Cleanbot 3000

Ashley Mendoza, Joshua Garner, Haibert Hatamian, Menua Aghajanian, Arnold Ortega, Wilder Josue Gomez, George Flores, Jesus Alvarez, Justin Nghiem, Branden Fitzwater, Harut Ketsoyan, and Shiban Radhanpuri
Advisor: Professor James Flynn
California State University Northridge
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ABSTRACT— **JPL provided a project whose focus is on designing an autonomous sanitization robot. The Cleanbot 3000, as the robot is called, has the objective of safely navigating and sanitizing a Jet Propulsion Laboratory (JPL) facility clean room. The robot must fulfill the task of sanitizing clean rooms of various dimensions while following multiple requirements and constraints which would prevent it from tampering with any projects within the clean rooms. With such guidelines, the Cleanbot 3000 team focused on the requirements and components which the robot needs to meet the requirements and constraints given by the JPL.**

Keywords: navigation, guidance reflectors, sanitization, sensors

INTRODUCTION

The objective of this project is to develop an autonomous robot that has the following two tasks, the main task is to sanitize the Jet Pollution Laboratory (JPL) "clean room floors" to TBR microbes using Uv lights. The second task that we had to consider was that it must remain 1 meter away from any flight hardware. This project has high expectations that we are working to overcome, the following are some requirements given by JPL.

- The robot must be autonomous for the most part
- The robot must not outgas
- The robot must sanitize the floor to TBR microns using UV light
- The robot must have brushless motors, oil free motors
- The robot must not mark the ground with its mechanism
- The robot shall charge to itself without operation intervention intervention for TBD time
- The robot shall keep at least 1 meter distance from any flight hardware

Based on the information provided by JPL, they move objects around constantly which adds more challenge to overcome, due to rearranging of objects the cleanbot must re-map the room which requires a fast and efficient navigation system and reliable sensors in order to fulfill the requirements. Lastly, we will be using the UV lights in order to sanitize the floor, a problem to overcome for this task is that the uv LED layout dissipates a large amount of power due to the amount of dosage needed in order to exterminate the microbes.

PROJECT DESCRIPTION

The purpose of the cleanbot design is to autonomously sanitize the cleanroom floors with UV-C LEDs while following the strict constraints and requirements given by the JPL. The purpose of following such constraints is to maintain the safety of the flight hardware in such rooms that vary in the cleanroom that vary in size. The cleanbot will improve sanitization in the cleanrooms while limiting the need for human interaction to sanitize the cleanroom. To do so, the cleabbot must be able to navigate and sanitize on its own.

HIGH LEVEL REQUIREMENTS

1.1 The Cleanbot shall navigate the clean room without any assistance.
1.2 The Cleanbot shall sanitize the floors of the clean room.
1.3 The Cleanbot shall retain one meter away from all flight hardware.

I. NAVIGATION

Clean rooms can vary in dimension with various objects such as sensitive flight hardware and standard objects the robot must avoid; however, the avoidance priority is high on flight hardware as opposed to standard objects, they both vary in constraints. The following image in Figure 1 demonstrates the objects the robot must detect and avoid within a clean room.

Figure 1: JPL Clean Room

Guidance Reflectors

The location at any position in the room shall be known before allowing the robot to navigate through the clean room. To target this issue, a set of three guidance reflectors will act as reference points located on the walls near the ceiling. Due to the complexity of the various rooms, where certain rooms range in ceiling height and others have cranes, we were not able to position the reflectors on the ceilings; therefore, the reflectors will be positioned on the walls. The guidance reflectors will act as a trident where one of the reflectors is located higher than the other two reflectors. Depending on the position of the camera, it will locate the three reflectors, each color coded, and form a distinct triangle. The guidance reflector colors were chosen by analyzing the relative spectral response of the CMOS sensitivity wavelength of 500nm - 600nm.

To understand the position of the reflectors relative to the camera sensor, the angle of view (AOV) and the field of view (FOV) acted as guidelines. The size of a camera sensor's active area assisted the determination the systems FOV. Equation 1 determines the angle of view, while the field of view is determined in Equation 2.

