Air Quality Detection and Display;

Revised Project Proposal

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Customer Problem

Customer Definition

This design addresses individuals ages 35 and older with chronic obstructive pulmonary disease (COPD) within the Region of Waterloo, affecting about 4.7% of the population [1]. This amounts to approximately 34 000 people in Waterloo. COPD is defined by the Global Initiative for Chronic Obstructive Pulmonary Disease [2] as “a heterogeneous lung condition characterized by chronic respiratory symptoms (dyspnea, cough, sputum production and/or exacerbations) due to abnormalities of the airways (bronchitis, bronchiolitis) and/or alveoli (emphysema) that cause persistent, often progressive, airflow obstruction”. The affected population within the Region of Waterloo is the customer of this design.

The Problem

COPD is a serious lung disease that prevents airflow in the lungs, affecting breathing. It is the second leading cause of hospitalizations in Canada [3]. Poor air quality is one of the conditions that exacerbate this illness. In the presence of low air quality, individuals with COPD may experience worsened symptoms, such as inflammation of lung tissue cells [4], leading to decreased lung function, as well as increased morbidity and mortality rates [5]. In 2016, ambient air pollution accounted for 43% of COPD deaths [6].

It is therefore crucial for those with COPD to be constantly aware of the air quality around them, especially as climate change continues to worsen air quality across Canada, increasing the commonness of wildfires, emitting more pollutants into the air than ever before [7]. If individuals with COPD could easily access the quality of air around them, they would be able to make decisions based on the conditions in order to best preserve their health, such as staying inside, minimizing their time outside, or wearing a face mask. This greatly increases the amount of control individuals have over their health, potentially working to prolong their lives.

Stakeholders

Shadi Vandvajdi (ECE 198 Graduate Teaching Assistant)

Vandvajdi evaluates all group work in the project. She is interested in project progress and adequate time management and organization. Since Vandvajdi will be observing the group's progress in developing the project, it is in her best interest for the group to be on track and possibly ahead of key due dates in order to deliver a project on time to be graded. She is interested in a fully developed, rather than a half-finished, project by the end of this course.

Part Suppliers

Part suppliers include all corporations and organizations who supply the components that will be used in the project. This includes STMicroelectronics NV, who supplied the STM32 Nucleo-64 development board, as well as the corporations who will supply the gas concentration sensors. Part suppliers are interested in the success and notoriety of the project, as this will reflect well upon the suppliers who provided the products used, which could possibly increase their publicity and profits.

Public Health Agency of Canada

The Public Health Agency of Canada (PHAC) is responsible for public health in Canada [8]. In regards to this project, one of the agency's responsibilities is preventing disease, such as COPD. Thus, PHAC is interested in the efficacy of this project in reducing COPD-related incidents. If successful, the reduction in incidents reflects positively for Health Canada's reports.

Health Canada

Health Canada is responsible for maintaining and helping to improve the health of Canadians [9]. It is the parent department of PHAC. Together with Environment and Climate Change Canada, both departments jointly define the Air Quality Health Index (AQHI) used in Canada. Thus, Health Canada is interested in the project's implementation of the measurement and computation procedures for calculating the AQHI.

Environment and Climate Change Canada

Environment and Climate Change Canada (ECCC) is responsible for conserving Canada's natural heritage and ensuring a sustainable environment for Canadians [10]. ECCC and Health Canada jointly define the AQHI used in Canada. Similar to Health Canada, ECCC is interested in the project's compliance to procedures specified when collecting data for calculations, as well as the implementation of the AQHI formula itself.

The Public

The public concerns the wider community of people outside the project authors. This includes fellow classmates. The public will be able to view the project after it is finished and possibly during the process of developing the project. The public is interested in the project's ability to deliver on its functionalities, especially those outside of Waterloo with COPD. If proven to work properly, the public would be able to benefit from the features provided by the project if used.

Initial Requirements

Functional Requirements

The following requirements define the operations of the system that the client will expect and the specifications they want to be aware of:

Air Quality Detection

The gas sensors of the device will detect harmful gases such as carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3), or other pollutants with a concentration ranging from 10–10 000 ppm, as this is the standard for most gas sensors compatible with the STM32F401RE microcontroller being used [11].

Data Display

To indicate health risk levels, the system will employ RGB LEDs emitting wavelengths from 520–633 nm, corresponding to red, orange, yellow, and green, which indicate very high risk to low risk, respectively. These colors were chosen as “our eyes catch the light emitted by red, orange, and yellow the fastest” and “green is associated with calmness” [12].

With an approximate generating time of 5–15 seconds for each gas sensor, the data will be processed and displayed every 50–60 seconds as “It is always wise to obtain multiple measurements over the widest range possible” [13], ensuring data is more consistent (Sample Mean Principle).

