CG2111A Engineering Principle and Practice II
Semester 2 2023/2024

"Alex to the Rescue"
Design Report
Team: B03-1B

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Section 1 System Functionalities

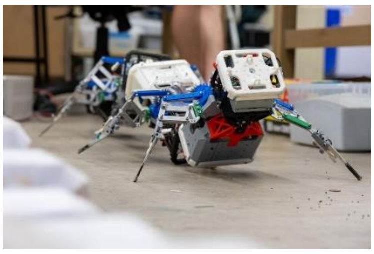
The construction of a robotic vehicle, named Alex, is intended for utilisation in search and rescue missions. It is to be assembled using the provided motors, embedded controllers, power bank, chassis, colour sensor and Lidar without making any alterations to these components. Alex is to be controlled remotely via a laptop that sends commands to a Raspberry Pi, which in turn is interfaced with an Arduino Uno.

The task for Alex involves remote operation from a distance to navigate and chart a maze. As Alex navigates through the maze, there are obstacles such as tables, chairs, and boxes through which Alex needs to locate two or more human figures in distress using a colour sensor. These human figures are categorised as "green" for those who are healthy but unable to escape, or "red" for those who are injured and trapped. The objective is to pinpoint all the individuals in need of rescue within the allotted time, while ignoring objects of various colours that do not represent victims, ensuring they are not mistakenly identified as such.

Alex should employ its Lidar system to generate a map of its surroundings and detect human figures within the generated map and proficiently make its way from a specific starting location to a determined end location within the maze. The fundamental capabilities required of Alex include the ability to move forward and execute turns to the left or right. It should be equipped to handle difficult terrain features, like bumps within the maze, by overcoming them without causing any collisions.

Section 2 Review of State of the Art

2.1 Centipede-Inspired Multilegged robots



Inspired by centipedes, the robot is designed with multiple legs (potentially ranging from 6 to 16 or more) to traverse uneven and challenging terrains effectively. These robots are capable of navigating through intricate, uneven landscapes, presenting opportunities for their application in fields like farming, space exploration, and search and rescue operations. The robot is equipped with a multitude of legs, each playing a vital role in ensuring its overall stability and movement. It is also integrated with software designed to help maintain its balance and navigate effectively over uneven and varied terrains. It is also built to withstand the rough terrains and environments typically encountered in search and rescue operations.

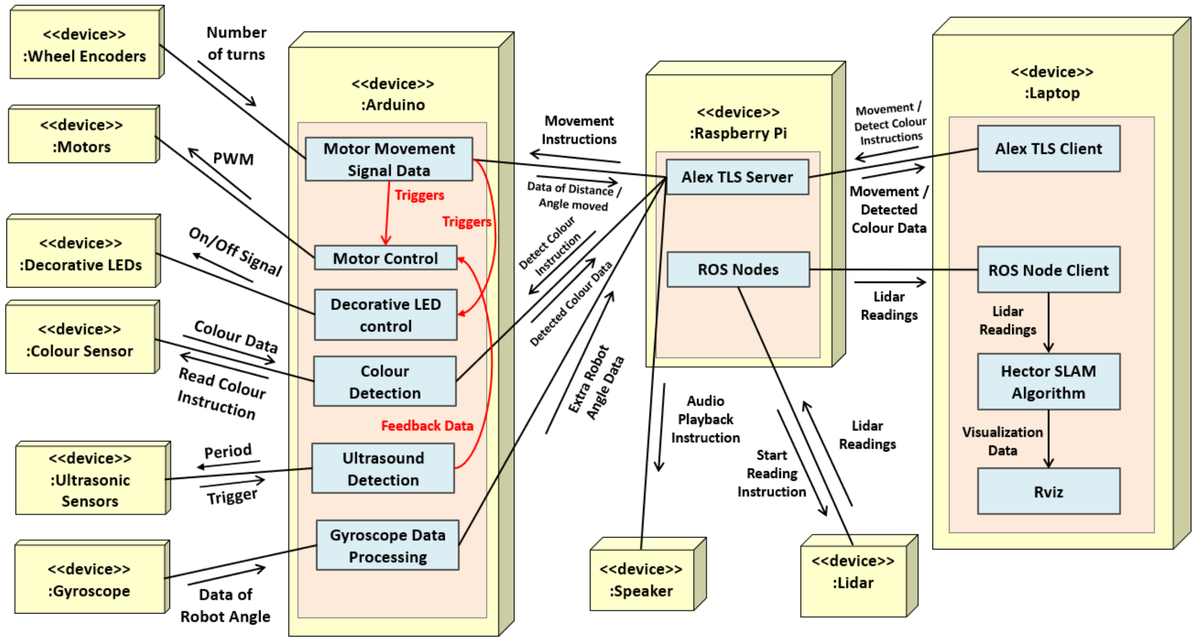
Strengths include that it can navigate through difficult landscapes where traditional wheeled or bipedal robots might struggle. Its redundant Leg Design ensures that the robot can continue moving efficiently even if one or more legs falter, ensuring consistent mobility. It also lacks the need for intricate sensor systems, making it potentially more reliable in harsh or unpredictable environments. However, its weakness is that having more legs might reduce the overall speed or increase energy consumption. The exact number of legs for optimal balance between cost, efficiency, and robustness is still a subject of ongoing research. While the simplicity of the control system is a strength, it also means the robot might not be as adept at nuanced navigation or obstacle avoidance as sensor-equipped robots.