AOV=2ATAN(SENSOR WIDTH/2*FOCAL LENGTH))*(180/PI)

Equation 1: Angle of View

FOV=2(TAN(AOV/2)*DISTANCE TO SUBJECT)

Equation 2: Field of View

An image plane was replicated through a paint application to represent the low density of the pixel size, shown with grid representation. The bottles acted as a reflector, and their image plane coordinated were compared after one step was taken to the right, as a result, there was an approximation of pixel shift of 25. A replication was created on Matlab to determine the minimal distance a coordinate should move to notice movement of one pixel by translation without rotation. The resolution on 0.9 MP was used to work with low density, and the two wall reflectors were placed at height 60ft while one was placed at 65ft. The following replication of how the camera would view the reflectors in the zenith angle is shown in Figure 2. Figure 3 represents a top level view of the FOV of the camera, where the camera would form a unique triangle to determine location.

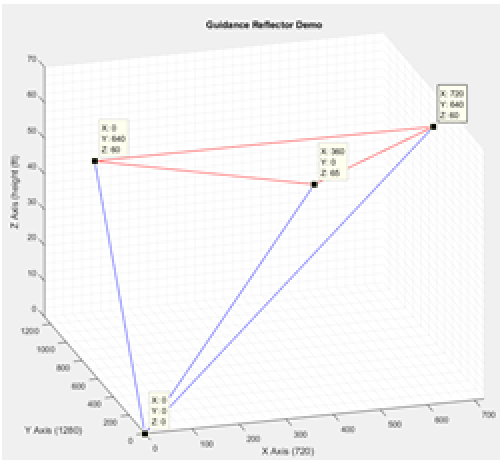


Figure 2: Guidance Reflector Demo 3-D

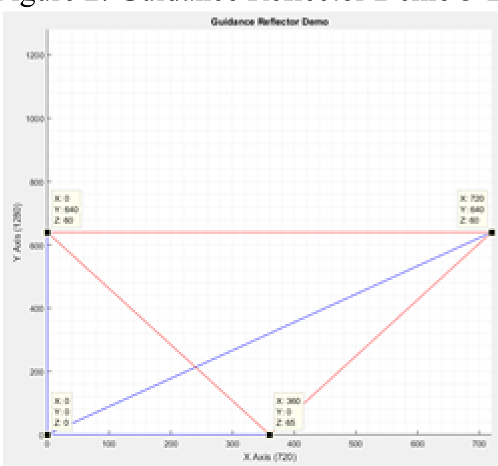


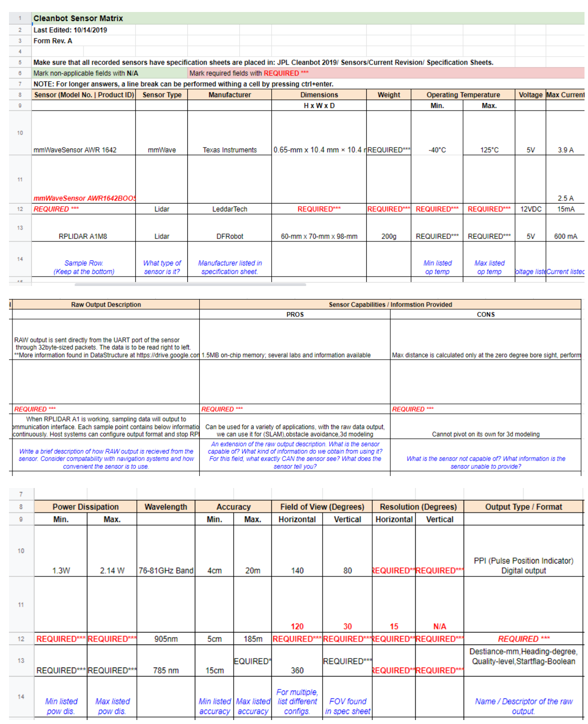
Figure 3: Guidance Reflector Demo 2-D

SLAM Algorithm to Map

The clean room is compact with flight hardware and various other obstacles that the robot needs to avoid with varying constraints. The Simultaneous Localization and Mapping (SLAM) algorithm will be used to map out the clean room with the assistance of the Gmapping source code. SLAM is able to construct a map given the environment of the clean room which has the potential to alter weekly or daily. The SLAM algorithm is implemented in Python and other languages such as C++; however, the team has decided to design and update the code on Python as it is compatible with the ROS libraries. The algorithm requires raw laser data and odometry. The source uses range (m) and bering (Θ) from the laser data. The SLAM algorithm requires certain data inputs to

II. SENSORS

Sensors are one of the crucial components of the Cleanbot 3000. Our team has been researching on finding the ideal sensors that we will be using to integrate with the navigation system. The following matrix shown in figure 4 are the sensors that may be used for navigation and object detection, our team decided to narrow the options of the sensors based on efficiency and accuracy. The following three sensors were our top choices.



