Team 7: Autonomous Guidance Robot Proposal

Andre Nguyen*, Emma Brown†, Gabriel Kim‡, Jacob Wilkinson§, and Samuel Mandody¶
Department of Electrical and Computer Engineering, Tennessee Technological University
Cookeville, TN
Email: *annguyen42@tntech.edu, †egbrown42@tntech.edu, ‡gakim42@tntech.edu, §jawilkinso43@tntech.edu, ¶sgmandody42@tntech.edu

I. Introduction

The goal of this project is to create an efficient way for students and faculty members to be able to locate their classrooms within the Ashraf Islam Engineering Building (AIEB) by using safety, navigation, and power systems. Refer to Fig, 1 for an illustration of the project's goal. Because the AIEB is currently under construction, this causes a couple of issues with the testing process that will be discussed within the proposal. The robot will solve the time-efficiency problem of people finding their destination. There are several goals and challenges that will be faced during the project, which include knowing where it is and where it needs to go, battery power runtime, and environmental safety system. The team has three electrical engineers and two computer engineers. The team has been divided into two different categories, one is the hardware team and the other is the software team. The hardware team will oversee the sensors, power system, and the safety system components. The software team will oversee the implementation of coding aspects of the project, such as mapping, security, and embedded systems integration. The project will be completed in the first week of April 2023. This will include the documentation, and the testing phases. The proposed budget is $1000, but this amount is subject to change due to implications or other necessities that are needed throughout the process. The team is eager to have a working prototype that can be modified for the next team to pick up where it left off.

II. Formulating the Problem

Due to the scope of the project, creating the autonomous robot (AuR) will require multiple specialized engineering teams.The chassis and locomotion of the AuR will be designed by a separate team of mechanical engineers working separately, with occasional communication, from this capstone project. The stakeholders for this project, as shown in Fig. 2, are Jesse Roberts, Dr. Van Neste, Dr. Pardue, the mechanical engineering team, and Tennessee Technological University. Jesse Roberts is the primary instructor for this capstone course. Dr. Charles Van Neste is the primary supervisor for this project. Tennessee Technological University, represented by Dr. Andy Pardue, is the customer for which the AuR is being designed.

A. Specifications and Constraints

Primarily, the AuR shall not cause harm to the user, bystanders, or any property during its standard operation procedures. The AuR shall ensure this specification is met using a multi-faceted safety system. This safety system shall include multiple redundant sensors, including positional and preemptive collision detectors, to ensure that there is no single point of failure. In the event that the AuR detects that it will collide with a person or object, the AuR will stop and will wait for that person/object to move. There will additionally be a manual shutdown switch that will cut power to the AuR and notify the staff of the AuR's position.

Secondly, the AuR shall guide a user to the location the user selects then return to its home base. The AuR will only function on the first floor of the AIEB due to time constraints for this project. The AuR will primarily employ a custom simultaneous localization and map building (SLAM) algorithm in order to pathfind its way through the AIEB and bring the user to their destination. The AuR will have a positional error of no more than 1 meter from the location the user selects. In order to ensure that this positional constraint is met, the AuR will employ additional location tracking methods such as rangefinding from bluetooth beacons.

Additionally, the AuR shall be able to easily enter and leave its home base without a user's assistance. In order to accommodate this, the AuR will be powered via contact points at its home base. Contact-based charging allows for easy connection and disconnection without concerns such as tangled wires.

In addition, the AuR's major components shall all be independently replaceable. This independent replaceability means that if one major component is damaged or needs to be upgraded, that major component will be able to be replaced without needing to replace any other major components. These major components include the sensors, power systems, and main control board. This constraint is in place to ensure the AuR's longevity through easy repairs and upgrades.

