed simulations and software development. Looking forward, the learnings and outcomes from this initiative not only pave the way for sustainable agricultural practices in inhospitable terrains but also hold the potential to be applied in similar technologies worldwide, fostering innovation in robotic automation and smart farming solutions.