Team 7: Conceptual Design and Planning

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I. Introduction

The goal of this project is to design an autonomous robot to greet and guide students and faculty members in the Ashraf Islam Engineering Building (AIEB). To achieve this goal, several systems will be utilized: main control, safety, localization, and power systems. The first is the autonomous aspect that the robot needs to have. This would include the robot knowing where it is and where it needs to go. The navigation and localization portion of the AuR will be using LIDAR for mapping, implementing a SLAM (simultaneous localization and mapping) algorithm, and using WIFI-beacons to track position. All these methods will ensure the robot's awareness and the robot's destination. The second challenge will be the power system. The power system will include a main battery using additional capacitors to reduce ripple voltage and overall noise. The battery will be charged using contact-based charging in order to ensure easy connection and disconnection from the power source. The last hurdle that will be encountered is the safety system. To ensure a safe environment for the robot and others that will be encountered by it, the safety system will use proximity sensors and speed detection. To solve the issues of these different systems, we have researched and determined the micro-controllers that we will be implementing.

A. Specs and Constraints

The specifications and constraints of this project ensure the safety of the robot and its surroundings. The robot should not cause any harm to anyone. There will be a safety system that will be implemented to ensure that precautions will be taken. Using preemptive collision sensors, there should be no running into walls, students, faculty, or objects. The team has also taken into consideration of how the robot will react to these potential collisions. The robot should stop until the sensors are no longer detecting the issue. The robot will also have wheels that are similar to a Roomba so that it can have a wide range of motion. The second constraint is the robot will guide the user to their destination. It will be using the SLAM algorithm to know how the hallways are laid out to know where it currently resides at and where it is going. There will be tracking methods that will be utilized to ensure that the robot reaches its final destination. The next specification the robot will have is it must easily leave and return to its home base without any assistance. To get this to work, the robot will have contact points that are powered by the home base. Contact based charging allows the robot to have a simple means of charging. The robot will have each major component be individually replaceable. This will help with future issues such as replacement parts and upgrades. These components will include the power systems, sensors, and the main control board. The constraints of the robot base will take up no more than 1.5 x 1.5 x 1.5 cubic meters of area. The reason behind this is the amount of space the robot will take up. The next constraint that the robot will have is to not deviate from the intended course by more than 15 centimeters in any direction. The battery life will last between 2-4 hours. This specific constraint was requested by our customer and the reasoning for this is because it needs to be active throughout the day. The final constraint that the robot will have is that the robot will move at an average walking speed. The average velocity of the AuR is about 0.7 ± 0.1 meters per second and the average walking speed is said to be equivalent to 0.82 meters per second [9]. This will ensure the safety of the robot and its surroundings. The team was given these constraints from 2 sources: the customer (Dr. Andy Pardue) and the team's supervisor (Dr. Charles Van Neste). Here's a breakdown of where specifically each specification/constraint originates from:

1) Dr. Andy Pardue
   - The AuR shall guide the user to their destination.
   - Battery life of 2-4 hours
   - Speed of the AuR
   - AuR charging station/Home base
   - Modularity of the AuR
2) Charles Van Neste
   - Collision detection
   - Reaction time to collision
   - SLAM algorithm
   - Definite size
   - Minimal error in movement and final destination.

Further constraints are mentioned below.

II. Background

A. Lidar

The LIDAR (light detection and ranging sensor) will gather various points of data from within the building by using a laser and sensor. In order for the LIDAR to determine how long it takes for the light from the laser to travel to a reflective surface and back to the sensor, these points will be fed into the SLAM algorithm to generate and save a map [2].

B. WI-FI and Bluetooth Triangulation

WiFi and Bluetooth triangulation make use of at least individual three access points to assess the location of a device [3]. Beacons are positioned in various locations with overlap, this is to ensure that no gaps are left. Based on the connected beacons, the location can be calculated by the device and strength of each receiving signal.

C. SLAM

SLAM is "a method used for autonomous vehicles that lets you build a map and localize your vehicle in that map at the same time" [8]. SLAM works by taking information about the environment from visual sensors. Once this step is completed it will then processes the data. The purpose of this is to establish a consistent model of the environment. The position is also found in relation to that model. The input data is then compared to the existing model in order to reduce error.

