SLAM Airborne Particle Detection and Surveillance Robot

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Cleanliness counts!

All cleanroom facilities are issued an industry standard Class rating that reflects the purity of their cleanroom environment(s). This rating is based on how many contaminant particles of a particular size are detected in a set volume of air. The usual culprits that contaminate a cleanroom environment are very small dirt or debris particles that measure on the order of micrometers to tenths of a micrometer in size, beyond the detection threshold of even the sharpest human eye. A chart with the class of the cleanrooms visited at Freescale and ASU CSSER and the detection range of the current prototype is shown below.

FED STD 209E equivalent	Class	maximum particles/m3 size ≥0.1 µm	size ≥0.2 µm	size ≥0.3 µm	size ≥0.5 µm	size ≥1 µm	size ≥5 µm	
	ISO 1	10	2.37	1.02	*0.35*	0.083	0.0029	
	ISO 2	100	23.7	10.2	*3.5*	0.83	0.029	
Class 1	ISO 3	1,000	237	102	35	8.3	0.29	FREESCALE
Class 10	ISO 4	10,000	2,370	1,020	*352*	83	2.9	
Class 100	ISO 5	100,000	23,700	10,200	3,520	832	29	ASU CSSER
Class 1,000	ISO 6	1.0×10^6	237,000	102,000	*35,200*	8,320	293	
Class 10,000	ISO 7	1.0×10^7	1.0×10^6	1,020,000	*352,000*	83,200	2,930	
Class 100,000	ISO 8	1.0×10^8	1.0×10^7	1.0×10^7	*3,520,000*	832,000	29,300	
Room air	ISO 9	1.0×10^9	1.0×10^8	1.0×10^8	*35,200,000*	8,320,000	293,000	
						Our sensor		

Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones, FED-STD-209E, 1992

Air testing hardware is priced according to its particle resolution. The most sophisticated air testing hardware is capable of detecting airborne particles measuring less than 0.1um in diameter. Accordingly, this class of hardware comes at the highest cost, and can be over $20,000 per sensor. More economical solutions cannot detect particles at such small dimensions and are only useful for detecting airborne particulates on a larger scale.

Above: photograph of the Auer Precision cleanroom facility
http://www.medicaldevice-network.com/contractors/manufacturing/auer-precision/

Air testing is an operational cost that cannot be ignored. A business or organization's class rating is both a merit of pride and a promise to its customers. Sensitive electronics must be made and handled in environments of utmost purity and cleanliness. A single speck of debris can ruin the performance and lifetime of a product bearing the company's name. Without satisfactory contamination levels, cleanrooms cannot operate or be used. Thus, the need for reliable air quality testing has come to represent an unavoidable cost for all industries and academic institutions manufacturing electronic devices.

Expenditures

Total works-like prototype cost	$824.88
Chassis, motors, and motor driver	$43.40
BeagleBone Black	$55
LIDAR	$398.9
Dust particle sensor	$15.90
Batteries and charger	$49.85
Looks-like prototype	~$14
Custom PCB parts	$23.35
Test environment (wood and nails)	$81.23

Timeline

Project conception	January 2014
First order	March
First senior design class	August
Decided on air quality application	September
Robot drives around	November
Web interface and working sensors	December
Test environment built	February 2015
Looks-like prototype designed	March
Localization working	April
Demonstration	Today

Introduction

The SLAM Air Quality Monitoring Robot is a modular and inexpensive platform capable of solving multiple problems with application-specific add-on modules. SLAM, or Simultaneous Localization and Mapping, is the ability to quickly determine where a robot is and what the environment around it looks like, which adds a unique advantage to many problems faced in various industries. The focus of this prototype is on airborne particle detection and surveillance in cleanrooms using a SLAM robot. This new approach has the potential to reduce both the cost and disruption of air quality surveillance while increasing the quantity and comprehensiveness of data obtained.

The Industry and its Challenges

Businesses and academic institutions manufacturing electronics for research or sale commonly use cleanrooms, which are isolated units with highly controlled and monitored levels of particulate matter in the air. These cleanrooms require a substantial investment of monetary capital and human hours to maintain and monitor the air quality. Our research with industry experts suggests the current methods for monitoring these cleanrooms are not as effective as they could be, particularly in terms of cost and potential disruption to cleanroom operations.

