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Smart Spirometer: A Project-Based Learning Experience

Prof. Bala Maheswaran COE Distinguished Professor, Northeastern University

Bala Maheswaran, PhD COE Distinguished Professor Northeastern University 367 Snell Engineering Center Boston, MA 02115

Lindsey Evelyn Adamchik, Northeastern University
Kyle Murrah, Northeastern University
Sabina Perry, Northeastern University
Miss Kiersten Alexandra Tomas, Northeastern University
Dr. Haridas Kumarakuru, Northeastern University

Haridas Kumarakuru, PhD, MInstP Department of Physics, College of Science, Northeastern University, 360 Huntington Ave, Boston, MA 02115 E.Mail: h.kumarakuru@northeastern.edu

Hari has 18+ years of educational leadership experience amplifying academic and scientific endeavours in the higher education setting that has brought him to four separate continents. He capitalizes on his in-depth competencies in curriculum implementation, instructional delivery, scientific research, technical writing, and student mentoring to provide students with the tools for academic and professional success. Since 2007, he has had the privilege of mentoring numerous undergraduate and master's students, a pursuit he is most passionate about. He has applied his established teaching skills to a wide range of undergraduate courses in general physics, engineering physics, electronics for scientists, advanced physics labs and specialized courses in the fields of functional nano material science and nanotechnology. Hari is a member of IOP (UK), JSA, AAPT and ASEE and he is a reviewer for several scientific journals.

Smart Spirometer: A Project-Based Learning (PBL) Experience

Bala Maheswaran[1], Lindsey Adamchik[1], Kyle Murrah[1], Sabina Perry[1], Kiersten Tomas[1], and
Haridas Kumarakuru[2]

College of Engineering[1]
Department of Physics[2]
Northeastern University

Abstract

In the realm of Project-Based Learning (PBL), our focus was on developing a Smart Spirometer a transformative approach to modernizing the conventional volumetric spirometer. This project not only enriched our understanding of fundamental concepts but also served as a platform for refining problem-solving abilities within the engineering design process. Throughout this journey, we honed practical skills in fabrication, design, analysis, and technical writing. From computer-aided design (CAD) and programming to research and collaborative teamwork, our endeavor encompassed a wide range of valuable experiences. Importantly, the implications of our Smart Spirometer extend beyond the confines of our educational journey, offering potential applications within the broader field of engineering education. Our primary objective was to address the limitations of the dated volumetric spirometer, commonly used by individuals with chronic lung ailments. The conventional spirometer, reliant on physical airflow to elevate a ball within a cylinder, introduces potential errors and lacks the capability for independent patient testing.

To overcome these challenges, we propose the Smart Spirometer, utilizing a hot wire anemometer to measure breath. Data from the spirometer is seamlessly transmitted to a mobile device through a Bluetooth connection, facilitated by an affiliated app. This innovative approach significantly reduces the device's size, enabling users with limited mobility to conduct tests independently. Moreover, digital measurement eliminates subjective readings, providing a more accurate assessment of breath output. Our user-friendly app integrates the collected data, patient demographic information, and progress over time, offering personalized breath therapy exercises. In summary, our Smart Spirometer not only overcomes aesthetic and functional limitations of traditional spirometers but also provides users with a more personalized and efficient assessment of their lung health. This transformative solution holds promise for revolutionizing both engineering education and healthcare practices.

Introduction

Project-based learning fosters the development of skills crucial for success in today's world, including critical thinking, problem-solving, collaboration, communication, and creativity. Students learn to work together, think on their feet, and come up with innovative solutions. PBL projects are often centered around real-world problems or scenarios, making learning more relevant and engaging for students. They can see how the concepts they're learning in school apply to the world outside the classroom. PBL can be far more motivating for students than traditional lecture-based learning. They are more likely to be interested and invested in a project they choose or have some control over, leading to better learning outcomes. PBL goes beyond memorization.

By working on a project, students actively engage with the material and develop a deeper understanding of the concepts involved. PBL encourages students to take ownership of their learning; they are responsible for planning, researching, and completing their projects. This can help them develop important self-directed learning skills.

