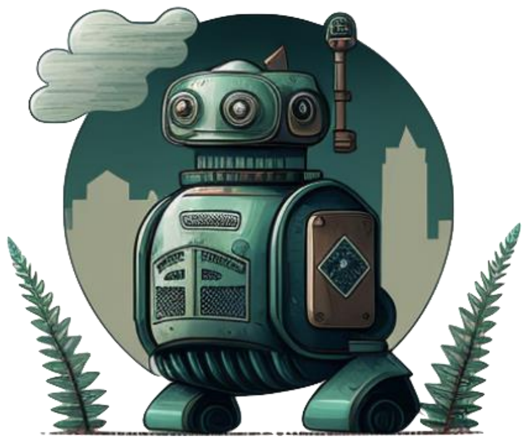
CONCEPTUAL DESIGN REPORT
BreatheSafeBot



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1.0 Executive Summary

Queen's Property Management Corporation (Q-PMC) has given the opportunity to the EnviroBotics team to design and implement the BreatheSafeRobot (BSB). This technical report details the development and concept of the BSB, an innovative mobile robot-based system that has been designed to provide an efficient method for monitoring the air quality in indoor environments. The BSB system is intended to remotely measure, survey, map, and report Carbon Dioxide levels in real-time, thereby ensuring that workplaces, schools, and other indoor spaces remain safe and healthy for the occupants.

The BSB is constructed on the Lynxmotion Aluminum 4WD1 Rover platform. To enable efficient motion, it utilizes differential steering and four-wheel drive. The Arduino microcontroller communicates with the motor driver, and the robot incorporates multiple sensors, including proprioceptive and extrospective sensors, to provide information about its surroundings.

The BSB's primary objective is to provide the client with essential information about the indoor environment, allowing for changes to be made to ensure the space is safe for the occupants. According to Health Canada, in indoor environments, long term exposure of carbon dioxide at a concentration of 1000 ppm over a period of 24 hours can place the occupants of the building at risk of respiratory symptoms, decreased test performance and neurophysiological symptoms. Short term exposure is usually higher concentrations of CO_2 for shorter periods of time [2]. Therefore, the BSB is equipped with sensors to monitor CO_2 concentration levels, providing the client with real-time data to ensure healthy working environments.

An improvement that has significantly enhanced the convenience, efficiency, and effectiveness of the BSB system is the implementation of automatic charging. Automatic charging guarantees that the BSB is always ready to collect and transmit data, enhancing the overall efficiency of the system. Additionally, automatic charging improves the convenience of the system, allowing for seamless and continuous monitoring of indoor environments.

2.0 Introduction

EnviroBotics is currently in development of the BSB for indoor monitoring of air quality, for the client Q-PMC. The client has requested the development and implementation of a mobile robot-based system for remotely measuring, surveying, mapping, and reporting CO_2 levels in indoor environments. Also, the client has requested an open-ended design for potential additional functionality.

2.1 Problem Background

A clean working environment is crucial for the productivity and well-being of employees in a workplace. Both the employer and employee see benefits from a cleaner work environment, such as increases in productivity and less sick days. The quality of an indoor environment is based on several factors, such as carbon dioxide concentrations, temperature, and humidity [1].

The BSB proposes a monitoring device, which will provide the client with essential information about the indoor environment, prompting for changes to be made which will ensure the space is safe.

3.0 Conceptual Design Documentation

3.1 Use-Case Study

The Roomba series of autonomous mobile vacuum cleaners, developed by the iRobot company, is a noteworthy innovation in the field of commercial robotics. The third generation of Roombas incorporates a "docking" button/function, which allows the robot to detect its docking station and automatically return to it for recharging purposes. The technology behind this functionality has enabled Roombas to autonomously clean larger rooms, as it can now recharge midway through a cleaning job.

The Roomba is powered by a rechargeable battery, which can enable the robot to clean an entire room or area before it needs to be recharged. When the Roomba detects that its battery is running low, it promptly returns to its charging station to recharge itself. This automated feature is a significant improvement over earlier versions of the Roomba, which required users to manually recharge the device.