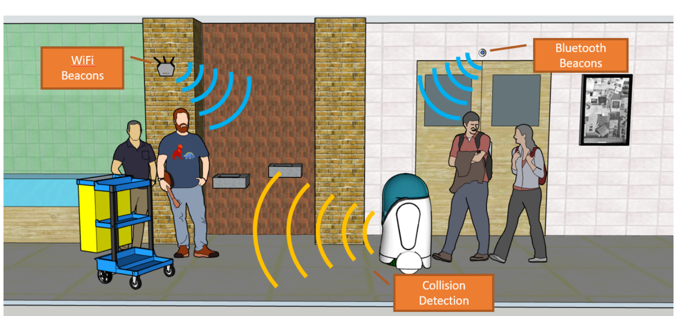

Fig. 1. Vision of Project

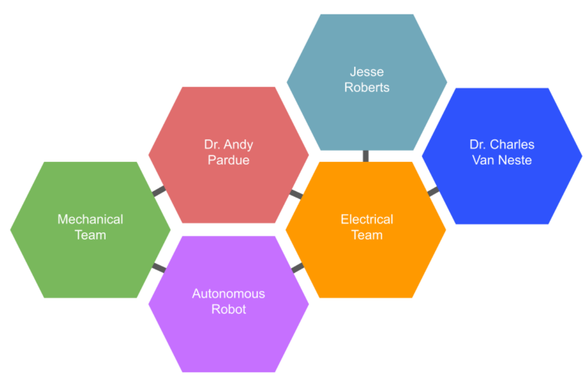

Fig. 2. Diagram of Stakeholders

The AuR's home base shall not take up more than a 1.5 by 1.5 by 1.5 meter cubic area. This constraint is in place to ensure that the AuR has sufficient space to dock and charge while also ensuring that it does not take up the entire hallway.

The AuR shall not deviate from its intended course by more than 15 centimeters in either direction. This constraint will ensure that the AuR maintains a consistent and predictable path. The AuR will additionally be able to stay within a designated section of a hallway.

The AuR's battery shall last between two and four hours without charging. This constraint was requested by the customer in order to ensure that the AuR will be operational throughout the day.

The AuR shall move at a rate of 0.7 ± 0.1 meters per second. The slow walking speed for the average person is 0.82 meters per second, so a rate of 0.7 ± 0.1 meters per second ensures that the majority of users will be able to follow the AuR at a slow walking speed. [11]

B. 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
   The standard aims to common terminology used to describe the areas in which an AuR is applicable (eg. indoor, outdoor, scale of space to be covered etc.) as well as the metrics used to describe the AuRs' functionality. It also aims to categorize the maps genrated by the AuRs' given the data above and the type of map used. The reason that we will be following this standard is because it will allow us to not only put together a foundation for all automated robots that are developed for TTU in the future, it will also 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 is put in place to ensure that appropriate wire gauging is used based on the temperature being generated from power flow. This standard grows more pertinent to the project sooner it approaches the final stages. During the initial stages, we will be doing all algorithm-based testing using the prototype that was given to us by the ME team. The prototype is very low power and uses low power motors given its small form factor overall relative to the envisioned final product (refer to Fig. 1). As we implement the power system and connect the low power embedded system IoT devices to the much higher power DC motors, we could run into many fire related safety issues if this standard is not followed closely [9].
3) UL Standard 1642 Standard for Lithium Batteries
   This standard covers the safety of lithium batteries (both rechargable and non-rechargeable). It includes many rigorous stress tests that are performed on the battery/battery pack to ensure that it will not cause fires. If we are 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 [13].
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 to ensure that any and all collaborations are painless for the humans. This is an important standard to keep at the forefront of our project throughout all stages. The AuR will be operating indoors around people at all times, so it's important that the robot will be unable to cause any bodily harm to any individuals [6].

C. Challenges

The challenges the team may encounter fall into two categories: location-related challenges, supply-related challenges, time-related challenges, and customer-related challenges.

1) Location-Related Challenges: One challenge which may hinder testing is that the AIEB has not been fully built. If the construction of the AIEB is not completed by the testing phase, then the robot cannot be tested in its intended environment. This challenge can be mitigated by conducting the testing phase in the Lab Science Commons (LSC), which is the building most similar in structure to the AIEB.

2) Supply-Related Challenges: Another challenge which may hinder the building process is that essential components may not ship fast enough or in the worst-case may not be available. This challenge is mitigated by considering many different sources for the needed components as well as considering alternative components which are similar in function to the chosen ones.