Alerts

Upon the gases reaching a concentration of over 8501 ppm, a hazardous level, the system will trigger an audible sound of 65–70dB to alert the client. This range is chosen as most individuals are able to hear it, and it remains within a comfortable sound limit [14].

Technical Requirements

The following requirements specify the technical operations within the system that the engineers are concerned with, so that the product may function as intended:

Air Quality Detection

The system will display air quality levels according to health risk. To determine at which level the air quality is at, gas concentrations will be calculated. Depending on the gas, the range may vary but the base scale will be,

- Low risk: 10–3500 ppm
- Moderate risk: 3501–6500 ppm
- High risk: 6501–8 500 ppm
- Very high risk: 8501+ ppm

These ranges were chosen according to the minimum and maximum concentration each sensor can detect and their association with low density and high density gas inputs [11].

Power Supply

The sensor system will operate with a supply voltage between 3.3V–5V DC in order to account for both the amount of volts the microcontrollers need to operate, as well as the sensors, without burning out the RGB LEDs [15].

Resistors

The RGB LEDs must remain on and continuously display light without burning out, thus, 20–100 ohm resistors will be placed along the system to account for each diode’s max input [16]. This will help “control the amount of current flowing through the circuit”, protecting the sensitive components from damage and allowing for optimal visual communication [17].

Safety Requirements

The following requirements ensure that the engineers and client remain safe during the construction and implementation phases:

Thermal Safety

The system will operate within the specified temperature range of the gas sensors and the STM32F401RE microcontroller to remain within safe temperature limits, avoiding overheating that could result in component failure or fire risks [18].

Electrical Safety

The system will include current-limiting resistors for the RGB LEDs and sensors to avoid excessive current draw and potential damage to both the engineer and component [19].

Environment Safety

The gas sensors will be calibrated according to the manufacturer's specifications to avoid inaccurate readings and ensure reliable air quality measurements.

Principles

Mathematical Principles

Ensuring Measurements are an Unbiased Estimator: Sample Mean

By taking the sample mean of the concentrations of gases over a certain interval of time, an unbiased estimator of the actual concentration of the gas is produced, which allows calculations of the AQHI to be made with greater accuracy. This is opposed to a single measurement of a concentration, which has higher variation.

Equation of the sample mean: $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$

Scientific Principles

Finding an Appropriate Resistance: Ohm's Law

In order to ensure that the LEDs in the design are bright enough without overcurrent, an appropriate resistor has to be used to resist current flow. Depending on the current rating of the LED, as well as the voltage from the power supply, Ohm's Law must be used in order to determine the resistance of the resistors used.

Ohm's Law: $V = IR$

Placing Resistors: Resistors in Series or in Parallel

In order to reflect the calculated resistance for an LED, one must use the equations for resistors in series or parallel to arrange the resistors correctly.

Resistance in Series: $R = \sum_{i=1}^{n} R_i$

Resistance in Parallel: $\frac{1}{R} = \sum_{i=1}^{n} \frac{1}{R_i}$

Maximizing Audio: Wave Superposition and Constructive Interference

When using two speakers in order to produce sound, such as in this project, one must consider wave superposition in order to maximize audio projection. The speakers must be spaced in such a way in order for the sound waves to overlap without phase shift. This would result in the summation of the sound waves, known as superposition or constructive interference, yielding more volume, increasing the efficiency of the speakers.

Constructive Interference: $m\lambda = dsin\theta$

Engineering Standards

Calculating the Air Quality Health Index: Floating Point Arithmetic

The Air Quality Health Index used by Canada is computed using the following equation [20]:

$$AQHI = \frac{10}{10.4} \times 100 \times [(e^{0.000537 \times O_3} - 1) + (e^{0.000871 \times NO_2} - 1) + (e^{0.000537 \times PM_{2.5}} - 1)]$$

Within a program, floating point arithmetic must be applied in order to compute this value. Computers today use the technical standard, IEEE 754 [21] to represent floating point numbers, which will be used to calculate the index, as the formula involves the use of real numbers, represented as floating point numbers in code, to compute the AQHI.