In the context of the BSB, implementing automatic charging would be highly advantageous. Since the BSB is powered by a rechargeable battery, it needs to be able to recharge itself when the battery runs low to ensure that it remains operational during a monitoring session.

The implementation of automatic charging for the BSB would mean it would guarantee that the BSB is always ready to collect and transmit data, even if the battery runs low during a monitoring session. It would enhance the overall efficiency of the system, as the robot would never shut down during data collection and would continue transmitting data while docked, rather than requiring a manual reset after being taken offline due to a dead battery.

The implementation of automatic charging for the BSB would be a highly beneficial advancement, improving the convenience, efficiency, and effectiveness of the system.

3.2 System Architecture

The BSB is designed on the Lynxmotion Aluminum 4WD1 Rover platform and he robot's body comprises all necessary components and sensors for its intended purpose, as illustrated in Figure 1. Power is supplied through an internal 12-volt battery and auxiliary power components.

Figure 1: The BSB utlizes the Lynxmotion 4WD1 rover chassis [3].

3.3 Motion System

The BSB uses four-wheel drive for motion, utilizing differential steering. The Hsiang Neng model HN-GH12-1634T geared motors, powered in pairs by the SeeedStudio L298 Dual H-Bridge Motor Driver shown in Figure 2, drives the robot's wheels. The Arduino microcontroller communicates with the motor driver through Pulse-Width Modulation (PWM) signals. Figure 3 demonstrates how the microcontroller affects the wheel output. The microcontroller calculates the required amount of PWM to obtain the desired wheel rotation.

(a) (b)

Figure 2: (a) Hsiang Neng model HN-GH12-1634T geared motor | (b) SeeedStudio L298 Dual H-Bridge Motor Driver [3].

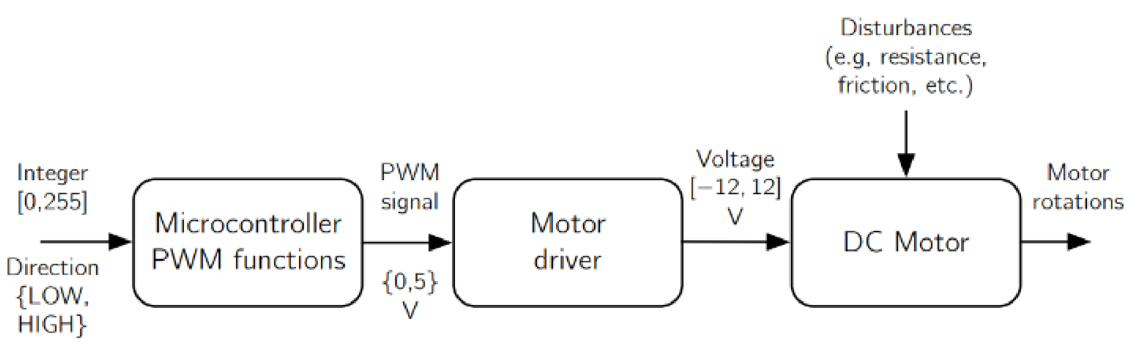

Figure 3: Systems diagram of motion system [3]. The PWM is sent into the motor driver, sending the appropriate voltage and current to each motor.

3.4 Sensors

The BSB has multiple sensors that provide information about its surroundings. The two types of sensors that are present on BSB are proprioceptive and extrospective.

The Adafruit SCD-30 NDIR CO_2 Temperature and Humidity Sensor measures CO_2 concentrations ranging from 400 ppm to 10,000 ppm with an error of ±3% [4]. It also contains the SHT31 temperature and humidity sensor, shown in Figure 4. It measures temperature in degrees Celsius with an accuracy of ±0.3% and relative humidity with an error of ±2% [5]. The sensor serves as a measurement tool of the environment, providing input to be processed and displayed to the user.