3) Time-Related Challenges: Working with the mechanical engineering team may present the challenge of not having the chassis completed in time to build and test the AuR. This challenge can be mitigated by building an extremely basic chassis which can only support the essential functions and mobility needed to test the AuR and fulfil the Measures of Success.

4) Customer-Related Challenges: The customer has the option to request changes to the AuR specifications along the lifespan of the project. This may cause developmental issues due to specifications changing after they have been implemented. This challenge can be mitigated by giving the customer desired checkpoints, after which certain specifications cannot be changed.

D. The Measures of Success

The functionality of the AuR will be verified in a series of testing phases.

1) Phase 1: Phase 1 will focus on simulated data and non-physical tests and will be related to the battery, power systems, and circuitry of the AuR. Battery and power stability will be tested by conducting a noise simulation[7] on the circuitry in LT Spice. The test is successful if the input noise does not significantly affect the output noise. This shows that the noise from the power system should not significantly affect the components connected to the output of the power system.

The power system circuitry will also be simulated with a range of loads to insure consistent power quality. The test is successful if the output voltage of the power system stays within a consistent range. This matters because the devices connected to the power source accept a limited range of voltages in order to operate consistently and accurately

The complete circuitry will be designed in KiCad and verified to ensure that there are no issues with the wiring and other related circuit construction. The test is successful if KiCad reports no errors when running a test on the circuit. This test will not flag any functional issues however, it will flag fatal circuitry issues.

2) Phase 2: Phase 2 will focus on testing individual systems and components.

The kill switch will be tested by connecting a power source in series with the switch, a resistor, and an ammeter. The switch will be toggled. The test is successful if toggling the switch to the open position produces a current reading of 0A ± 1μA. This ensures that the kill switch will shut everything down when toggled to the open position.

The lidar and SLAM algorithm will be tested by traversing the area of a room multiple times holding the lidar device. The data from each traversal will be compared to the data from the others and the real world information[16]. The test is successful if the test data is within an accuracy of ± 15cm and a precision of ± 5cm.

The power system will be tested by introducing a range of loads to the output of the power system and measuring the voltage across the load and current through the load. The test is successful if the voltage has low variance and the current stays within a safe range

3) Phase 3: The AuR will be set to traverse a simple room with stationary obstacles. The test is successful if the AuR correctly maps the room, avoids all obstacles, and can accurately know where it is within the room at any given moment.

The AuR will be set to travel in a straight line while obstacles move across the its path. The test is successful if the AuR reaches the end of its path while avoiding the obstacles.

4) Phase 4: In Phase 4 the AuR will be given a series of locations to navigate to within a hallway. The test is successful if the AuR accurately maps the hallway and successfully navigates, without collision, to every location.

5) Phase 5: In Phase 5 the AuR will be given a series of locations to navigate to the LSC. Obstacles will be placed around the floor and people will be walking around. The test is successful if the AuR accurately maps the floor and successfully navigates to every location. The AuR should also avoid all obstacles and people in the process.

E. Broader Implications, Ethics, and Responsibility as Engineers

Although the AuR will provide great benefit to visitors of the AIEB, there are several resulting impacts that must be considered. Firstly, the AuR will increase congestion in the hallways while directing individuals due to its slow pace. The AuR will partially mitigate this increased congestion by returning to its home base between guiding visitors. The AuR can also mitigate this by setting its path along a wall out of the center of the walkway.

Secondly, maintenance of the AuR will potentially increase the workload for employees overseeing the AIEB. These maintenance issues will be partially alleviated by the planned modularity of the AuR. Employees will be able to easily swap out and upgrade malfunctioning and outdated components.

Aside from the direct impacts of the AuR, there are certain ethical considerations to take into account when developing a service robot. The McKinsey Global Institute estimates that "half of today's work activities could be automated by 2055"[10] and while this specific AuR concept is not directly displacing any current jobs, a development in this area of technology has the potential be applied to future AuR or service bots which do directly replace human labor. "Service Robots: A Systematic Literature Review" notes the concern of human attachment to the robot[4]. While this AuR will is not designed with the intention of emotional influence there remains the possibility of emotional attachment and subsequent damage especially with "vulnerable users such as the elderly with cognitive or physical disabilities"[4]. With this in mind guidelines for proper human-robot interaction must be established.