Cleanbot Sensor Matrix
Last Edited: 10/14/2019
Form Rev. A

Make sure that all recorded sensors have specification sheets are placed in: JPL Cleanbot 2019/ Sensors/Current Revision/ Specification Sheets.
Mark non-applicable fields with N/A | Mark required fields with REQUIRED ***
NOTE: For longer answers, a line break can be performed withing a cell by pressing ctrl+enter.

Sensor (Model No. | Product ID)	Sensor Type	Manufacturer	Dimensions	Weight	Operating Temperature		Voltage	Max Current
			H x W x D		Min.	Max.		
mmWaveSensor AWR 1642	mmWave	Texas Instruments	0.65-mm x 10.4 mm × 10.4 r	REQUIRED***	-40°C	125°C	5V	3.9 A
mmWaveSensor AWR1642BOOS								2.5 A
REQUIRED ***	Lidar	LeddarTech	REQUIRED***	REQUIRED***	REQUIRED***	REQUIRED***	12VDC	15mA
RPLIDAR A1M8	Lidar	DFRobot	60-mm x 70-mm x 98-mm	200g	REQUIRED***	REQUIRED***	5V	600 mA
Sample Row. (Keep at the bottom)	What type of sensor is it?	Manufacturer listed in specification sheet.			Min listed op temp	Max listed op temp	oltage liste	Current listec

Raw Output Description	Sensor Capabilities / Informstion Provided	
	PROS	CONS
RAW output is sent directly from the UART port of the sensor through 32byte-sized packets. The data is to be read right to left. **More information found in DataStructure at https://drive.google.con	1.5MB on-chip memory; several labs and information available	Max distance is calculated only at the zero degree bore sight, perform
REQUIRED ***	REQUIRED ***	REQUIRED ***
When RPLIDAR A1 is working, sampling data will output to ommunication interface. Each sample point contains below informatio continuously. Host systems can configure output format and stop RPI	Can be used for a variety of applications, with the raw data output, we can use it for (SLAM),obstacle avoidance,3d modeling	Cannot pivot on its own for 3d modeling
Write a brief description of how RAW output is recieved from the sensor. Consider compatability with navigation systems and how convenient the sensor is to use.	An extension of the raw output description. What is the sensor capable of? What kind of information do we obtain from using it? For this field, what exactly CAN the sensor see? What does the sensor tell you?	What is the sensor not capable of? What information is the sensor unable to provide?

Power Dissipation		Wavelength	Accuracy		Field of View (Degrees)		Resolution (Degrees)		Output Type / Format
Min.	Max.		Min.	Max.	Horizontal	Vertical	Horizontal	Vertical	
1.3W	2.14 W	76-81GHz Band	4cm	20m	140	80	REQUIRED**	REQUIRED***	PPI (Pulse Position Indicator) Digital output
					120	30	15	N/A	
REQUIRED***	REQUIRED***	905nm	5cm	185m	REQUIRED***	REQUIRED***	REQUIRED**	REQUIRED***	REQUIRED ***
REQUIRED***	REQUIRED***	785 nm	15cm	EQUIRED*	360	REQUIRED***	REQUIRED**	REQUIRED***	Destiance-mm,Heading-degree, Quality-level,Startflag-Boolean
Min listed pow dis.	Max listed pow dis.		Min listed accuracy	Max listed accuracy	For multiple, list different configs.	FOV found in spec sheet			Name / Descriptor of the raw output.

Figure 4: Sensor matrix

Based on the data sheets and the matrix we've decided to use the *"AWR1642 mmWavesensor"* for object detection , mmWave sensor is a Texas Instruments (TI)

that will provide us with accurate sensing and enable us to navigate without colliding, the TI offers short, medium, and long-range proximity to avoid collision towards the direction of the cleanbot.
Another reason we believe the mmWave sensor is ideal for the cleanbot is due to its other capabilities. The "*AWR1642 mmWaveSensor*" sensor's main application is object detection as well as it is capable of working in poor conditions, such as poor lighting. These features make the "*AWR1642 mmWavesensor*" type convenient to use. The previous semester we were determined to use an array of ultrasonic "HC-SR04 ultrasonic sensor". However, JPL did not like the idea to use ultrasonic so we had to outscope the Ultrasonic, however, they suggested to find a more accurate and more expensive as last resource which is something our team will work in the future.