Existing Techniques

Cleanroom air contaminants are typically detected by either handheld or fixed wall-mounted sensors. Handheld sensors generally cannot detect particles smaller than 0.5um. Although the lower cost of these sensors and the ability to carry them to multiple points in the cleanroom makes them beneficial for lower-budget facilities, they remove a staff member from their normal duties to periodically monitor air quality levels. Fixed sensors can offer a much higher precision, detecting particles as small as 0.1um, with no staff involvement. Unfortunately, these limit data collection to a single location, which necessitates the installation of several units across the facility.

Left: Airborne Particle Counter 942300, 0.3um, portable
http://www.ebay.com/itm/like/261598922390?lpid=82
Right: Lasair 110-2, 0.1um, stationary
http://www.fabsurplus.com/sdi_catalog/salesItemDetails.do?id=8082

Our Prototypes

Right: The works-like prototype is capable of monitoring air quality in a pre-known environment with the following features:

- ARM Cortex A8 running Debian Linux for fast computations
- RPLIDAR for determining location using 360º laser triangulation
- Shinyei PPD42NS dust sensor for measurement of particles larger than 1um diameter
- Approximately 2 hours battery life
- WiFi and web interface for wireless monitoring and control
- Manual control using keyboard or gamepad

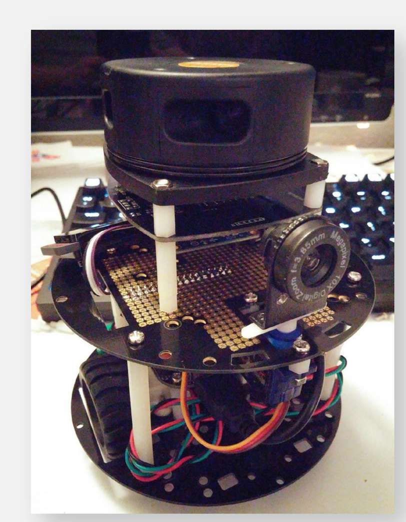
Far Right: The looks-like prototype is 3D printed 1:10 scale concept of what a final product could look like, adding the following additional features:

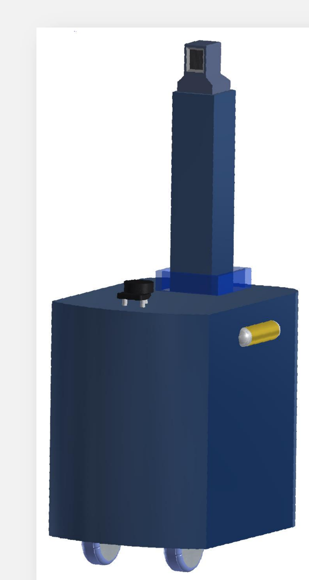
- Robust, clean-room friendly design
- Sealed motors and electronics to prevent generation of dust or electro-magnetic interference
- Larger with yellow LEDs for better visibility
- Fully autonomous with the ability to operate without human intervention, or in an unknown environment
- Extendable particle sensor for monitoring from 2.5 to 7 feet
- Charging dock for long-term use