III. Existing Solutions

One solution is purchasing a commercial product that also achieves the specifications and constraints. For example, the artificial intelligence company Orion Star, offers several high quality AuRs that meet the expectations of the project. The expectations it meets includes having a default speed of 0.7 m/s and having a battery life of 12 hours, which exceeds our minimum requirements [3]. The disadvantage of using a commercial product is its high cost and reliance on third parties. Another existing solution to our objective is having dedicated personnel to perform greeting and guidance duties. Having personnel is a simple and effective way of meeting the project's expectations. However, it is extremely cost-ineffective due to needing to provide hourly pay, benefits, and breaks. A third solution would be having several maps of the AIEB spread throughout the building. Maps would be a very cost-effective method of guiding people throughout the AIEB. Unfortunately, maps do not perform guidance duties and can be difficult for some people to utilize. Furthermore, maps do not meet several of the stakeholders' specifications.

The AuR is broken down into three separate subsystems: navigation and location, safety, and power. The navigation and location system shall be responsible for traversing the robot through the AIEB while keeping track of its position. The safety system of the AuR is tasked with preventing any harm to any personnel and property. The power system provides a steady flow of power to the other systems at the rated voltage.

A. Navigation and Localization System

Unfortunately, the system is not able to utilize GPS signals due to it not being precise enough within an indoor environment. On the other hand, there are numerous methods that can be implemented in the design of the system. WiFi signal strength-based localization can be used to determine the position of the AuR within the AIEB. The AuR would run an algorithm that measures and records the strength of WiFi signals at various positions. By comparing previous measurements with current measurements of WiFi signal strength, the AuR is able to approximate its location. The downside of using WiFi signals to locate the AuR's location is the inaccuracies due to objects and people creating interference with the WiFi signals [17].

An additional method that can be used for the localization and navigation system is applying a pathing algorithm that plans a route from the AuR's current position to the objective location. The algorithm would create a path on a 2d map using multiple pathing templates. After creating the path, the AuR would follow a set of instructions created by the algorithm to reach the AuR's final destination. As the AuR traverses the path, sensors would be used to track the AuR's current location and compare the measured location with the predicted location of the AuR. If the algorithm detects that the AuR is not at the predicted location, the algorithm will use the real location to create a new path for the AuR. The pathing algorithm would be a simpler method of navigation compared to other existing methods. Additionally, implementing a pathing algorithm would be cost effective due to only needing a couple of cheap sensors to operate. However, using the pathing algorithm method for the system has some caveats. There could be times where the AuR could encounter a deadlock situation. The algorithm could also have trouble handling more complex layouts such as navigating different floor levels [14].

The LiDAR will provide the algorithm with scattered points which will be translated into vectors with accurate distance information to determine what obstructions surround the AuR /citething1. Using the map data in tandem withand extra information via external algorithms for the collision detecting and general pathing (ex. Matlab), the AuR will traverse the floor safely and effectively.

B. Safety System

Infrared sensors can be attached to the AuR to achieve collision avoidance. The sensors would obtain the orientation of the AuR and distance from objects in the environment. Then the data can be utilized to have the AuR stop before a collision occurs or go around encountered obstacles. The benefit of using infrared sensors is their low cost and simplicity of implementation. All though very effective, other methods of collision avoidance will be used to ensure reliability [8].

A hybrid method can also be used for the safety system design. The hybrid method utilizes both sensors and data from a map stored on an AuR. Sensors, such as ultrasonic sensors, would be used to detect new obstacles around the robot. The data from a map can be used to avoid known obstacles in an AuR's path. Using map-based information for collision avoidance could reduce the need for expensive sensors to detect smaller obstacles in an environment. Having the AuR using the hybrid method for collision avoidance would be a very cost-effective way of adding redundancy to the safety system. The drawback of using the hybrid method is the need to have a highly accurate map stored on the AuR [2].

