Team 7: Conceptual Design and Planning

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I. Introduction

For this project, the team was tasked to create an autonomous robot (AuR) to guide people throughout the Ashraf Islam Engineering Building (AIEB) located on the Tennessee Technological University campus. The team designed a system that would integrate several different subsystems to allow the robot to function to its full potential. Information on each of these subsystems and how they will interact with one another is shown in the block diagram and discussed below. Furthermore, analytical verification methods will be discussed to show that the different subsystems of the AuR will be able to function both individually and in coordination with one another.

A. Technical Problems

The objective of this project is to create a full functioning autonomous robot. This robot will have a fully functioning Localization system, Power system, and User Interface system. A GPS system cannot be used within indoor environments due to being too inaccurate, and this has become one of the team's main technical problems. The team will design a system that will be implementing several different techniques to provide accurate positional data in an indoor environment. The Localization subsystem will be using specific methods to create redundancy in triangulating the position of the system in the building.The specifics of each of these functions of the Localization Subsystem are discussed further in the corresponding sections of this document.

The AuR will have a power subsystem that will provide power to the rest of the AuR's subsystems. The subsystem will meet the stakeholders' specifications which includes: battery life, autonomous charging station,and meet engineering standards regarding power systems. In order to meet the Customer's needs, the robot should have a minimum battery life for 3-4 hours. The team will design a subsystem a function that will monitor that battery's condition. This function will relay the information of the battery life back to the main control of the robot. The main function of the power system is to supply power to all of the different subsystems in the robot. The power system will include components that will keep the ripple voltage within a tolerance of 100 mV peak to peak. The power will be distributed through a bus bar which will reduce electrical damage to the robot's systems. The specifics of each of the power subsystem's functions are discussed further in the corresponding sections of this document.

The Human Interface Subsystem will be tasked with taking in the user's input and sending this information to the Main Control subsystem which will process this data into a set of instructions for the AuR. The subsystem will use voice implementation and button interfacing to accomplish its functions. Additionally, audio output will be added to notify the user that they have reached their desired destination. The specifics of each of these components are discussed further in the corresponding sections of this document.

B. Specifications and Constraints

Table I lists the specifications and constraints that the design of the AuR will adhere to. Further explanation on how the specifications and constraints affect the AuR's design is described further in the document.

TABLE I
Specifications and Constraints List

No.	Specifications and Constraints	Origin
1	Shall detect the AuR's position to a precision of 15 cm	Customer: Dr. Andy Pardue
2	Shall have a battery life of 3-4 hours	Customer: Dr. Andy Pardue
3	Shall have utilize plug-less charging	Supervisor: Dr. Van Neste
4	Shall have a manual override switch	Supervisor: Dr. Van Neste
5	Shall have a ripple voltage tolerance of 100 mVpp	Supervisor: Dr. Van Neste
6	Shall maintain a distance of 0.5 m from obstacles and people	Broader Implication
7	Shall use voice assistant technology for user interface	Ethics
8	Shall follow proper wire gauging standards	Standard: NEC 310.16(b)
9	Shall operate on one floor only	Supervisor: Dr. Van Neste
10	Shall travel of a speed of 0.7 ± 0.1 m/s	Standard: ISO/TS 15066
11	Shall not deviate from the expected path by more than 15 cm	Broader Implication
12	Shall guide users to within 1 m of their desired room	Supervisor: Dr. Van Neste
13	Shall not operate below 15-20% of the battery capacity	Ethics

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. These points are found by measuring how long it takes for the light from the laser to travel to a 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 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 the information is gathered, it will then be processed into a model of the environment. The position of the subject is then found in relation to that model and compared to a preexisting model in order to reduce error.

D. Contact-Based Charging

A contact-based charging system consists of two metal tiles connected to the charging source and two metal tiles connected to 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 because the system has a slower degradation rate and there is less of a chance for the system to become damaged when contact is initiated.

III. Ethical, Professional, and Standards Considerations

A. Ethical Considerations

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.

B. Professional Considerations

The 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 is a 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.

C. 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) 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]. To ensure this, the speed of the robot will not exceed that of the average walking speed of a typical human being.

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.

1) Input Processing: The input processing subsystem will receive location selection data from the user interface. This data will then be sent to the navigation system.

2) Navigation:

Map Data: The map data is a consistent model which takes inputs generated by the Lidar mapping subsystem.

Pathfinding: The pathfinding subsystem takes a location input from the input processing subsystem and generates a route to the given destination according to the map data.