A spirometer serves as a vital medical tool for measuring lung function, essential in the diagnosis and monitoring of conditions like chronic obstructive pulmonary disease (COPD) and asthma. However, conventional volumetric spirometers face a limitation—they lack a systematic approach to tracking and controlling progress in lung strength. This is particularly crucial as patients with varied conditions require different levels of exercise and monitoring.

In response to this challenge, our focus is on developing a cost-effective and user-friendly digital spirometer. Paired with a mobile application via Bluetooth, our solution not only records information from each breathing test but also guides users through personalized exercises aimed at enhancing lung health.

The spirometer project is innovative due to its forward-thinking application of technology to enhance medical devices, specifically targeting the improvement of lung health assessments. It bridges theoretical knowledge, such as physics concepts, with practical healthcare needs, fostering interdisciplinary learning by combining engineering design with medical insights. It emphasizes the integration of technical skills in design, programming, and analysis with practical applications in healthcare.

The primary beneficiaries of our innovation are asthmatic and chronically ill patients who can now seamlessly integrate breathing exercises into their daily routines. By incorporating proven techniques from medical practices, our application provides step-by-step guidance on breath patterns, overcoming both accessibility and motivation barriers. This approach ensures that users receive live feedback through a Bluetooth connection, significantly improving user motivation.

Our device measures key spirometer metrics—forced vital capacity (FVC), forced expiratory volume (FEV1), and peak expiratory flow (PEF). These metrics are essential for medical professionals to diagnose and manage respiratory conditions. Internally, our system features a sensitive sensor connected to a timer, gauging breath strength by detecting pressure and wind flow. As we fine-tune our internal systems based on material availability and time constraints, our smart spirometer aims to revolutionize respiratory care, offering patients a proactive tool for symptom management and lung strength improvement. The addition of guided exercises overcomes both accessibility and motivation barriers, providing a comprehensive solution for individuals seeking to proactively manage their respiratory health.

Methods and Approach

Our envisioned spirometer incorporates several key features that distinguish it from other models on the market. Firstly, it seamlessly connects to common mobile devices via Bluetooth, displaying collected data within the affiliated app. With a handheld, compact, and affordable design, our spirometer is accessible to the general population, aiming to reduce costs compared to existing digital spirometers priced between 110 to 1,100 USD. Our goal is to make this device usable by anyone in their own home or on the go, thereby increasing accessibility.

The design of our Smart Spirometer revolves around three main goals. Firstly, it aims to accurately measure the user's breath output. Unlike traditional volumetric spirometers that rely on estimated measurements, our device ensures precision. Secondly, our spirometer efficiently stores user demographic data, crucial for understanding lung measurements affected by factors such as age, ethnicity, and gender. Users can track their progress over time based on this data. Lastly, our mobile application guides users through effective breath therapy exercises tailored to their medical needs and demographics.

In determining the exact design, we prioritized low costs, accessibility, and user ease. The device is lightweight and handheld with a comfortable silicone-like material, ensuring comfort and a non-slip grip, making it suitable for elderly patients and those with joint mobility problems.

For users with visual impairments and to maintain a low-cost design, our device foregoes a screen in favor of two buttons and three LED bulbs. These buttons power the device on and off and facilitate Bluetooth pairing with a mobile device. The absence of a screen reduces production costs and encourages users to utilize their personal mobile devices for viewing data and exercises.

To enhance reading accuracy, our device features a mouthpiece similar to that of an inhaler chamber. This design allows users to fully close their mouth around the piece, facilitating complete inhalation and exhalation into the device. The cylindrical shape, with a diameter of approximately an inch, proves more effective than the end of a typical inhaler, which is rectangular and approximately half the size.

Prototype

In the evaluation of various design approaches, thorough analysis is essential before selecting the most suitable option to proceed with. For the Smart Spirometer, we explored four concepts, each differing in shape and primary method of function. While each concept presents a potential solution, the key lies in identifying the design that best aligns with the needs of our users. To achieve this, we established critical criteria for evaluation, focusing on the device’s cost, ease of operation, function, and aesthetic.

Design A emerged as the preferred choice due to its simplistic, screenless design, offering a cost-effective and user-friendly solution. With our product relying on a mobile app connected via Bluetooth, Design A allows users to easily access the spirometer's functions. Its small and sleek design further contributes to its aesthetic appeal.

