BME 301: Biomedical Engineering Design (Spring 2010)

Project #19: An Indoor Air Quality Monitor

Mid-Semester Report

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Problem Statement

Poor indoor air quality is a major issue worldwide and results in millions of deaths each year. Currently, there is no simplistic and inexpensive device which monitors air quality. Our goal is to design a device that will monitor particulate matter levels in the surrounding air, display these levels in a clear manner, log the data which it collects, and provide a means of downloading this data for further research.

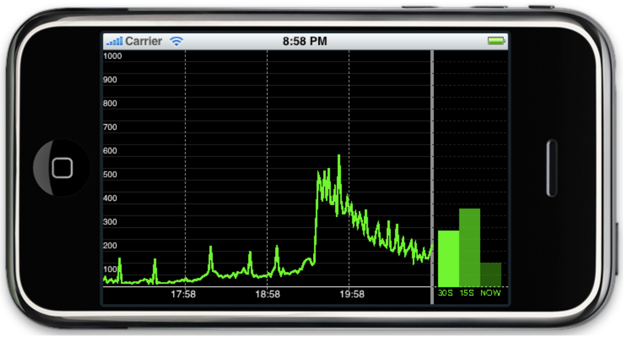
Background Information

A typical person spends 90% of the day indoors eating, sleeping, working, cooking, and spending time with family [1]. However, poor indoor air quality can contribute to the development of chronic respiratory diseases such as asthma, heart disease, and lung cancer [1]. The U.S. Environmental Protection Agency (EPA) designates a standardized air quality level known as the Air Quality Index (AQI). This is a function of mainly the following pollutants: carbon monoxide, nitrogen dioxide, particulate matter, carbon dioxide, and sulfur dioxide [2].

In the last decade, a number of quantitative epidemiological studies have been carried out in low and middle-income developing countries that attribute respiratory diseases to indoor tobacco use and burning of biomass fuels for cooking and heating purposes [3]. Indoor tobacco use results in high concentrations of volatile organic compounds such as benzene and carbon monoxide. Indoor burning of biomass fuels, such as liquefied petroleum gas or kerosene, is a major source of particulate matter. Particulate matter is conventionally termed "coarse" if more than 10 microns in diameter and "fine" if less than 10 microns in diameter [4]. Exposure to fine particles, notably $PM_{2.5}$, poses the greatest respiratory risks because they can penetrate deep into the lung alveoli upon inhalation [1]. The EPA standard is that indoor $PM_{2.5}$ mass concentrations should not exceed an average of 35 $\mu g/m^3$ in a 24-hour period [4]. However, a study of Indian households has detected mass concentrations of more than 1000 $\mu g/m^3$ [3]. Poor air quality due to indoor tobacco use and biomass fuel burning is thought to result in 1.5-2 million deaths per year [3].

www.treehugger.com/20091203-india-cooking.jpg

Developing a reliable method to detect pollutants in the air is important as the initial process of air-quality improvement techniques such as source control, improved ventilation, and air cleaning [2]. Currently, a variety of new commercial products monitor and provide visual feedback on indoor air quality (for examples, please pursue the Ambient EnergyJoule or inAir references); however, they incorporate technology that may not be well-suited for developing countries. The main motivation behind this project is to develop a low-cost indoor air quality monitoring device that can be used as an intervention tool in developing households adhering to indoor tobacco use and biomass fuel burning. It will seek to monitor some indicator of poor air, such as carbon monoxide, $PM_{2.5}$, or a combination of the two, and display the overall air quality in a simple "stoplight" manner so families can easily see current conditions and the improvements due to lifestyle changes seeking to reduce indoor pollution. From a research perspective, the device will also periodically log air quality measurements and provide a means to download the data.



inAir: Measuring and Visualizing Indoor Air Quality, Sunyoung Kim & Eric Paulos

If this project results in a functional prototype, it will be rapidly integrated into two ongoing projects on indoor air quality in India and Rwanda, as well as Project Quit Tobacco, a large US National Institutes of Health-funded tobacco cessation project currently being carried out in India and Indonesia.