D. Contact-Based Charging

A contact-based charging system consists of two metal tiles on the source and two metal tiles on the recipient. [1]. When the two receiving tiles make contact with the two source tiles, a circuit is formed and charging will begin. Contact charging is superior to plug-in charging for autonomous purposes, since the system has a slower degradation rate. When the robot tries to make contact, there will be less of a chance for the system to become damaged.

While the AuR's purpose is to benefit its' users, the article "Service Robots: A Systematic Literature Review" mentions potential mental health concerns as a result of emotional attachment to the AuR [4]. In order to address this concern, the speech of the AuR will be limited to non-colloquial phrasing such that the chances of emotional connection are reasonably diminished. The second response would be to communicate clearly with the user, that they have reached their destination. This would be indicating that the AuR is no longer paired with the user.

III. Ethical, Professional, and Standards Considerations

Profession ConsiderationsThe most prominent concern about the AuR is the impact that it will have on hallway congestion. In order to diminish this concern, the AuR will need to be in close proximity to the neighboring walls on the way to the destination. This is so that the robot will stay away from the central traffic in the hallway. To achieve this, the AuR will traverse the AIEB on the right side of the hallways.

Maintaining the AuR a is significant consideration that needs to be accounted for. This will affect TTU employees who will be working at AIEB due to increased maintenance. Maintenance of the AuR should be required as infrequently as possible to give employees more time for other tasks. Therefore, the AuR shall be modular so that general maintenance can be easily performed. Each individual major system shown in Fig. 1 will be as modular as possible.

A. Relevant Standards

There are many standards to be considered for this project. Some of the most prevalent ones include but are not limited to:

1) IEEE Standard 1873-2015: Room mapping uniformity
This standard aims to define common terms used to describe the areas where AuR is applicable (eg indoors, outdoors, the size of the space to be covered, etc.). This standard discusses the metrics used to describe the AuRs' functionality as well. It also aims to classify the maps generated by AuR based on the data and the type of map used. The reason that we will be following this standard is because it will allow us to not only create a foundation for all automated robots that are developed for TTU in the future, but also it will help define the use case constraints of the AuR to high degrees of detail [5].
2) NEC Standard 310.16(b) Proper Wire Gauging
This standard was created to ensure that the proper wire gauge is used based on the temperature produced by the power flow. This standard becomes increasingly relevant to the project as the project approaches its final stage. During the initial stages, the team will be doing all algorithm-based testing using the prototype that was given to us by the customer. The prototype uses a low-power motor due to its small form factor relative to the intended final product. As power systems are implemented and low-power IoT devices are connected to relatively high-power DC motors, the team may encounter many fire-related safety issues if the standard is not strictly adhered to [7].
3) UL Standard 1642 Standard for Lithium Batteries
This standard covers the safety of lithium batteries (both rechargeable and non-rechargeable). It includes many rigorous stress tests that are performed on the battery/battery pack, this to ensure that it will not cause fires. If the team is going to be making our own battery pack, we will need to be following this standard closely for the testing of the pack; however, if we end up buying a battery pack, we will definitely need to ensure that the battery pack meets the standard [10].
4) ISO/TS Standard 15066 specifications of safety requirements for collaborative robot applications
This standard covers the safety aspects of the interaction of humans and robots. This is to ensure that any and all encounters are painless for humans. This is an important standard to keep at the forefront of our project throughout all of the stages. The AuR will be operating indoors and around people at all times. It is very important, that the robot will be unable to cause any bodily harm people that it interacts with[6].

IV. Block Diagram

A. Main Control

The main control system of the AuR will consist of the user input processing subsystem, the audio encoder, the notification system, the locomotion data encoder, and the navigation subsystem. These subsystems will be located on a Raspberry Pi model 3B. The input processing subsystem will receive location selection data from the user interface. This data will be sent to the navigation system which will then generate a route to the given destination. The audio encoder will process sound clips stored on the main control board to provide audible feedback to the user. The notification system will simply notify the staff of the AuR's current position, received from the localization system, in the event the kill-switch is activated. The locomotion data encoder will convert route data received from the navigation subsystem into direct instructions usable by the locomotion system.