The final design is a compact device that fits comfortably in the user’s hand, crafted from high durability plastic. Featuring a mouthpiece for exhaling into the device, the user's breath is channeled into the inner mechanisms for measurements. Two buttons beneath the mouthpiece control power and Bluetooth pairing, facilitating seamless connectivity to the app for data storage and display. Additionally, the device includes a USB charging port and three LEDs on the left side. When powered on, the LEDs illuminate to indicate battery life, providing a visual cue in addition to viewing the battery life accessible through the mobile app. The design of this compact spirometer device integrates various physics principles, including material science, fluid dynamics, electronics, optics, and wireless communication, to create a functional and user-friendly product.

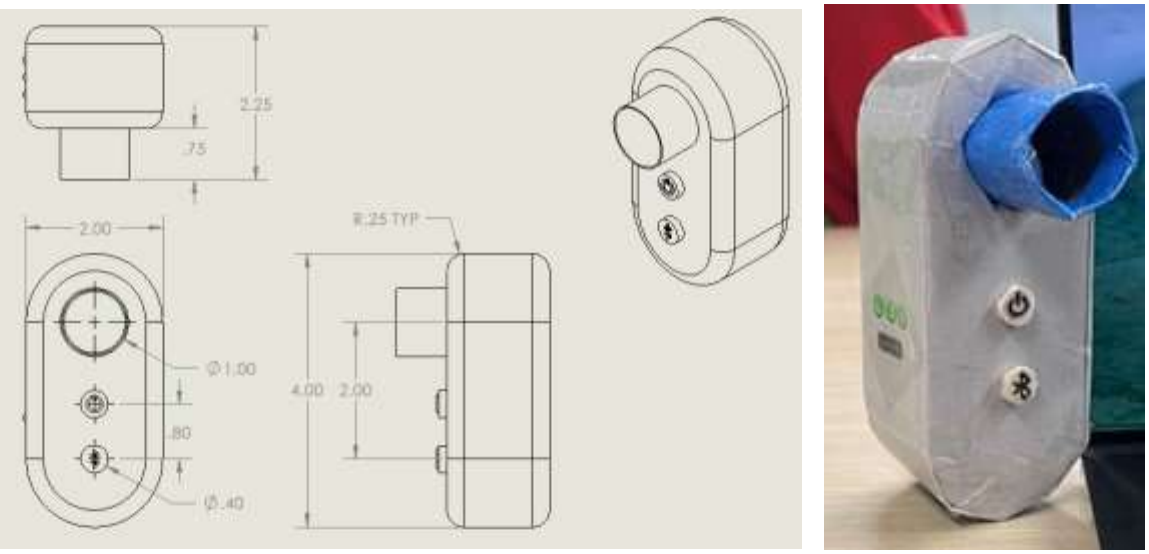


Figure 1: F*inal design AutoCAD sketch and paper prototype*

Graphical Model

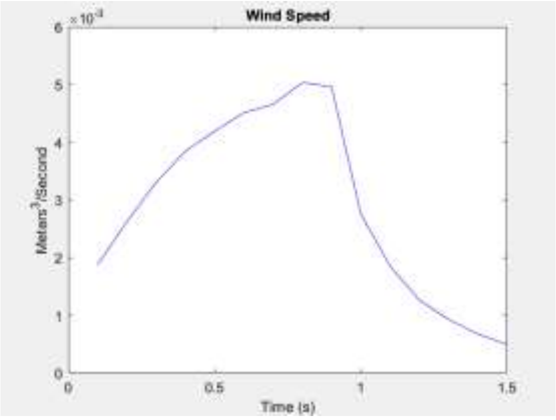


Figure 2: *Graphical model*

Design Details

For our final design, we have incorporated a Hot Wire Anemometer Sensor to measure the speed and direction of air passing through the device. The sensor accomplishes this by assessing the energy/heat loss of an electronically heated wire positioned in the air stream within the device. This principle operates based on the 'Hot Wire Anemometer Principle', wherein air blown onto the wire absorbs heat from it, resulting in the cooling of the wire. The subsequent temperature change in the wire alters its resistance, allowing us to calculate the speed of the air flow.