C. Power System

The power system can utilize wireless charging to supply power to the AuR. In a wireless power transfer systems, coils are used to transfer energy from one circuit to another without any form of contact. So, wireless charging would allow the AuR to recharge on its own, which means human intervention would not be necessary to charge the AuR. Wireless power systems would decrease the safety risks involved with power systems too. There would not be any exposed conductive material that can electrocute people. However, wireless charging is not the most efficient method of supplying power. The maximum efficiency of wireless charging is about 43%. If a wireless charging is implemented into the AuR, there would be concern about the misalignment between the coils used to transfer the power. This issue could be solved by using sensors and markers to keep the robot in alignment when charging. The major problem with using wireless charging is the cost of it. The cost of wireless systems would exceed the budget of the project by a large amount [12]. An alternative to wireless charging for the power system is contact charging. This method requires two pieces of conductive material to make contact with each other to transfer power from one circuit to another. It is a very simple method that can be used to supply power from a power source to the AuR. Contact charging is a more cost-effective option compared to wireless charging. The only concern with contact charging is safety. There would be an exposed piece of conductive material that can electrocute people. Some forms of safety measures would need to be implemented to prevent any harm [1].

A crucial concern with the power system design is the ripple voltage from the power supply. Ripple voltage can cause adverse effects on the AuR's system. Some of the effects include interference and damage to the sensor systems. An acceptable tolerance for ripple voltage would be 100 mV peak to peak. To keep the ripple voltage within the tolerance, smoothing capacitors can be added. The values of the capacitors can be determined using equation 1 [15].

$$V_{ripple} = \frac{I_{load}}{f \times C} \tag{1}$$

IV. The Resources

A. Personnel

The following list shows the team members' skills that can be used for this project.

System	Component	Price
Navigation	ESP32S3	20
	Bluetooth Beacons	100
	Bluetooth 5.1 Module	20
	LIDAR	100
	Raspberry pi 3b+	45
	PCB Design	30
Power	Battery	125
	Power Supply	225
Safety	Collison Sensors	25
Unknowns		130
Total		**$810**

Fig. 3. Itemized Cost

1) Andre Nguyen
   - Power System Analysis
   - Soldering
   - Leadership Skills
2) Emma Brown
   - Knowledge of SMD/SMT Components
   - Sensors
   - Soldering
3) Gabriel Kim
   - Arduino
   - IoT Devices
   - MQTT Protocol
4) Jacob Wilkinson
   - Embedded Devices
   - Soldering
   - Software Development
5) Samuel Mandody
   - Embedded Systems
   - RTOS
   - C Language

Additional skills that the team may need to successfully complete the project are KiCAD, 3D Printing, PCB Design, and machine learning.

B. Budget

The estimated material cost for this project is $810, as shown in Fig. 3. The costs are categorized by the subsystem they are a part of. The majority of these costs are from the power and navigation systems. Robust sensors and power supplies are needed in order to ensure the correct functioning of the AuR. These costs have been gathered by comparing prices from various manufacturers. The "Unknowns" portion represents additional cost due to unforeseen complications such as shipping delays or extra components.