2.2 Rooster Robot

The Rooster, developed by RoboTiCan, is a versatile search-and-rescue robot designed for natural disasters. Its unique mobility allows it to walk and fly as needed. Encased in a durable metal cage, it withstands impacts and falls from heights of six metres. Its communication system enables autonomous operation and the formation of wireless mesh networks for coordination in disaster zones without relying on cellular connections.

Strengths of the Rooster include its versatile mobility, combining walking and flying capabilities for efficient navigation across diverse terrains. Encased in a durable metal cage, it withstands substantial impacts, ensuring resilience in challenging environments. Its unique communication system enables seamless coordination among multiple units, allowing a single operator to control a team of Roosters simultaneously. These robots establish independent wireless mesh networks, facilitating communication in areas without cellular coverage, ideal for disaster response. The relay system extends communication range as more units join the network, enhancing operator control over extended distances. However, the Rooster's weaknesses include its bulky design, which may hinder manoeuvrability in tight spaces. Lacking artificial intelligence, it heavily relies on human operators for guidance and decision-making. Additionally, while boasting dual functionality, it's not as agile as standard drones, potentially impacting its effectiveness in certain scenarios.

Section 3 System Architecture



The figure above shows the high-level components of Alex. Instructions from the laptop are relayed to the Arduino through the Raspberry Pi to either move Alex or take a reading with the colour sensor. Wheel encoders and ultrasonic sensors will be used to provide feedback data to the Arduino to ensure the accuracy of Alex's movement, while a gyroscope is used for more accurate tracking of the angle at which Alex is positioned. Movement data and detected colour readings will be relayed from the Arduino to the laptop through the Raspberry Pi. Meanwhile, Lidar readings will be sent to the ROS Node Client on the laptop via the Raspberry Pi, which creates a visualisation of the Lidar readings through Hector SLAM and Rviz. When Alex is moving or has detected a certain colour, audio will be played through a speaker controlled using the Raspberry Pi while decorative LEDs will be turned on/off via the Arduino.

Section 4 Component Design

High Level Steps:

1. Initialization
2. Generating Map using Hector SLAM
3. User sends command
4. Arduino processes command
5. Repeat step 2 until navigation is over

Further breakdown:

Step 1. Initialization

- RPi sends a predetermined hello packet to the Arduino.
- Arduino reads the packet and checks for any data corruption using Checksum.
- Arduino then replies to the RPi if the received packet is good or corrupted.
- In the case of a good packet, the Arduino will start listening for the next packet from the RPi.
- In the case of a bad packet, serial communication with the Arduino will be disabled.
- A TLS server is then created on the RPi.
- A TLS client on the laptop connects to the TLS server on the RPi. After the TLS client verifies the authenticity of the certificate sent by the server and a common session key is generated, communication is established.
- After the RPi has successful handshakes with the Arduino and laptop TLS client respectively, a command will be sent to the RPi via SSH to start the Lidar.