3) Output Processing: The output processing subsystem will take route completion data from the navigation subsystem and play related sound clips on the smart speaker.

4) Error Processing: The error processing subsystem will receive signals from the battery voltage sensor and the manual override in addition to location data from the localization system. In the event the manual override is activated or the battery voltage drops too low and the AuR is unable to return to its charging pad, the error processing system will notify the error reporting system, which will notify staff of the AuR's location.

5) Error Reporting: The error reporting subsystem will take in error input from the error processing subsystem and will then notify staff of the AuR's position and the error.

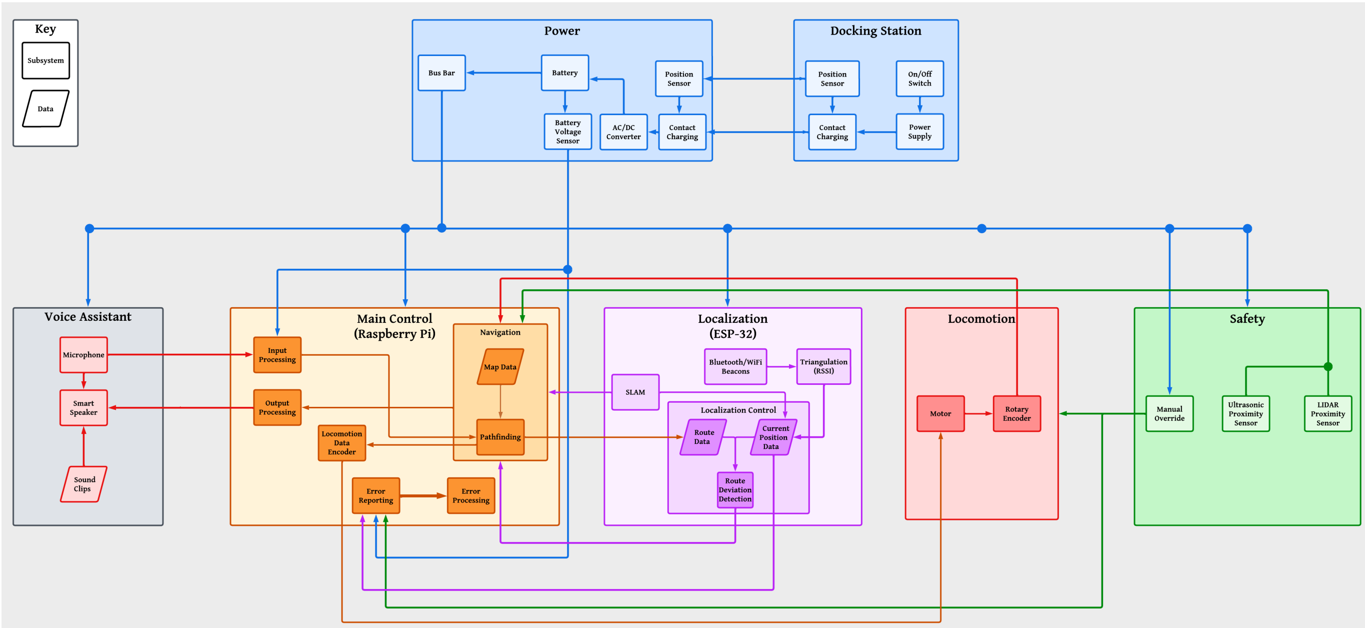

Fig. 1. Block Diagram

6) Locomotion Data Encoder: The locomotion data encoder will receive route data from the navigation system and output signals usable by the motor.

B. Localization

1) Bluetooth/WiFi Beacons: In order to facilitate higher accuracy of the AuR's localization system, the team plans to place Bluetooth beacons throughout the AIEB. Using a received signal strength indicator (RSSI), the AuR will be able to find its distance from these beacons and will thus be able to more accurately gauge its location. This subsystem is in place to ensure specification 1, as shown in Table 1, is met.

2) Triangulation (RSSI): The AuR will use triangulation of the RSSI from bluetooth beacons in order to more accurately determine its location. This subsystem is in place to ensure that specification 1, as shown in Table 1, is met.

3) SLAM: The AuR will additionally employ a LIDAR mapping subsystem using a SLAM algorithm. This subsystem will generate a local map of the AuR's surroundings and then determine the AuR's position within that map. It will send the map data to the navigation system and the position data to the localization control system. This subsystem is in place to ensure that specification 1, as shown in Table 1, is met.

4) Localization Control:

Route Data: The route data is generated by the navigation subsystem's pathfinding algorithm. This data is then passed into the route deviation detection subsystem of the localization control subsystem.