To utilize the air speed in our spirometer, we need to determine the air volume. This involves multiplying the air velocity by the area of the mouth chamber/tube, where air is directed. This calculation provides the volume of air passing a point per unit of time, in our case, seconds. This data enables our spirometer to measure both the volume of air exhaled in one breath and the volume of air exhaled in one second—both crucial components of a spirometer.

The incorporation of a hot wire anemometer sensor proves to be a cost-effective and accessible method for measuring breath in our spirometer. Leveraging a concept already widely used in HVAC, exhaust, and furnace systems streamlines the development process on a small scale, as we are not creating an internal system from scratch. Additionally, the simplicity of this device makes it relatively straightforward to implement on a smaller scale and connect to a computer/device capable of storing and processing data. A small computer chip attached to the wire system should suffice, connecting to mobile devices through Bluetooth to transmit data and calculations to the app.

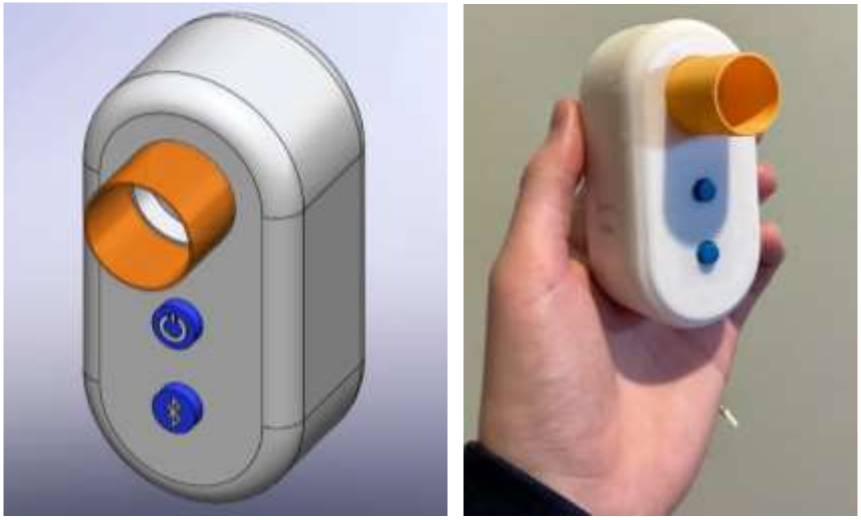
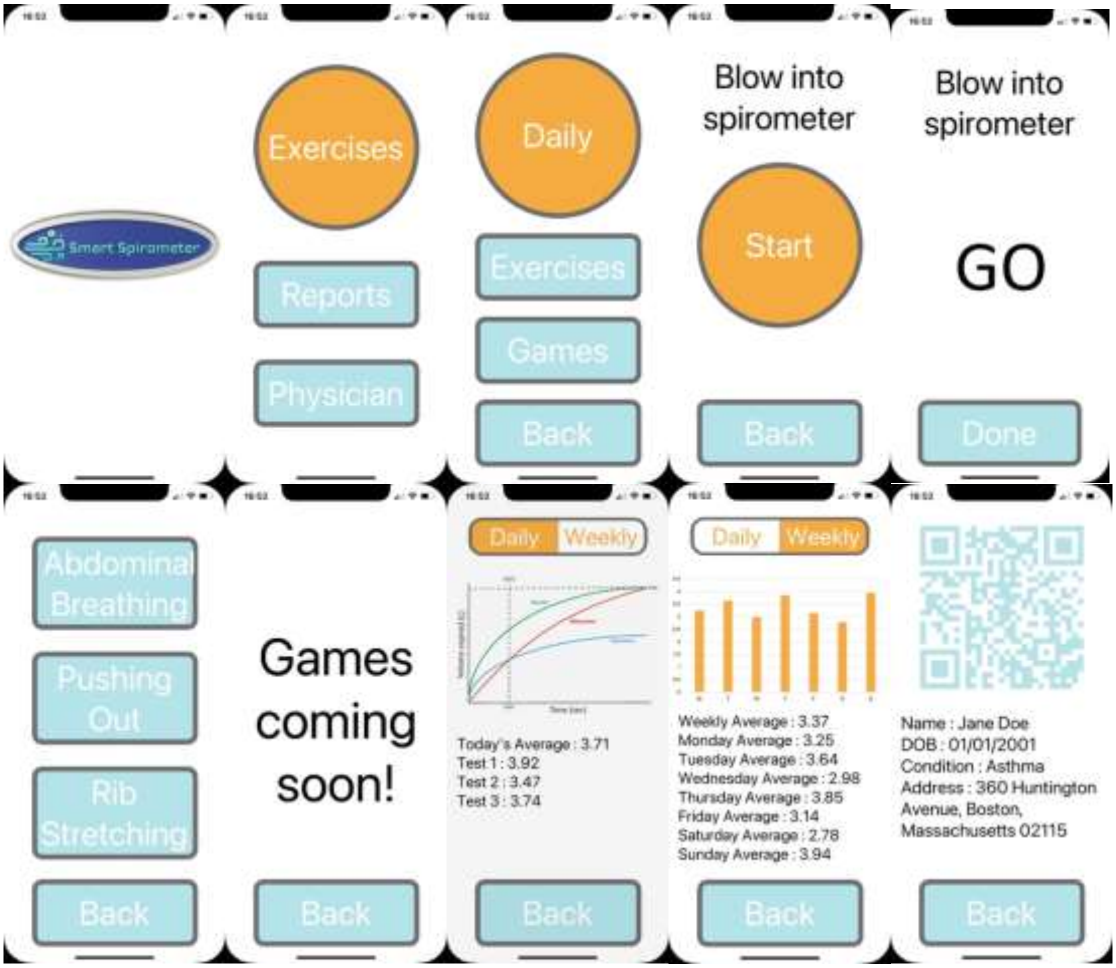