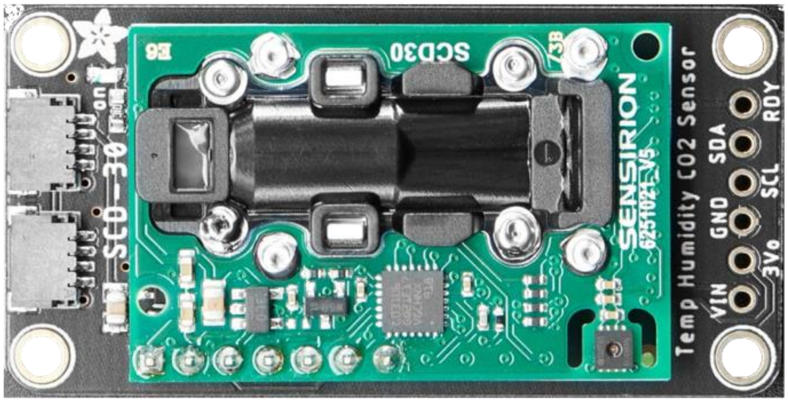

Figure 4: Adafruit SCD-30 NDIR CO_2 Temperature and Humidity Sensor and SHT31 temperature and humidity sensor [4].

The rover contains optical rotary encoders which provide the controller with information about the wheel speed and direction. A US Digital E4T miniature optical encoder is mounted on the rear wheels with the motors. The proprioceptive sensor aids in the control and navigation systems by monitoring the activity of the motors.

Three Sharp GP2Y0A21YK optoelectronic range sensors are attached to every side of the rover except for the back. They can detect objects from 10 to 80 centimetres [6]. These sensors provide the robot with short-range detection of objects and obstructions. The sensor data informs the controller of its position relative to other objects or walls in the room. The Sharp sensor provides significantly faster responses than LIDAR and allows the robot to maintain a specified distance from walls and obstacles.

The BSB also utilizes LIDAR for mapping the CO_2 concentrations around the room, shown in Figure 5. The LIDAR is implemented through the SLAMTEC RPLIDAR A1 and Raspberry Pi 4 microcontroller, also shown in Figure 5. The RPLIDAR provides a 360-degree field of view, with a range of up to 12 meters [7]. The robot observes its surroundings through the LIDAR, mapping out the room layout. The information is relayed to the Arduino and back to the dock for processing and transmission to the end-user. The LIDAR is implemented through the Robotics Operating System (ROS) on the Raspberry Pi. Some information, such as distance, is also redirected into the Arduino for position information.

(a) (b)

Figure 5: (a) RPLIDAR A1, with the PWM board [7] | (b) Raspberry Pi 4 communicating and controlling the LIDAR.

3.5 Control System Design

The control system for the BSB will be based on a proportional-integral (PI) controller which will be implemented using the Arduino Uno Wi-Fi REV2 microcontroller, shown in Figure 6. The controller will use a closed feedback-loop to correct itself and reach a desired state. The system will use rotary optical encoders to determine the state of the motors, and the controller will accept a desired steering rate and desired velocity as inputs. Through testing, this approach has been proven effective at matching the desired state quickly and consistently and is widely used in the control of mobile robots.

Figure 6: Arduino Uno Wi-Fi REV2 for Proportional-integral (PI) controller.

To implement the PI controller, the optical encoders will be configured to use interrupts to count the number of ticks that the rear motors have turned forwards or backwards. The ticks will be counted over time intervals of approximately 100 milliseconds and used to calculate the linear velocity of the left and right wheels. From the inputted desired velocity and desired steering rate, the desired left wheel linear velocity and desired right wheel linear velocity will be calculated.

The control system will then calculate the error between the actual velocities and desired velocities of the rear wheels. A standard PI controller with a proportional constant of 250 and an integral constant of 300 will be used. The values of the constants were selected after many tests, with the goal of minimizing the error in the least time with the motors operating smoothly rather than appearing erratic.