References

[1] Statistics Canada, “Waterloo Wellington (Health Region),” Dec. 12, 2013. https://www12.statcan.gc.ca/health-sante/82-228/details/page.cfm?Lang=E&Tab=1&Geo1=HR&Code1=3503&Geo2=PR&Code2=35&Data=Rate&SearchText=Waterloo%20Wellington&SearchType=Contains&SearchPR=01&B1=All&Custom=&B2=All&B3=All

[2] Global Initiative for Chronic Obstructive Pulmonary Disease, “GLOBAL STRATEGY FOR PREVENTION, DIAGNOSIS AND MANAGEMENT OF COPD: 2024 Report,” Global Initiative for Chronic Obstructive Pulmonary Disease, 2024. [Online]. Available: https://goldcopd.org/wp-content/uploads/2024/02/GOLD-2024_v1.2-11Jan24_WMV.pdf

[3] Canadian Institute for Health Information, “Inpatient Hospitalization, Surgery, Newborn, Alternate Level of Care and Childbirth Statistics, 2017–2018,” Apr. 2019. [Online]. Available: https://www.cihi.ca/sites/default/files/document/dad-hmdb-childbirth-quick-stats-2017-2018-snapshot-en-web.pdf

[4] R. R. Duan, K. Hao, and T. Yang, “Air pollution and chronic obstructive pulmonary disease,” *Chronic Diseases and Translational Medicine*, doi: 10.1016/j.cdtm.2020.05.004.

[5] D. D. Sin *et al.*, “Air pollution and COPD: GOLD 2023 committee report,” *European Respiratory Journal*, vol. 61, no. 5, p. 2202469, Mar. 2023, doi: 10.1183/13993003.02469-2022.

[6] World Health Organization, “Healthy environments for healthier populations: Why do they matter, and what can we do?,” Sep. 13, 2019. https://www.who.int/publications/i/item/WHO-CED-PHE-DO-19.01

[7] Environment and Climate Change Canada, “Air quality and weather,” Aug. 21, 2024. https://www.canada.ca/en/environment-climate-change/services/air-quality-health-index/weather.html

[8] Public Health Agency of Canada, “Public Health Agency of Canada,” *Canada.ca*, Sep. 12, 2024. https://www.canada.ca/en/public-health.html

[9] Health Canada, “Health Canada,” *Canada.ca*, Sep. 12, 2024. https://www.canada.ca/en/health-canada.html

[10] Environment and Climate Change Canada, “Environment and Climate Change Canada,” *Canada.ca*, Sep. 18, 2024. https://www.canada.ca/en/environment-climate-change.html

[11] “Gas Detection and PPM Measurement using PIC Microcontroller and MQ Gas Sensors,” *circuitdigest.com*.https://circuitdigest.com/microcontroller-projects/gas-detection-and-ppm-measurement-using-pic-microcontroller-and-mq-gas-sensor

[12] Dopely Colors. “The Most Visible Colors For Human Eyes! | Inside Colors,” Apr. 07, 2021. https://colors.dopely.top/inside-colors/the-most-visible-colors-for-human-eyes/

[13] The University of North Carolina, “Measurements and error analysis,” *Webassign.net*, 2011.https://www.webassign.net/question_assets/unccolphysmechl1/measurements/manual.html

[14] A. Savchuk, “How Many Decibels Can A Human Hear | What Is The Lowest Decibels A Human Can Hear,” *Decibel Meter App | Best Digital Sound Level Meter For Your Smartphone*, Oct. 12, 2021. https://decibelpro.app/blog/how-many-decibels-can-a-human-hear (accessed Sep. 18, 2024).

[15] "Basics of power supply design for MCU - stm32mcu." Available: https://wiki.st.com/stm32mcu/wiki/Basics_of_power_supply_design_for_MCU#Voltage

[16] Series *led Resistor Calculator - engineering calculators & tools. All About Circuits*. Available at: https://www.allaboutcircuits.com/tools/led-resistor-calculator/ (Accessed: 26 September 2024).

[17] Libretexts (2024) *17.2: Controlling current in Electric Circuits*, *K12 LibreTexts*. Available at: https://k12.libretexts.org/Bookshelves/Science_and_Technology/Physics/17:_Electric_Circuits/17.02:_Controlling_Current_in_Electric_Circuits (Accessed: 26 September 2024).

[18] "Electrical Safety and Protection." Available: https://www.ltrc.lsu.edu/pdf/STT205-ElectricalSafety.pdf

[19] Sreyas Dasika, "UL/CSA/IEC 61010-1: A Comprehensive Guide to Compliance Requirements for Laboratory Equipment - Megalab Group Inc.," *Megalab Group Inc.*, Jun. 14, 2023. https://megalabinc.com/safety/ul-csa-iec-61010-1-a-comprehensive-guide-to-compliance-requirements-for-laboratory-equipment (accessed Sep. 18, 2024).

[20] D. M. Stieb, R. T. Burnett, M. Smith-Doiron, O. Brion, H. H. Shin, and V. Economou, "A new multipollutant, No-Threshold air quality health index based on Short-Term associations observed in daily Time-Series analyses," *Journal of the Air & Waste Management Association*, vol. 58, no. 3, pp. 435–450, Mar. 2008, doi: 10.3155/1047-3289.58.3.435.

[21] *IEEE Standard for Floating-Point Arithmetic*, IEEE Standard 754, Institute of Electrical and Electronics Engineers, 2019.