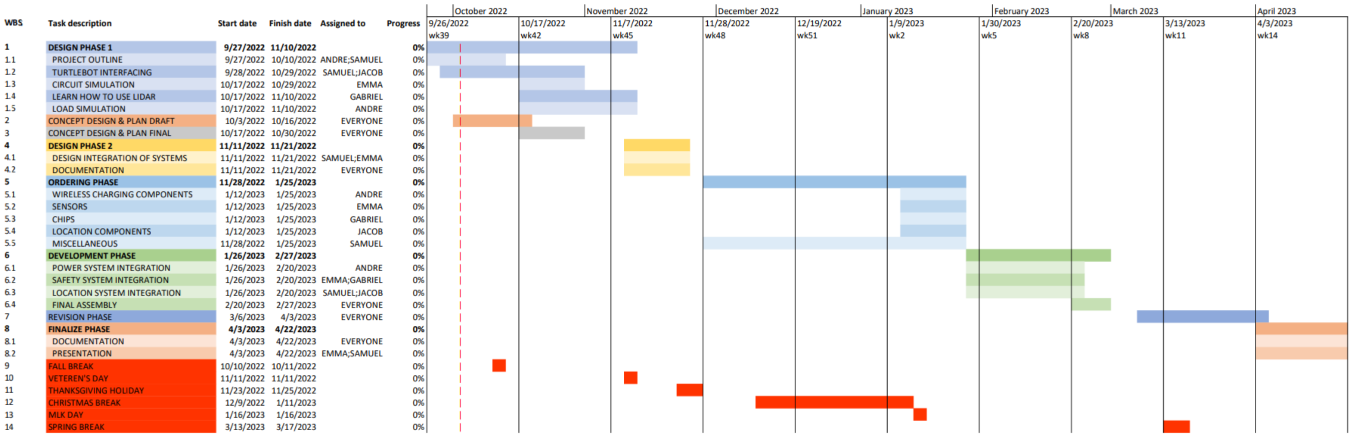

Fig. 4. Gantt Chart of Project Timeline

C. 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.

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, our 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. [Online]. Available: https://www.skycharge.de/technology. [Accessed: 13-Oct-2022].

[2] D. Fox, W. Burgard, S. Thrun and A. B. Cremers, "A hybrid collision avoidance method for mobile robots," Proceedings. 1998 IEEE International Conference on Robotics and Automation (Cat. No.98CH36146), 1998, pp. 1238-1243 vol.2, doi: 10.1109/ROBOT.1998.677270.

[3] "Greeting robot - ai greeting robot - orion star," AI Robot Greeting. [Online]. Available: https://en.orionstar.com/greeting-robot.html. [Accessed: 13-Oct-2022].

[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] "LTspice: Noise Simulations," www.analog.com. https://www.analog.com/en/education/education-library/videos/5579265856001.html (accessed Oct. 12, 2022).

[8] M. M. Almasri, A. M. Alajlan and K. M. Elleithy, "Trajectory Planning and Collision Avoidance Algorithm for Mobile Robotics System," in IEEE Sensors Journal, vol. 16, no. 12, pp. 5021-5028, June15, 2016, doi: 10.1109/JSEN.2016.2553126.

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

[10] McKinsey Global Institute, "A Future That Works: Automation, Employment, and Productivity," mckinsey.com. https://www.mckinsey.com/ /media/mckinsey/featured%20insights/Digital%20Disruption /Harnessing%20automation%20for%20a%20future%20that%20works /MGI-A-future-that-works-Executive-summary.ashx (accessed Oct. 14, 2022).

[11] 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.

[12] N. Hasan et al., "A practical implementation of wireless power transfer systems for socially interactive robots," 2015 IEEE Energy Conversion Congress and Exposition (ECCE), 2015, pp. 4935-4942, doi: 10.1109/ECCE.2015.7310356.

[13] 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/: :text=UL%201642%20and%20UL%202054,a%20power %20source%20in%20products. [Accessed: 13-Oct-2022].

[14] R. N. De Carvalho, H. A. Vidal, P. Vieira and M. I. Ribeiro, "Complete coverage path planning and guidance for cleaning robots," ISIE '97 Proceeding of the IEEE International Symposium on Industrial Electronics, 1997, pp. 677-682 vol.2, doi: 10.1109/ISIE.1997.649051.

[15] "Ripple," Sunpower UK, 09-Dec-2015. [Online]. Available: https://www.sunpower-uk.com/glossary/what-is-ripple/: :text= Acceptable%20ripple%20voltage%20is%20about,to%20have%20 slightly%20higher%20values. [Accessed: 13-Oct-2022].

[16] Team Ouster, "Guide to evaluating SLAM," ouster.com. https://ouster.com/blog/guide-to-evaluating-slam/ (accessed Oct. 12, 2022).

[17] Y. Sun, M. Liu and M. Q. . -H. Meng, "WiFi signal strength-based robot indoor localization," 2014 IEEE International Conference on Information and Automation (ICIA), 2014, pp. 250-256, doi: 10.1109/ICInfA.2014.6932662.