The control system will provide the BSB with a reliable and precise means of controlling its motion. The use of interrupts and rotary optical encoders will ensure accurate measurement of wheel velocities, and the PI controller will provide effective and efficient feedback control to achieve the desired state of the robot.

Figure 7 below shows the systems diagram for the BSB.

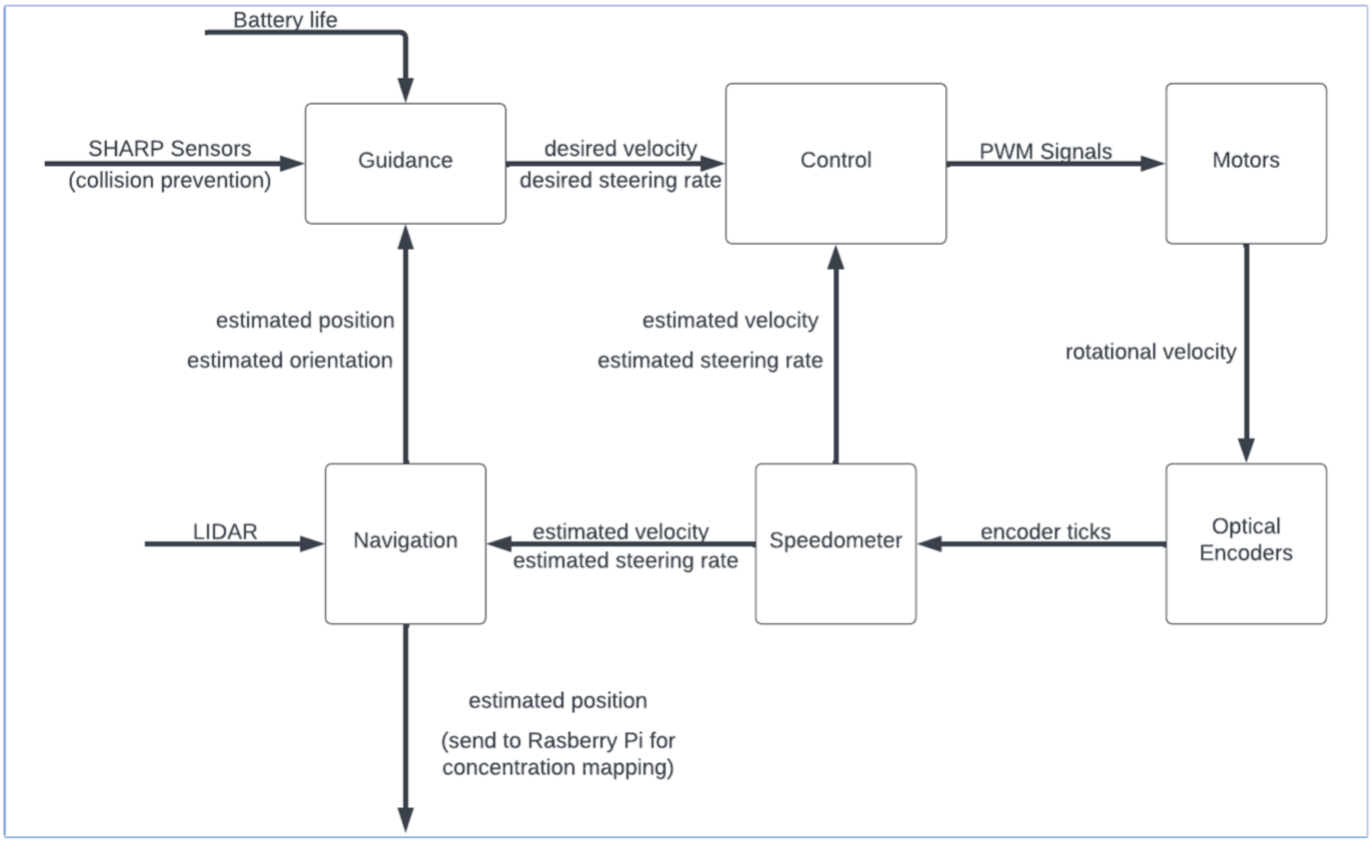

Figure 7: Overview of BSB systems diagram.