Current Position Data: The current position data is generated by a combination of RSSI triangulation of the Bluetooth beacons and the LIDAR Mapping subsystem's SLAM algorithm. This data is then passed into the route deviation detection subsystem where it is used to evaluate the AuR's pathing error.

Route Deviation Detection: The route deviation detection subsystem will take in the AuR's currently detected location in addition to the expected position from the route data. Using this data, the route deviation detection system will compare the expected position to the detected position. If these positions differ by more than 15cm, the route deviation detection system will signal the navigation subsystem to generate a new path from the current position. This subsystem exists in order to ensure that constraint 11, as shown in Table 1, is met.

C. Safety System

1) Manual Override: The AuR will include an emergency manual override that will immediately stop the AuR and cut power to the locomotion subsystem. When this manual override is activated, the manual override subsystem will raise an error to the error processing subsystem which will then handle the error, then send it to the error reporting subsystem to notify staff of the error. This subsystem exists in order to ensure that specification 4, as shown in Table 1, is met.

2) LIDAR Proximity Sensor: The AuR will primarily use the LIDAR for proximity detection. In the event that the proximity sensor detects an obstacle within 0.5 meters, the subsystem will notify the navigation subsystem which will halt the AuR's progression along the route until the obstacle is no longer detected. This subsystem exists in order to ensure that constraint 6, as shown in Table 1, is met.

3) Ultrasonic Proximity Sensor: The AuR will additionally employ ultrasonic proximity sensors that will act as an auxiliary detection method to the LIDAR. These sensors will assist the LIDAR with proximity detection in addition to providing redundancy in case of LIDAR malfunction. This subsystem exists in order to ensure that constraint 6, as shown in Table 1, is met.

D. Power System

1) Position Sensor: The power system's position sensor will detect whether the AuR is close enough to the charging dock to begin charging. When this subsystem and the corresponding position sensor on the charging dock detect that the AuR is sufficiently aligned to begin charging, the charging dock will connect to the AuR and charging will begin.

2) Contact Charging: The contact charging subsystem will transfer AC power from the power supply to the AC/DC converter. This subsystem exists to ensure that specification 3, as shown in Table 1, is met. Additionally, the position sensors will enable or disable the contact charging subsystem when the AuR is in position.

3) AC/DC Converter: The AC/DC converter will ensure that the power delivery from the wall outlet to the AuR will have minimal ripple voltage to ensure that specification 5, as shown in Table 1, is met.

4) Battery: The battery provides power to the AuR.

5) Battery Voltage Sensor: The battery voltage sensor will measure the battery's voltage and send data to the input processing and error reporting subsystems. This ensures that enough power is available for the AuR to perform its responsibilities. This subsystem satisfies specification 13, as shown in Table 1.

6) Bus Bar: The bus bar will take power from the battery and distribute it to the rest of the AuR's subsystems. The bus bar will also have fuse connection to reduce the risk of electrical damage to the AuR. Additionally, smoothing capacitors and filter circuits will be added to keep the ripple voltage within the 100 mVpp tolerance. This will assist in accomplishing specification 5, as shown in Table I.

E. Docking Station

1) Position Sensor: The docking station's position sensor will detect whether the AuR is close enough to the charging dock to begin charging. When this subsystem and the corresponding position sensor on the AuR detect that the AuR is sufficiently aligned to begin charging, the charging dock will connect to the AuR and charging will begin.

2) Physical Charging Interface: The physical charging interface will connect the AuR to the charging dock. This subsystem exists in order to ensure that specification 3, as shown in Table 1, is met.

3) Power Supply: The docking station's power supply will connect to the wall power of the AIEB. It will then feed this power over the physical charging interface to the AuR which will begin charging.

4) On/Off Switch: The docking station will have an on/off switch to allow an operator to ensure there is no current running through the device for maintenance and installation.

F. Voice Assistant

1) Microphone: The voice assistant system will include a microphone in order to pick up and process user voice input. This microphone will allow the user to verbally ask the AuR for directions to a given room. This subsystem exists in order to ensure that specification 7, as shown in Table 1, is met.

2) Smart Speaker: The voice assistant system will also include a smart speaker that will allow the AuR to provide audio feedback to the user. The AuR will notify users of any errors in addition to verbally notifying users when they have reached their destination. This subsystem exists in order to ensure that specification 7, as shown in Table 1, is met.