Step 2: Generating Map using Hector SLAM

- Lidar readings of Alex's surroundings are recorded continuously and sent to the ROS Node on the RPi, which is relayed to the ROS Node Client on the laptop.
- ROS Node Client on laptop uses received Lidar readings to map out Alex's surroundings using the Hector SLAM Mapping Algorithm, which is then visualised using Rviz.
- This map is updated as the bot moves.

Based on the data of Alex's surroundings according to the generated map, the user will send commands to the RPi which are relayed to the Arduino through command packets.

Step 3: User sends command

- User sends commands from laptop to TLS server on RPi
- RPi checks if received data is good or corrupted. If it is good, command will be relayed to the Arduino.
- RPi will also play selected audio files via a speaker connected to it upon receiving and transmitting movement instructions to the Arduino depending on direction of movement.

Step 4: Arduino processes command

- Arduino checks if the data packet received from the RPi is good or corrupted. If it is good, it will check if the command sent is a valid command.
- If the command is valid, the Arduino executes commands for movement and colour detection. In conjunction, the Arduino also activates a gyroscope for more accurate

tracking of distance/angle moved, ultrasonic sensors to prevent bumping into walls/obstacles and LEDs for cosmetic effect.

- After command is executed, Arduino sends data such as total distance moved/angle turned by Alex and detected colour readings to the RPi, which will relay the information to the laptop upon request.

- RPi will play certain audio files via the speaker connected to it upon successfully receiving certain colour readings from the Arduino.

Section 5 Project Plan

Week 8: (11 Mar ~ 15 Mar)

All group members will work together to assemble Alex. After thoroughly going through the assembly guide, we will examine and plan the arrangement of our hardware and begin the wiring of the electronics. Using the studio guides, we will also set up Alex's motor control routines, set up and test the wheel encoders, and set up the Arduino libraries into the RPi. Once we configured the software on RPi to allow Alex to move fixed distances, the whole team discussed on additional components we should use to further improve Alex's rescue capability.

Week 9: (18 Mar ~ 22 Mar)

Subteam 2 will work on getting the TLS connection between our laptop and the RPi online by following the week's studio instructions to build the TLS server on the RPi and the TLS client on our laptop. Subteam 1 will concurrently work on implementing the colour sensor into our Alex, which will be done through adding code to the Arduino file and then testing it on different colours.

Week 10: (25 Mar ~ 29 Mar)

Following the studio instructions, both subteams will work on implementing ROS on the Raspberry Pi while ensuring that previously implemented functionalities like being able to control Alex using our laptop via TLS were still working. Both subteams will also work on completing the Design Report.

Week 11: (1 Apr ~ 5 Apr)

Subteam 2 will figure out how to implement Hector SLAM and ROS on the laptop and connect with the ROS node on the RPi to process RPLidar data for RViz on the laptop and test this connection. Moreover, if time permits, Subteam 2 will work on establishing a ROS network that enables Lidar data to be rendered remotely on our laptop instead of the RPi. They will be going through the tutorial for ROS networking. Subteam 1 will configure the ultrasonic sensors and decorative LEDS into the current robot and run a test to ensure that the components are functioning. They will create the code for these components and figure out how to call these codes from the laptop.

Towards the end of the week, our additional parts will arrive. Subteam 1 will be tasked with integrating the new components (gyroscope and speaker) into the Arduino, using basic code from online websites to test the functionalities and get testing data. Subteam 2 will be working on implementing the existing code required to use the gyroscope and speaker seamlessly with the previous code. Moreover, Subteam 1 will be 3D printing a powerbank and Lidar holder to be placed on the top of Alex, this will make Alex neater and more secure. After the additional components are integrated and working, we will proceed with the first trial run of Alex.

Week 12: (8 Apr ~ 12 Apr)

Subteam 1 will work on touching up the wiring on Alex to minimise the risk of wires coming loose during the actual runs, and rewrite as much of the existing Arduino code to bare-metal as possible. Subteam 2 will work on fine-tuning the accuracy of Alex's movements to ensure that Alex accurately moves the distance/angle specified in each command sent to it. We will also conduct more trial runs to ensure that Alex is consistent in accurately traversing and mapping out the maze.

Reference

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