3.6 Dock Architecture and Functionality

The BSB is designed to be docked when not in use or when its battery level is low. The dock acts as a charging station for the robot, with contact pads that the robot can park on to initiate charging as shown in the SolidWorks model in Figure 8. The dock also serves as a connectivity hub for the robot and an access point for the customer. As the dock is connected to the internet, the user can remotely access the BSB and the processed data including high-data transfer devices such as cameras.

Figure 8: Solid works model of BSB dock [8].

The dock connects to the robot through a separate wireless LAN connection, which is established solely between the dock and the robot. This connection enables the robot to operate in any indoor environment without requiring network setup in each room, provided that the dock is within range of the robot.

The dock can be customized with a high-performance microcontroller, the Raspberry Pi, which will mainly serve as the wireless LAN connection. In addition, the dock includes a redundant drive for data storage, which can be accessed locally.

The dock serves a vital role in the BSB architecture, providing charging, connectivity, and data processing capabilities to enhance the robot's functionality and efficiency.

3.7 Deployment Plan

The BSB is designed to operate in indoor environments, where it will be deployed by the client. Upon delivery, the robot will come equipped with a dock and all the necessary auxiliary components, such as a power cable and a manual. The robot will be tethered to the dock through a wireless LAN connection, enabling the robot to communicate with the dock. The robot will park itself after performing a task or when its battery is low and needs to recharge and the dock can be connected to the internet using a wired or wireless connection, providing flexibility in its placement on the floor.

When the robot is deployed for the first time, or in a new room, it will perform an initial sweep of the room to create a general map of the area, taking note of objects and obstacles like tables and chairs. This map will be used by the robot to navigate the room during its subsequent sweeps.

Once the robot has completed its initial sweep and is back at the dock, it will go into standby mode, awaiting a call from the end-user. The end-user can call the robot whenever they need it to perform a sweep, which involves measuring CO_2, humidity, and other relevant environmental parameters. The robot will use its closed feedback-loop proportional-integral controller, along with rotary optical encoders, to navigate the room and perform its sweep, ensuring that it matches the desired state quickly and consistently.

The BSB's deployment plan is intended to provide the client with a versatile, reliable, and efficient system for monitoring indoor environments, providing valuable insights into the quality of the air and other environmental parameters.

3.8 Ontario Regulatory Compliance Plan

The BSB, being a device that is expected to operate in indoor spaces, must adhere to several regulatory standards, including privacy laws, building codes, workplace safety, and cybersecurity.

Depending on the type of building in which the BSB is to be installed and used, certain building code requirements must be met. For instance, the Ontario Building Code (OBC) provides specific requirements for building automation and control systems, which may encompass provisions for sensors, cameras, and other equipment. To ensure compliance, EnviroBotics has taken steps to abide by these requirements.

In workplaces where the BSB is to be utilized, employers must ensure the safety of their employees, including the safe use of the device, as mandated by the Occupational Health and Safety Act (OHSA). To this end, EnviroBotics has mandated that persons in the indoor space being monitored conduct a risk assessment and implement appropriate measures to protect workers from potential hazards associated with the use of the device.

Finally, it is worth noting that the use of LIDAR cameras may pose cybersecurity risks, such as unauthorized access, use, or disclosure of personal information. To mitigate these risks, EnviroBotics has implemented appropriate cybersecurity measures, such as hosting all its code on private servers (GitLab), to protect against such risks.

Finally, it is worth noting that LIDAR cameras may pose cybersecurity risks such as unauthorized access, use, or disclosure of personal information (layout of indoor spaces). To mitigate these risks, EnviroBotics has hosted all its code on private servers (GitLab), implemented appropriate cybersecurity measures, and suggests that encryption features are added in case of an attack.