1) Navigation: The map data is obtained from the LIDAR component of the localization system and stored on the main control board. The pathfinding software will use the map data to create a path from the AuR's initial position to the user's desired position. This data will be sent to the localization control and the locomotion data encoder. If the AuR deviates from the initial route, the pathfinding software will receive new positional information from the route deviation detection module. With this new positional data, the pathfinding software will generate a new path to the user's destination.

B. Localization System

The localization system consists of LIDAR, the localization control, and Bluetooth/WiFi beacons. The localization control subsystem will be driven by an ESP-S3 board. The localization control will receive positional data from the beacons and LIDAR system in addition to route data from the navigation system. Using this data, the localization control will compare the AuR's current detected position with the expected position. If the detected position deviates from the expected position by more than 15 cm, then the localization control will send data regarding AuR's current position to the navigation system, which will reroute the AuR from its current position. Furthermore, current position data will be continuously sent to the notification system of the main control board.

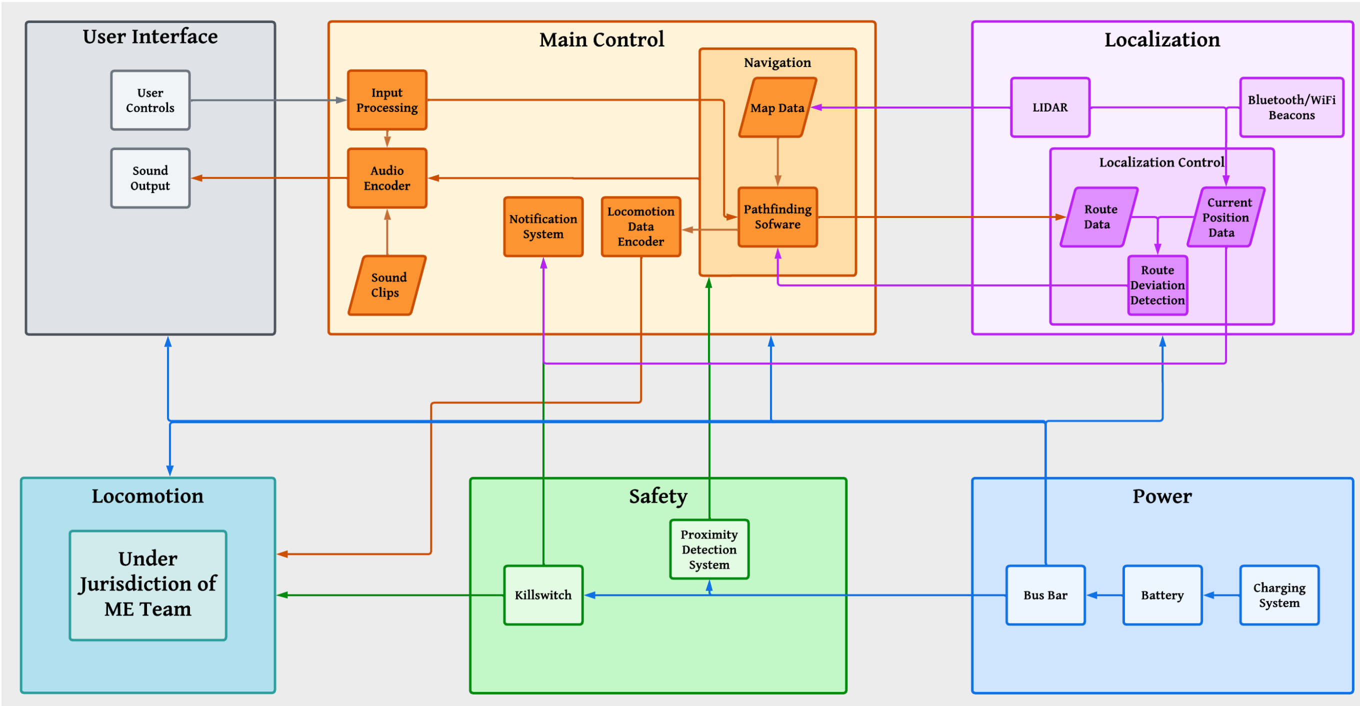

Fig. 1. Block Diagram

C. Safety System

The proximity detection system will be comprised of different sensors such as ultrasonic and infrared sensors. These proximity sensors will be continuously pulled for data that would indicate that an obstacle is obstructing the AuR. If the AuR detects an obstacle within 0.5 ± 0.1 m of itself, the safety system will notify the navigation subsystem that an obstacle is detected. In addition to the proximity sensors, a manual kill-switch will be included as part of the AuR's safety system. This kill-switch will be a button or flip switch that will cut off power from the bus bar to the locomotion system if the user deems it necessary.