Figure 3: *Final design SolidWorks model and prototype:*

The integration of a Hot Wire Anemometer Sensor into the design of our spirometer presents significant educational value in various aspects. Practical application of physics principles, such as understanding the 'Hot Wire Anemometer Principle', allows students to grasp concepts related to heat transfer, resistance, and how they are utilized to measure air velocity. This hands-on experience helps solidify theoretical knowledge into practical application. Furthermore, this design bridges concepts from physics, engineering, and biology. Students can appreciate how different disciplines intersect to solve real-world problems, fostering a holistic understanding of science and technology. Designing and incorporating a sensor into a complex device like a spirometer requires critical thinking and problem-solving skills. We learn to troubleshoot challenges related to sensor calibration, data interpretation, and integration into the overall system. By building a functional spirometer prototype, we engage in hands-on experimentation and learn the iterative process of design, testing, and refinement, fostering creativity and innovation in problem-solving.



Today's Average : 3.71
Test 1 : 3.92
Test 2 : 3.47
Test 3 : 3.74

Weekly Average : 3.37
Monday Average : 3.25
Tuesday Average : 3.64
Wednesday Average : 2.98
Thursday Average : 3.85
Friday Average : 3.14
Saturday Average : 2.78
Sunday Average : 3.94

Name : Jane Doe
DOB : 01/01/2001
Condition : Asthma
Address : 360 Huntington Avenue, Boston, Massachusetts 02115

Figure 4: Final app design:

Results and Discussion

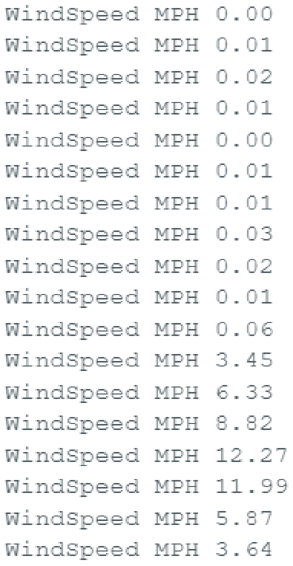
We are using a hot wire anemometer to measure the wind speed entering the spirometer mouthpiece. This data is initially a voltage value (in volts) and we are converting it to a velocity (in meters per second) for our calculations. We ordered a hot wire anemometer from Modern Device, a sensor production company, and soldered wires to the component to allow compatibility with the Sparkfun "RedBoard" Arduino microcontroller being used for the electronic implementations of the device. The hot wire anemometer measures the change in resistance from a change in temperature due to wind flow. This change in resistance can be used for our calculations.