Sensor for navigation

We will be using the "Slamtec RPLIDAR A1 -360 Laser Range Scaner " (RPLIDAR) sensor with the navigation system , the navigation system will be using SLAM. SLAM needs laser data and Odometry , the RPLIDAR sensor fulfills the needs of SLAM the following are the reason why we concluded that the RPLIDAR will be the chosen one for our navigation system.

- RPLIDAR A1 is a 360-degree 2D laser scanner
- The produced 2D point cloud data can be used in mapping, localization and object/environment modeling.
- Environment scanning and 3D remodeling
- RPLIDAR A1's scanning frequency reached 5.5hz when sampling 360 points each round
- General simultaneous localization and mapping (SLAM)
- Measures distance data in more than 8000 times/s

Note* The following images shown in figure 5-8 are for illustration purpose only. Figure 5 shows the physical RPLIDAR sensor. Figure 6-7 shows the illustration of samples of its navigation process. Figure 8 shows an illustration of the relative environment of the sensing.

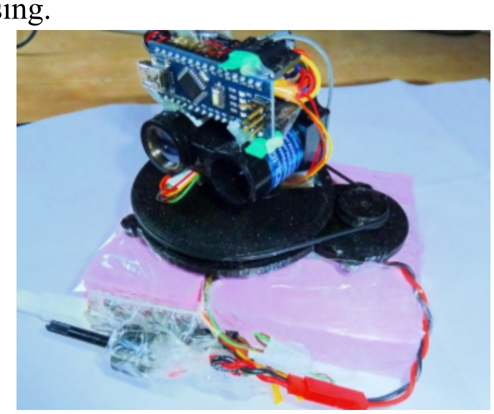


Figure 5: Physical RPLIDAR sensor

Figure 6:RPLIDAR A1 Sample 1

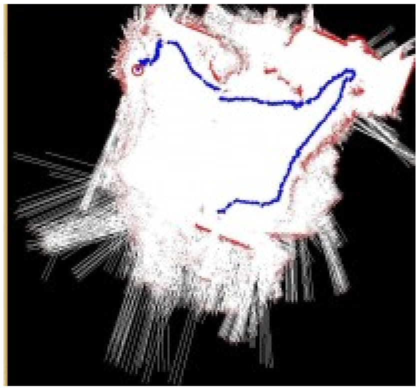


Figure 7: RPLIDAR A1 Mapping example 2

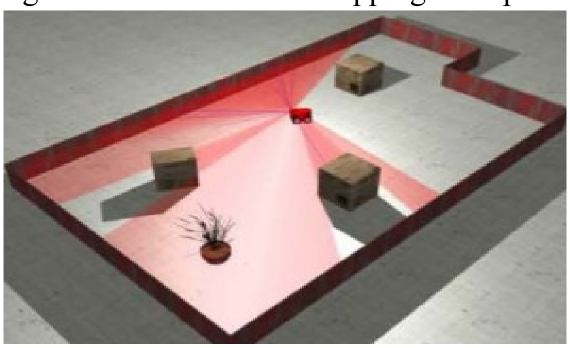


Figure 8: Odometry Sensing

According to its specification, the RPLIDAR is capable of this will be ideal in our cleanbot, we would like a high speed mappin so we can navigate the JPL clean rooms and the LPLIDA enables us with its high speed rotation and samples provides. The images in figure ()shows a mapping example.

Leddar sensor is also object detection , however, due to the lack of information of Leddar , we have currently discoped this option. And so we are left with "*AWR1642 mmWaveSensor*" for object detection and "*Slamtec RPLIDAR A1 -360 Laser Range Scaner*" for our navigation system.

III. SANITIZATION/ POWER

The autonomous vehicle is required to sanitize the clean room floors without causing any harm to any other devices or objects in the room; therefore, UV-C LED light was determined to be the most effective method of sanitizing the floors. UV-C LED light ranges from 200nm-280nm, such wavelength disinfect and are directed at viruses, bacteria and other harmful pathogens. The high level of sanitization is required to omit the robot from allowing the flight hardware to carry life from earth into space.