3) Sound Clips: The AuR will play sound clips in addition to using text-to-speech technology as audio feedback to the user. These sound clips will allow for a more streamlined user experience as the user will not have to look at a screen while the AuR is in motion.

G. Locomotion

1) Motor: The AuR's locomotion system will be driven by an electric motor. This motor will be driven by the main control system's locomotion data encoder.

2) Motor Encoder: The motor encoder will connect to the motor and count the motor's revolutions. The motor encoder will then send this data to the navigation system, which will use the data to calculate the AuR's approximate speed. This subsystem exists in order to ensure that specification 10, as shown in Table 1, is met.

V. Analytical Verification Methods

A. Main Control

The software components of the main control system will be validated by comparison to existing designs in order to ensure feasibility.

B. Localization

The bluetooth and WiFi beacons will be validated by comparing values in their datasheets to the needed values for the AuR. All other localization components are software, so they will be validated by comparing them to existing designs.

C. Safety

The safety system will be validated by comparing datasheet values to needed values for the AuR. The team will additionally use circuit simulations to validate the functionality of the manual override.

D. Power

The power system will be verified using load simulations and power calculations to ensure enough power is supplied to other subsystems of the AuR. Electrical measuring equipment, such as an oscilloscope and multimeter, will be used to confirm components operate according to their specifications. The exact values needed for the analytical testing phase will be determined in the future due to the unknown requirements of the other systems.

E. Docking Station

The proximity sensors will be tested using software to ensure the sensor can properly control the contact charging system, This will ensure power transfer between the power supply and AuR is done safely. A circuit simulation will be used to ensure that the power supply can be disabled in case of emergencies such as an electrical fire.

F. Voice Assistant

The voice assistant system is primarily software, so it's feasibility will be validated by comparison to existing designs.

G. Locomotion

The locomotion system will be verified using circuit simulations in order to ensure that the motor is given sufficient power at the needed voltage.

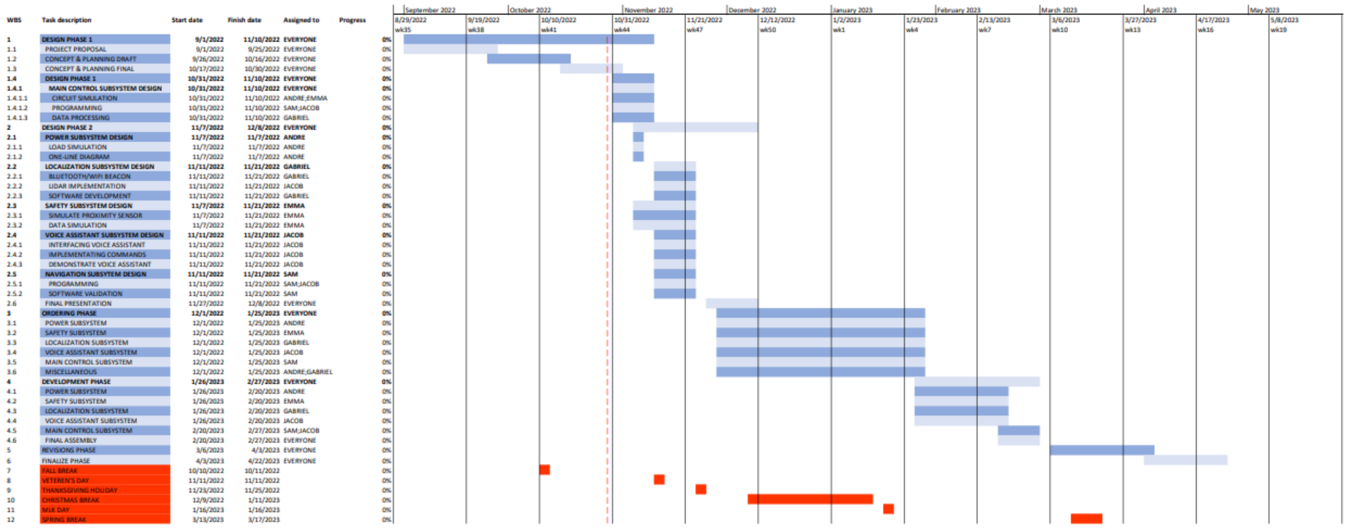

Fig. 2. Gantt Chart of Project Timeline

VI. Timeline

The gannt chart ensures that the entire project timeline is properly defined, but subject to change due to potential unforseen circumstances that could surface during the spring semester. It includes deadlines and shows timeframes for said deadlines. This will ensure that the team can make efficient use of the time allotted per task to deliver a complete product by the end of the project.

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