Initial Results:

With the air velocity, we will calculate FVC (forced vital capacity – the total amount air exhaled in one breath) and FEV1 (forced expiratory volume – the total amount of air exhaled in one second) which are the two indicators of breathing/lung issues. To do this, we will code the calculations described below:

Starting with raw data values in volts:

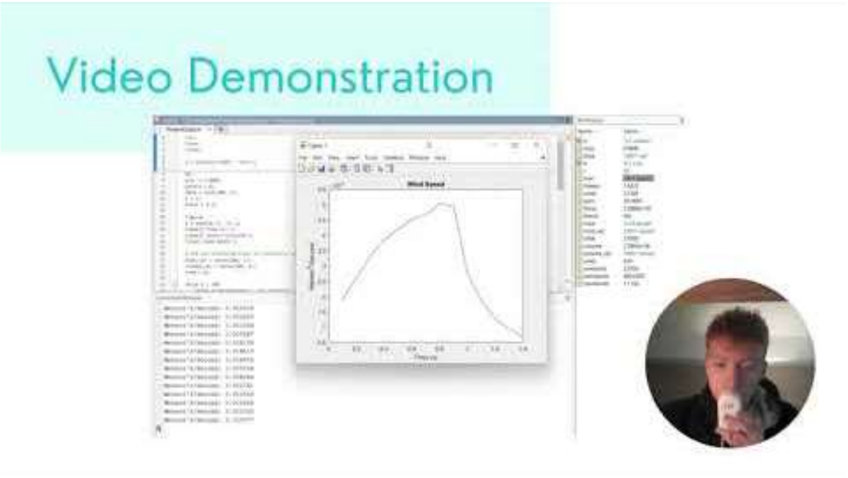
1. Convert to meters/second. This process is described with the sensor's specifications.
2. Multiply wind velocity (m/s) x area of tube that air is flowing through (m^2) = volume of air flowing past a point per second (m^3/s).
3. For volume of air exhaled in one breath: total volume from beginning of change in wind flow to end (m^3) calculated with an integral.
4. For volume of air exhaled in one second: total volume of air exhaled in one breath (m^3)/ /total time (s) calculated with an integral.



```
WindSpeed MPH 0.00
WindSpeed MPH 0.01
WindSpeed MPH 0.02
WindSpeed MPH 0.01
WindSpeed MPH 0.00
WindSpeed MPH 0.01
WindSpeed MPH 0.01
WindSpeed MPH 0.03
WindSpeed MPH 0.02
WindSpeed MPH 0.01
WindSpeed MPH 0.06
WindSpeed MPH 3.45
WindSpeed MPH 6.33
WindSpeed MPH 8.82
WindSpeed MPH 12.27
WindSpeed MPH 11.99
WindSpeed MPH 5.87
WindSpeed MPH 3.64
```

Figure 5: Initial test of data calculations

Demonstration Test:



Final Test Results:

```
Meters^3/Second: 0.005034
Meters^3/Second: 0.004964
Meters^3/Second: 0.002761
Meters^3/Second: 0.001856
Meters^3/Second: 0.001268
Meters^3/Second: 0.000930
Meters^3/Second: 0.000677
Meters^3/Second: 0.000497

Volume Exhaled: 4.325662 Liters
FVC Percent: 78.648393
```

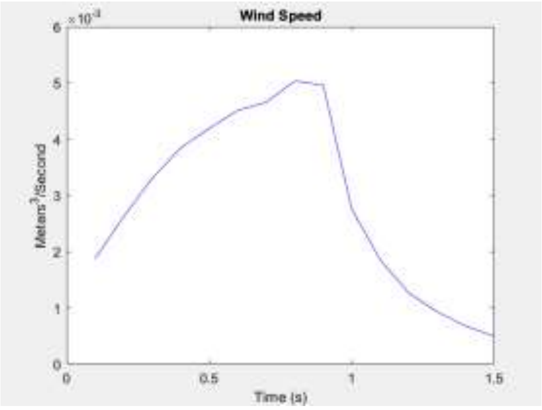


Figure 6: Final test run data output.