The Klaren G Series UV-C LED was selected as the potential LED to run test on, and two models were of the 265 series. A Python program was created to determine the various aspects of an LED can provide towards sanitization. Such calculations were towards the following: area, efficiency, power over area, and dosage time. Area was calculated through the double angle formula, efficiency was by powerdraw/powerout, power over area was powerout/area while dosage was in mj/cm^s. Constraints were added to the program to make it more modular, including the max power draw where it is used as a global variable to determine the quantity of power the robot is to use and return to the number of LEDs that can be used. The max amount of LEDs was calculated through the power and dimension. The power life was also determined in the program along with the speed the robot could travel to sanitize the floors effectively. Given the power budget of ten LEDs, the dosage time was 4.3 seconds to effectively sanitize. The battery life was 2.1 hours while allowing the robot to maintain a speed of 2.1 cm/s. The python program was able to run the previous calculations given the required info of the LEDs.

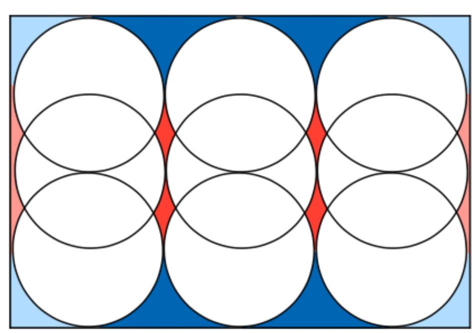


Figure 9: LED Area Rectangle Configuration

The layout of the LEDs provides how effective in time and cost it could be. Initially, the design was in a horizontal configuration of ten LEDs; however, a comparison was made to change the design to a 3x3 rectangle configuration shown in Figure 9. As a result, the rectangular configuration allowed for a more effective source of LED dosage and power. Inscribed circles were used to calculate the gap areas in a 3x3 rectangular configuration. The area of the overlap could be determined by integration. Due to observation, more overlap is seen as less overall area, and the next step was to determine and decide on a minimal acceptable overlap. The dosage applied over the area covered after moving for a certain amount of time needs to be determined.

A power budget is under process due to the various potential modules that will be added to the cleanbot. As a result of calculating heat as an output of the LED system, there is 1% of efficiency, leaving 99% of lost heat from the chosen LEDs input power. The following heat transfer by radiation equation in Equation 3 was used to determine the heat.

$$\frac{dQ}{dT} = \epsilon\sigma A\, T^4$$

Equation 3: Heat Transfer by Radiation

The junction temperature of the given LED equation was used for the LED, as shown in Equation 4.

$$Tj \ = T_a + (R_{th\,j-a} \times P_a)\ (1)$$

Equation 4: Junction Temperature of LED

The heat and power for the next potential modules to be added onto the cleanbot add onto the power budget and such values will be added onto the overall power budget. As for the sanitization power, 27 watts are required as a total of the nine LEDs have been chosen for the layout due to each LED requiring 3 watts of power. The LIDAR sensor ranges from 2-20 watts in power consumption depending on the range of the sensor chosen. The power budget will continue to add on new modules; however, the RRC2053-S was chosen for the moment for test and analysis. The manufacturer is RRC Power Solutions and it's voltage is 14.4V, with 6.9 Ah in current, along with 99 watt/hour. The battery held a requirement of no outgassing and a minimum capacity of 60Wh which was met with the chosen battery.

DESIGN APPROACH

SECOND LEVEL REQUIREMENTS

1.1.1 The Cleanbot shall avoid and detect obstacles in its path.
1.1.2 The Cleanbot shall navigate the room to sanitize the maximum area of the clean room.
1.2.1 The Cleanbot shall use UV-C irradiation to sanitize the floors of the clean room.
1.2.2 The Cleanbot shall maintain a speed that requires sufficient UV-C coverage.
1.3.1 The Cleanbot shall differentiate flight hardware from standard objects.
1.3.2 The Cleanbot shall avoid flight hardware by one meter.

BUILD vs BUY

In this project our team has agreed that it is convenient to buy rather than build. Due to the complexity of the requirements that we must overcome we have not yet considered building any components/resources. We plan on buying all the resources we need, resources such as sensors , UV LED, software development kit (SDK) , cameras and any other component we might need throughout the project. As of right now it is more efficient to buy than build, we are currently researching for reliable and efficient components, we are relying trusted distributors such as Texas Instruments and Slamtec.