Above: Looks-like prototype laser etched on acrylic

Our Solution

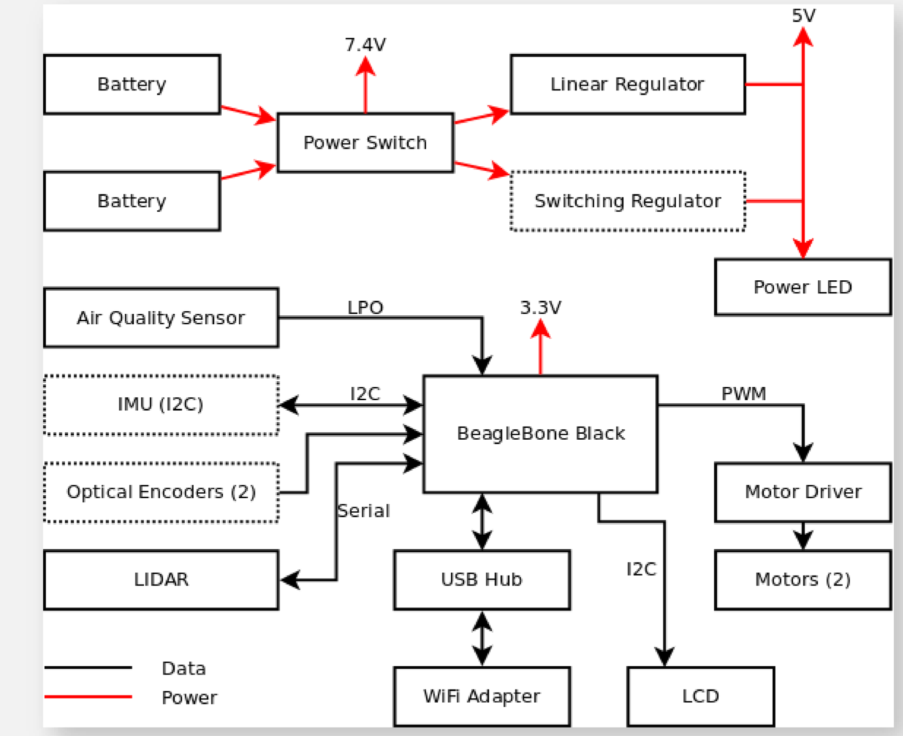
The proposed product is a fully autonomous air quality surveillance robot with all the advantages of existing techniques and none of the compromises. It monitors air quality levels by driving through a cleanroom and taking air data across many points, building a color-coded "particle map" of the facility, or it can monitor levels changing over time. This data is delivered to staff on an easy-to-use web application usable on any computer, and stored in memory for later use. It may be controlled directly, or run autonomously and alert staff when airborne particle levels are above a set threshold. With some guidance it can build a map of any unknown environment, or use an existing map of a specific facility. Due to its modularity, the robot may be outfitted with particle sensors of any resolution to fit the needs and available capital, making it an ideal product for many different types of cleanroom facilities.





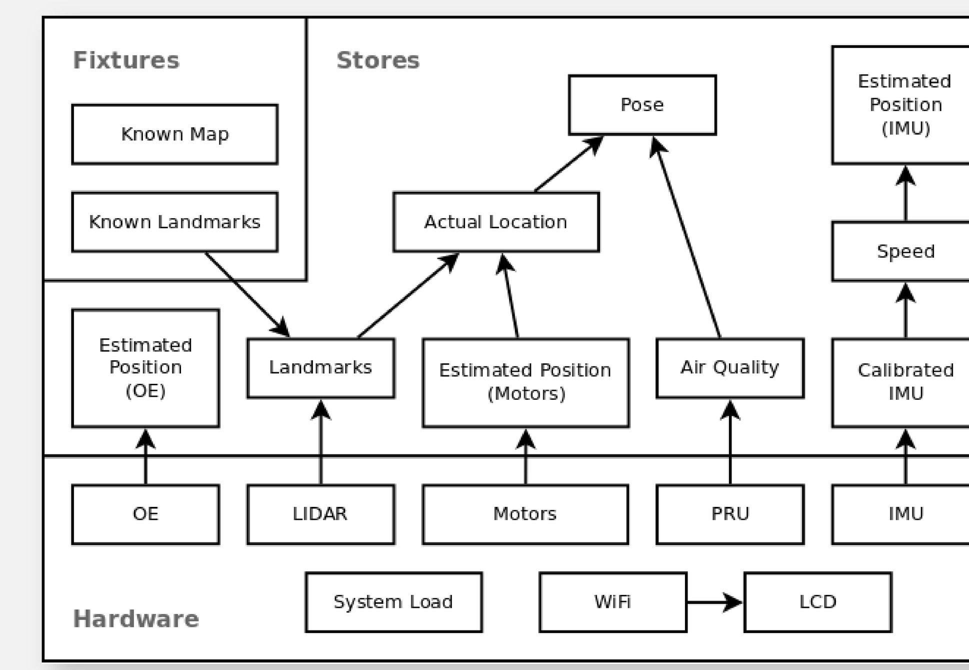
Conclusion

Facilities allocate very large amounts of capital and resources annually to safeguard the sterility of their work environments and ensure compliance with industry standards: sophisticated facilities and equipment, elaborate staff training, and exacting laboratory conduct regulations. Sacrificing the accuracy or comprehensiveness of air quality monitoring to save time and money can prove disastrous down the road for a business or institution. Cleanroom operators are always searching for a better way of measuring air contaminants that requires less human operation, is free of disruption, and gives the comprehensive data they need. This project will deliver on all these while maintaining the accuracy of existing methods, revolutionizing the way air quality is surveyed in facilities.