Conclusion

In summary, we are pleased with the current functionality and design achieved in our Smart Spirometer. However, we acknowledge that the full potential of the app's capabilities has not been realized yet. Our next steps involve dedicating substantial effort to coding and developing the app further. Our goals include incorporating features such as demographic data storage, progress tracking, and breath therapy capabilities. We also plan to enhance the user interface, introducing game functionality to make the app more engaging. Additionally, refining the code for a more accurate conversion of wind speed in mph to Forced Vital Capacity (FVC) and Forced Expiratory Volume (FEV1) is a priority. This adjustment is crucial for ensuring that the data collected by the device is not only usable but also interpretable in a medical context. While our current device can measure up to 60 mph, recognizing that breath can reach speeds of up to 80 mph prompts us to enhance our capabilities.

Furthermore, we recognize the need for improvements in data collection features to minimize errors. Despite these challenges, we view our device as being in its early stages, steadily progressing in the right direction to become an innovative and valuable addition to the biomedical device sphere. Moving forward, our focus remains on continuous refinement and expansion of both hardware and software components to realize the full potential of our Smart Spirometer. We are committed to overcoming current limitations, ensuring accurate data collection, and delivering a device that positively contributes to respiratory health monitoring and management.

The development of the smart spirometer represents a significant educational shift towards hands-on, project-based learning. This approach enriches students' educational experiences by providing them with practical, real-world challenges to solve. Overall, project-based learning can be a powerful tool for promoting deeper learning, developing essential skills, and making education more engaging and relevant for students. The paper predominantly emphasizes developing and applying the smart spirometer project, highlighting its interdisciplinary nature, including physics concepts and the engineering design process, and its potential impact on healthcare and engineering education.

This work holds considerable value for fellow educators, serving as a noteworthy addition to the realms of engineering education and healthcare practices. Through the lens of project-based learning, it showcases innovation, adept problem-solving, utilization of physics concepts, and the potential for tangible real-world impact.

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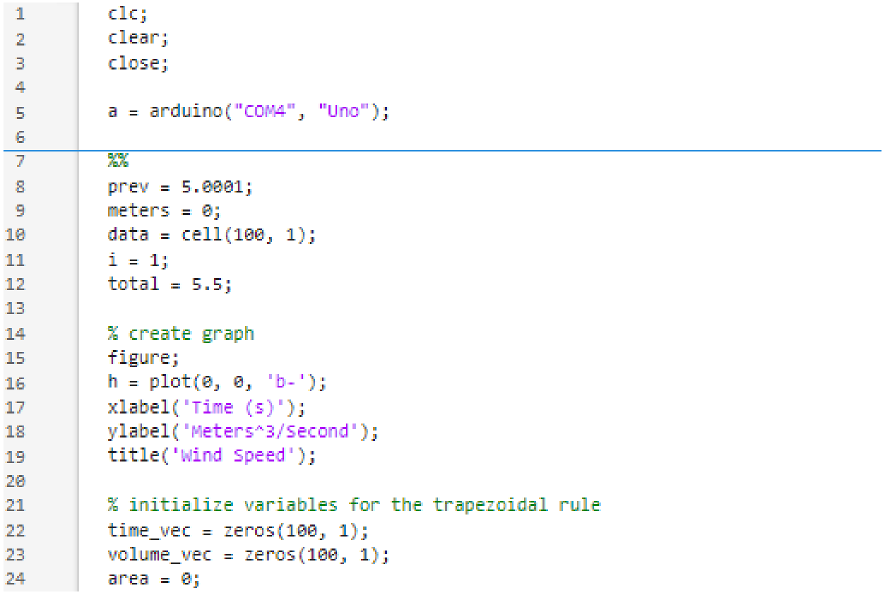
Appendix 1