COST vs BENEFITS

Sanitization relies on a bulb or an LED UV-C source, and due to the reliability, power, and safety, we have chosen to purchase the LEDs. The bulbs cons included a possible mercury leakage, short lifetime and a significant energy requirement. The LED on the other hand is fracture resistant, flexible, and can reduce heat generation rate. The benefit of purchasing the LED is that you will have a secure and reliable source of UV-C light that will remove harmful microbes from the environment.

The interaction of the cleanbot with the environment relies on various sensors; therefore, reliable and effective sensors are required. The guidance reflectors will be purchased as they are inexpensive and do not require any modification once placed on the walls of the room. The camera sensors, on the other hand require reliability and effectiveness. The CMOS camera sensor was chosen over the CCD due to a lower power consumption ranging from 3.3 to 5 volts and the parallel processing speed that allows for a quicker response. The RPLIDAR that will assist the SLAM algorithm will also be borrowed temporarily for testing; however, the LIDAR from LeddarTech hold a better accuracy with a bigger range window of 5cm minimum range to 185 m maximum range. Purchasing the reflectors and camera sensor will help with a reliable positioning method while borrowing the LIDAR sensor for testing reasons will assist towards a greater analysis.

RISK vs REWARDS

Creating the cleanbot with reliable and precise modules and components holds a risk towards ordering useful and ideal parts. Although there are various devices and objects that must be analyzed and tested, the python code can be expanded along with the Matlab code to simulate the possible results. The camera for the guidance reflectors may be overqualified in resolution or it may require more resolution. The LIDAR sensor may hold similar concerns; however, once tested, a comparison of the pros and cons can be determined, taking advantage of the pros the test result in. The overall risk is held in the cleanroom once the cleanbot is in its working environment. The risk is releasing and infecting the cleanroom environment causing the flight hardware to be contaminated, which allows it to transport bacteria to another planet or space in general.

TESTING

LEDs power, dosage and area covered were simulated and calculated through a Python code that was made more modular. The following code can be extended for the other modules such as the LIDAR sensor and the camera for the guidance reflector. Adjustments would need to take place to the code. The team was not able to run test on actual equipment due to limited funds; however, the simulation was able to give the team possible results to run an analysis. The simulation had the potential to support the purchase of one item or model over the other and/or completely avoid a certain product.

The guidance reflectors were simulated on Matlab through a matrix. The position of the reflectors was on the wall of a room and the coordinated were given in a 3-D structure. The camera was positioned at the origin and the movement was analyzed by translation without rotation. Two planes were created and compared to one another to notice the difference in movement. One plane was where the reflectors were positioned and the other plane was between the camera and the reflectors. So the difference when one reflector was noted. The purpose of moving the coordinated, is to notice the minimal distance the cleanbot would have to move to notice one pixel movement. The dimension of the tallest guidance reflector would also be determined. The simulation allows the resolution and the distance needed to travel to notice movement by one pixel.

CONCLUSION

The Cleanbot 3000 project advanced on determining navigation, positioning, and sanitization. Navigating through a room will be completed through the use of the LIDAR camera sensor and the SLAM algorithm, as it will map out the room. The position of the cleanbot will be determined through the use of the guidance reflectors and a CMOS camera through trigonometric calculations within the SLAM algorithm. The collision avoidance will be taken care of by the "awr1642 mmWaveSensor". The optimal uv-LED layout and dosage were also determined through the python program, which also hold the battery life depending on the LED usage and the other modules including the LIDAR sensor. The project is in early development which resulted in much of the focus on researching devices that will cooperate with each others data in an effective method. The specifications of various models were compared. The cost and reliability were analysed, which lead to choosing the potential and model to be added onto the cleanbot. The various requirements and constraints were given by JPL in order to keep the environment and the flight hardware safe at all times. The project is progressing and needs a continuation of development and testing.

FUTURE WORK

The future plans include a continuation in development with the navigation in the guidance reflectors and testing equipment. The navigation through the cooperation of the SLAM algorithm and the LIDAR sensor need to be tested and analyzed to notice if this method of mapping out the room is close to ideal when considering all the objects on the cleanroom. A chassey should be developed for the layout of the cleanbot for optimal performance while meeting the JPL requirements. The sanitization portion should continue determining the ideal layout and dosage for the LEDs to sanitize with the battery that is chosen. A continuation in python code to make it more modular and flexible for other components is required. The project in general shall continue development, as it is in the early stages of development.

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