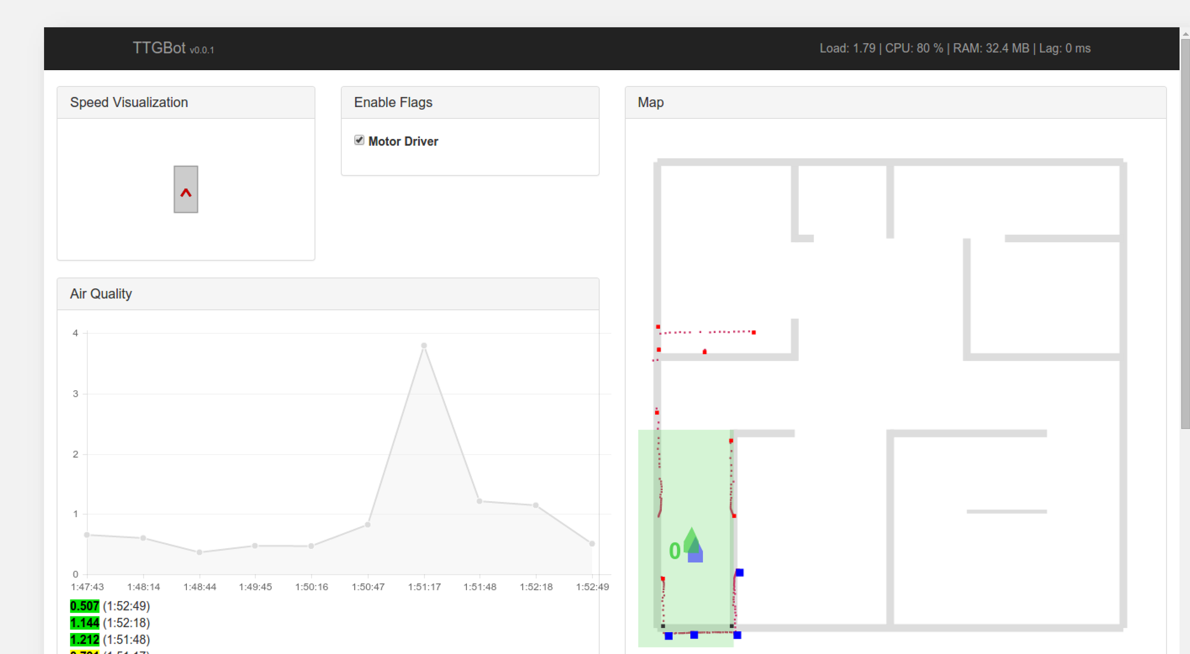
Hardware Diagram

The diagram above shows the hardware on the custom circuit board. Dual batteries power the robot, allowing one to charge while the other iis in use. A BeagleBone Black with the ARM processor runs the robot software and controls all electronics and sensors. Components with dashed borders are not in use in the current prototype. Data lines are labelled with the communication protocols used.



Software Diagram

The software is divided into two pieces: The robot software, and the web interface. The diagram above shows all modules for the robot software, which performs the majority of the tasks. The code is divided into three module types: hardware modules communicate directly with hardware; fixtures store fixed data; and stores calculate and store data.



Web Interface

The screenshot above shows the current web interface for the works-like prototype. A known map is shown on the right with the robot's current estimated and calculated position. Status information is shown on the top left and top right. A graph of air quality versus time is shown on the left; the spike occurred when the robot was moved quickly, increasing airflow through the sensor.

Acknowledgements

- Dr. Michael Kozicki (ASU), Rick Sparber (SMCC)
- Arthur Handugan & Stefan Myhajlenko (ASU CSSER), Tim Poet & Steven Salatino (Freescale), Mark Strnad (ASU MTW)
- The friendly employees and equipment at Techshop Chandler

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