3.9 Component and Labour Breakdown

The components of the robot can be outsourced from multiple sources, with many coming from China. AliExpress, a large online retail service that sells specific electronic parts for cheap, provides many of the components. Some exact components could not be found on AliExpress, and can be outsourced elsewhere, such as Amazon. Once the components arrive, they will be assembled by an electronics assembler.

Based on data gathered from Indeed, the average hourly rate for an electronics assembler is approximately $21 per hour in Ontario [9]. However, as there is no explicit data available regarding the assembly time of the robot in question, it can only be assumed that the level of effort required to assemble the robot is equivalent to that of an expert building a computer. As per TechGuided, the time required for an expert builder to assemble a computer is approximately an hour [10].

With regard to the robot, it is unequivocally easier to assemble compared to a computer. Hence, it can be inferred that the assembler would take less than an hour to assemble the robot. Therefore, the overall process from assembling individual parts to a fully functional robot would take about an hour, which includes assembly time, testing, and quality analysis. However, this is an approximation and does not account for several factors. Nonetheless, it serves as a valuable estimate of what can be expected and is porteayed along with other costs in Table 1.

Table 1: Table of components list, along with the total cost of a singular robot, including labour costs. Note, replacements include 4 Rotary Optical Encoders, 3 Raspberry Pi's, and 2 SD cards. Prices were estimated based on current amazon and AliExpress prices.

Category	Count	Cost Per Part ($)
Components		
Arduino UNO WiFi Rev2 micro-controller	1	74.99
DFRobot I/O Expansion Shield V7.1	1	12.24
Chassis	1	338.95
Hsiang Neng model HN-GH12-1634T geared motors	4	30.00
12 V Battery (delivers 5 A and has a capacity of 8000 mAh)	1	25.00
SeeedStudio L298 Dual H-Bridge Motor Driver	1	32.19
US Digital E4T miniature optical encoder	1	28.00
Raspberry Pi 4	1	211.93
Logitech F710 Wireless Gamepad	1	49.99
SanDisk 32GB Ultra 32 Gb SD Card	2	11.99
Sharp GP2Y0A21YK optoelectronic range sensing device	3	5.15
RPLIDAR A1 scanning laser rangefinder by SLAMTEC	1	138.90
Adafruit SGP30 TVOC/eCO2 Gas Sensor	1	7.89
Adafruit SCD30 NDIR CO2, temperature and humidity sensor	1	33.75
Other & miscellaneous Components		~10
Labor		
Electronics assembler hours	1	21
Ongoing		
Replacements	9	175.03
Total Cost	**$1319.29**	

4.0 Conclusion

The design and development of the BSB for indoor air quality (IAQ) monitoring is of utmost importance in ensuring optimal and healthy indoor environments, particularly in settings such as workplaces and schools. The BSB system is specifically engineered to remotely measure, survey, map, and report CO_2 levels in indoor spaces using advanced technological features. The robot is equipped with four-wheel drive motion capabilities, utilizing differential steering, and multiple sensors that provide essential information about the environment. The BSB is fitted with an

Adafruit SCD-30 NDIR CO_2 Temperature and Humidity sensor, which is measured continuously throughout the room to get a CO_2 map. To further enhance its functionality, the BSB employs SHARP range sensors that provide critical information to the control system. These sensors are designed to detect and capture essential data about the surrounding environment. In addition, it has LIDAR, which is used to map and navigate a room. The integration of an automatic charging mechanism into the BSB would is a significant advancement, resulting in improved convenience, efficiency, and overall system effectiveness. This capability allows the BSB to operate seamlessly and continuously without any disruptions while also improving the system's battery life and ensuring uninterrupted IAQ monitoring.

The BSB system provides Q-PMC with critical data about the indoor environment, enabling better decision-making on various environmental factors and ultimately contributing to a cleaner and healthier environment for all occupants.

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