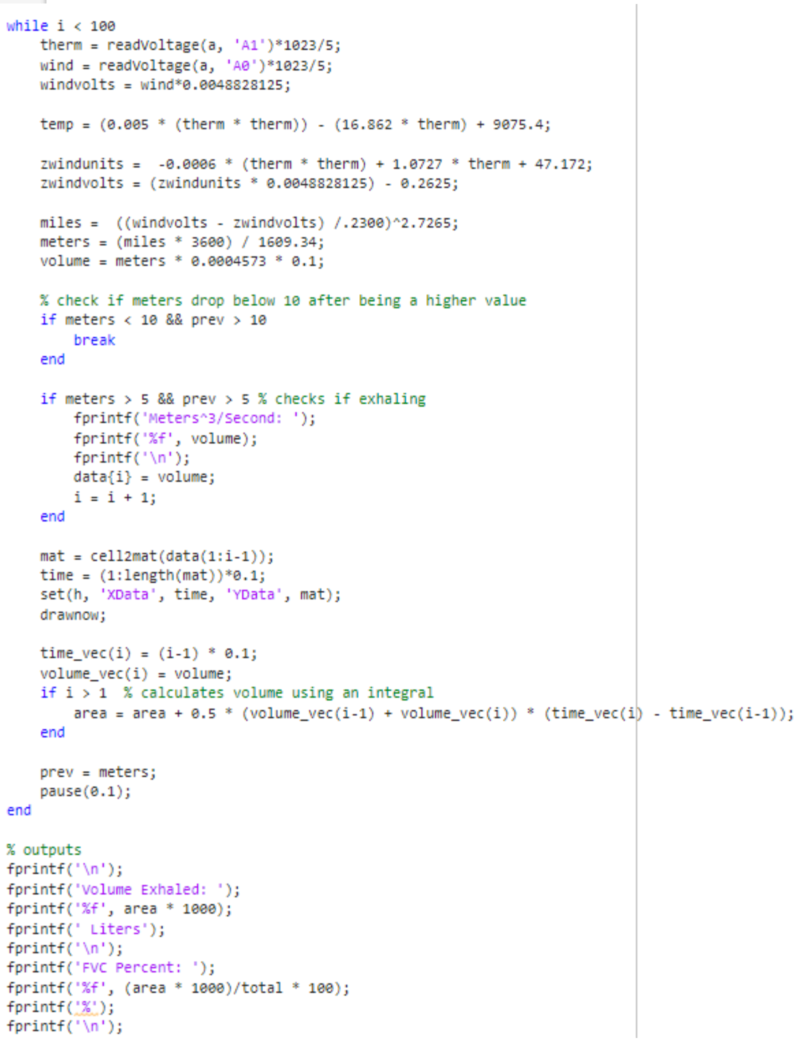
```
clc;
clear;
close;

a = arduino("COM4", "Uno");

%%
prev = 5.0001;
meters = 0;
data = cell(100, 1);
i = 1;
total = 5.5;

% create graph
figure;
h = plot(0, 0, 'b-');
xlabel('Time (s)');
ylabel('Meters^3/Second');
title('Wind Speed');

% initialize variables for the trapezoidal rule
time_vec = zeros(100, 1);
volume_vec = zeros(100, 1);
area = 0;
```



```
while i < 100
    therm = readVoltage(a, 'A1')*1023/5;
    wind = readVoltage(a, 'A0')*1023/5;
    windvolts = wind*0.0048828125;

    temp = (0.005 * (therm * therm)) - (16.862 * therm) + 9075.4;

    zwindunits =  -0.0006 * (therm * therm) + 1.0727 * therm + 47.172;
    zwindvolts = (zwindunits * 0.0048828125) - 0.2625;

    miles =  ((windvolts - zwindvolts) /.2300)^2.7265;
    meters = (miles * 3600) / 1609.34;
    volume = meters * 0.0004573 * 0.1;

    % check if meters drop below 10 after being a higher value
    if meters < 10 && prev > 10
        break
    end

    if meters > 5 && prev > 5 % checks if exhaling
        fprintf('Meters^3/Second: ');
        fprintf('%f', volume);
        fprintf('\n');
        data{i} = volume;
        i = i + 1;
    end

    mat = cell2mat(data(1:i-1));
    time = (1:length(mat))*0.1;
    set(h, 'XData', time, 'YData', mat);
    drawnow;

    time_vec(i) = (i-1) * 0.1;
    volume_vec(i) = volume;
    if i > 1  % calculates volume using an integral
        area = area + 0.5 * (volume_vec(i-1) + volume_vec(i)) * (time_vec(i) - time_vec(i-1));
    end

    prev = meters;
    pause(0.1);
end

% outputs
fprintf('\n');
fprintf('Volume Exhaled: ');
fprintf('%f', area * 1000);
fprintf(' Liters');
fprintf('\n');
fprintf('FVC Percent: ');
fprintf('%f', (area * 1000)/total * 100);
fprintf('%');
fprintf('\n');
```