D. Power System

The charging system will use a contact-based charging method that will provide 1.5 ± 0.5 A at no more than 25 V. This is assumed for the charging system as the mechanical team has not provided further details regarding the load of the AuR's motors. Further specifications of the battery will be determined later in the design process as more information is shared between the electrical and mechanical teams. The bus bar will be fed from the battery and will distribute power to the rest of the AuR's systems. The bus bar will also have fuses to ensure that electrical damage from one system is isolated from the other systems.

E. User Interface

The user controls will consist of buttons that allow the user to input their desired location. This selected location data will be fed into the input processing portion of the main control. The sound output will be a speaker taking in data from the main control's audio encoder. This data will be translated into sounds to provide audible feedback.

F. Locomotion

The electrical team will not be designing the locomotion system of the AuR. This responsibility has been given to the mechanical team. Currently, little information has been received from the mechanical team regarding this system.

V. TIMELINE

The team used current deadlines that we were given in the Capstone class. As a team, we have added additional tasks and dates to ensure that everything will be completed in a timely manner. We have given ourselves an adequate amount of time between each to make sure that we have additional time in case something happens.

1) Design Phase 1: (9/27/2022-11/10/2022) : This phase consists of the Project Outline, TurtleBot Interfacing, Circuit Simulation, learning how to use and implement LIDAR, and Load Simulation the TurtleBot interfacing is going to be used to test our designs and theories to get a better idea of what we need to work on. The TurtleBot will be used for troubleshooting and testing. The circuit and load simulation will be the basics of how the hardware components will work and testing the process. LIDAR will be used in the mapping process and understanding how it works is important for the testing process that happens later. There will be a testing process this will consist of troubleshooting different algorithms with the TurtleBot and the LIDAR. Each of these sections will be distributed to different team members. The distribution can be seen in the accompanying Gantt chart.

2) Design Phase 2: (11/11/2022-11/21/2022) : This phase includes the design integration of the system and documentation. Design integration of a system will design the hardware components and how they interact with the software. There will be a testing process this will consist of troubleshooting the different components within the system. The documentation will be the paper of the design process written out into detail. These two categories are divided among the team members. The distribution can be seen in the accompanying Gantt chart.

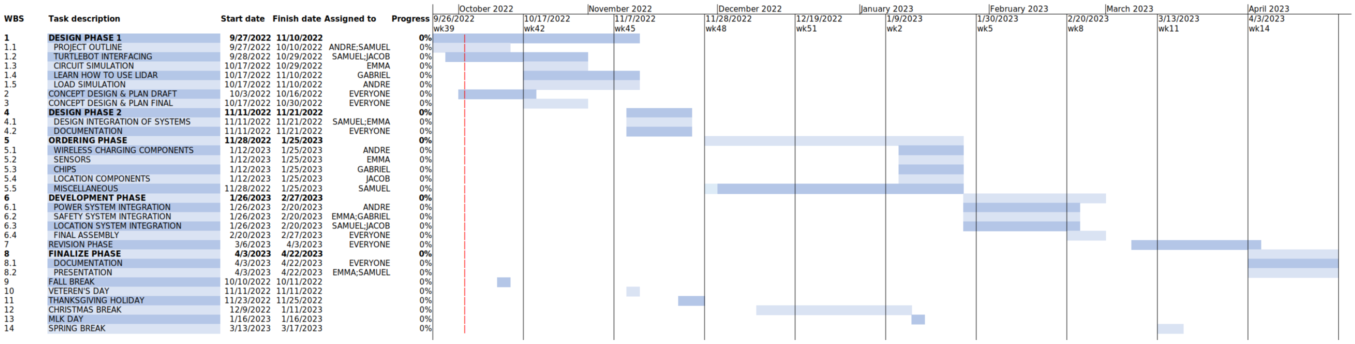

Fig. 2. Gantt Chart of Project Timeline

3) Ordering Phase: (11/28/2022-1/25/2023) : This phase consists of the Wireless Charging Components, Sensors, Chips, Locality Components, and Miscellaneous necessities. This process will consist of finding, researching, and ordering the necessary components that will be needed for the robot. These categories are divided among team members. The distribution can be seen in the accompanying Gantt chart.

4) Development Phase: (1/26/2022-2/27/2023) : This phase consists of the Power System Integration, Safety System Integration, Location System Integration, and Final Assembly. The power system will contain the battery, wiring, and charging aspects that are needed for the robot. The power system should be able to keep the robot running for 3-4 hours. Safety system integration will include crash sensors and speed detection. This is to ensure the safety of the robot and the people it interacts with. Location system integration will include LIDAR, Wi-Fi beacons, Bluetooth beacons and other aspects of navigation. This will be the mapping and the brains behind the robot being able to have the awareness of where it is. The Final Assembly is piecing each of these components together. There will be a testing process will consist of troubleshooting the software components and the hardware components. As we test, the team plans to use different phases to accomplish goals that need to be met. These goals include testing in the Capstone Lab, testing in the hallway, and testing in the Laboratory Science Common Building. These categories are divided among team members. The distribution can be seen in the accompanying Gantt chart.

5) Revision Phase: (3/6/2023-4/3/2023) : This phase consists of the revision process of the entire project. As a team, we will make sure that all the documentation and the prototype is up to our standards for presenting.

6) Finalize Phase: (4/3/2023-4/22/2023) : This phase consists of the documentation and presentation processes. This will take the revisions we made and apply them. This final process is distributed amongst the team members. This item can be seen on the Gantt chart.

References

[1] Automatic contact charging," Skycharge.de. https://www.skycharge.de /technology. (accessed: Oct. 16, 2022).

[2] D. Bastos, P. P. Monteiro, A. S. R. Oliveira and M. V. Drummond, "An Overview of LiDAR Requirements and Techniques for Autonomous Driving," 2021 Telecoms Conference (ConfTELE), 2021, pp. 1-6, doi: 10.1109/ConfTELE50222.2021.9435580.

[3] F. A. Abed, Z. A. Hamza and M. F. Mosleh, "Indoor Positioning System Based on Wi-Fi and Bluetooth Low Energy," 2022 8th International Engineering Conference on Sustainable Technology and Development (IEC), 2022, pp. 136-141, doi: 10.1109/IEC54822.2022.9807489.

[4] I. Lee, "Service Robots: A Systematic Literature Review," Electronics, vol. 10, no. 21, p. 2658, Oct. 2021, doi: 10.3390/electronics10212658.

[5] "IEEE Standard for Robot Map Data Representation for Navigation," in 1873-2015 IEEE Standard for Robot Map Data Representation for Navigation , vol., no., pp.1-54, 26 Oct. 2015, doi: 10.1109/IEEESTD.2015.7300355.

[6] "ISO/TS 15066 explained," Automate. [Online]. Available: https://www.automate.org/tech-papers/iso-ts-15066-explained. [Accessed: 14-Oct-2022].

[7] M. W. Earley, J. S. Sargent, C. D. Coache, and R. J. Roux, National Electrical Code Handbook. Quincy, MA: National Fire Protection Association, 2014.

[8] Mathworks, "What Is SLAM (Simultaneous Localization and Mapping)," www.mathworks.com. https://www.mathworks.com/discovery /slam.html (accessed: Oct. 16, 2022).

[9] Murtagh EM, Mair JL, Aguiar E, Tudor-Locke C, Murphy MH. Outdoor Walking Speeds of Apparently Healthy Adults: A Systematic Review and Meta-analysis. Sports Med. 2021 Jan;51(1):125-141. doi: 10.1007/s40279-020-01351-3. PMID: 33030707; PMCID: PMC7806575.

[10] R. Byczek and Name*, "Safety considerations for lithium and lithium-ion batteries," In Compliance Magazine, 12-Feb-2021. [Online]. Available: https://incompliancemag.com/article/safety-considerations-for-lithium-and-lithium-ion-batteries/. [Accessed: 13-Oct-2022].