Client's Requirements

Our client had a few specific requirements for this device which we used to construct our product design specifications. First, our client indicated that he wanted the product to monitor the indoor air quality specifically related to tobacco smoke and biomass fuel use; biomass fuel use involves burning organic fuel sources such as wood, coal, etc. [5]. Also, our client required our tool to indicate the level of air quality to the user in a simple fashion. This would incorporate a key function of the device: to serve as an in-home educational tool. The user interface needed to be something that could span language and cultural barriers, as the device is intended for use in India and Rwanda. It was based on these concerns that the team set out to design the user interface. Another key function of the device was to serve as a research tool. Thus, the client required that the device have some sort of non-volatile memory to record data. The client required that the data be taken at a frequency of approximately once per minute. Also, this data would need to be easily downloaded to a computer for analysis at a later date. Lastly, the client required that the device should function for at least 1 year without user maintenance. The main problem with this concept is that the areas in which our design is intended to be used (small villages in India and Rwanda) commonly experience power outages. The client therefore specifically required that the device have some means of a "back-up" power source. Besides having a consistent power source for one year, other components of the device should not break down within that time frame. In line with this concept, the device should be able to function at various conditions including wide temperature ranges.

Design Specifications

Based on the client's requirements we were able to compile several specifications for our initial prototype. The first set of specifications pertains to operational features. First, after considerable research and debate, we decided to monitor only particulate levels. Particulates are defined as "tiny subdivisions of solid or liquid matter suspended in a gas or liquid" [6]. This decision was based on the fact that particulates are the most diverse and all-inclusive byproduct of both tobacco smoke and biomass fuel burning [7]. Next, based on our client requirements for the user interface, we decided to use LEDs (light emitting diodes) to indicate the level of indoor air quality. We came up with a design that would make use of three separate LEDs in a manner similar to a stoplight. The different LEDs (green, yellow, red) would light up or turn off at different levels to indicate the relative level of contamination in the air. With respect to data storage, we decided to use a non-volatile flash memory connected to our microcontroller. We will then have a USB port on our device from which this data can be easily downloaded to a computer or other device. In attempting to solve the problem of providing power to our device, we decided to pursue an option based on one already used in other electronic devices: our instrument will utilize mainly a wall outlet (via a plug) power source, but also have a rechargeable battery, which will serve as the "back-up" power source. This design is similar to that used in some carbon monoxide detectors, which plug into the wall, or some clock-radios.

Our next set of design specifications defines physical aspects of our product. We determined that the device should function between 0 and 60 °C. The extreme end limits of this range were determined based on the extreme climates present in India and Rwanda; the thoughts of the client also enforced these limits. Also, the device should not be too small or too large. Thus, we determined that a size of approximately 8cm×10cm×8cm and a mass of approximately 2 kg are appropriate. Also, it was a given that our device would be made up of several different, basic electronic components. Most important among these are the particulate sensor and the programmable Arduino® microcontroller.

Lastly, we accumulated a few miscellaneous specifications pertaining to the prototype. We will only make one device initially. However, if our prototype is shown to work effectively, then several devices will be made and possibly put into use for research being conducted this summer (2010). While we have a larger budget for our initial design ($1,000 USD), it has been determined that the "off-the-shelf" cost of one of these devices should not exceed $100. Lastly, our device must bring something new or novel in its function and operation when compared to other devices, as there are several similar devices on the market. However, we feel that, given our specific design, our device will provide something unique and new compared to what is currently available in particulate detection.

Human Factors and Ergonomics

A primary concern in designing the air quality monitor device is ease of use. The first issue here is ease of interpreting the relative level of air quality from the user interface. As was mentioned earlier, this device is meant to serve as an educational tool in different regions of the world. Thus, it is essential that we insure that our user interface effectively communicates the quality of the air in its vicinity. The other main concern regarding human factors is closely related to the other main function of our device. Our device is meant to serve as a research tool, and thus must collect data that is easily downloadable. Thus, if one of the researchers wants to examine the data collected from a specific device, it should be no more difficult than connecting the device via USB to a computer.

Permanent Features of the Design

Several components of the proposed design were considered "permanent" features; they will be included in the prototype regardless of the manner in which the user output (e.g. LED lights) is displayed. This "permanence" is based on the fact that these proposed features effectively and efficiently work in concert to provide the desired user input-output functions, and they are therefore a logical choice for the purposes of the proposed design. The permanent features include: the sensor, the microcontroller, and the power supply.

The Sensor

http://www.futurlec.com/Gas_Sensors.shtml

The sensor transduces particulate-matter (i.e. smoke) concentration to an analog voltage signal. This is clearly a useful signal, as this can be used in subsequent processing to indicate air quality (as well as for data logging). According to the U.S. Environmental Protection Agency (EPA), which maintains an Air Quality Index (AQI), relatively healthy air quality conditions for 2.5 micron (or less) particulate matter ($PM_{2.5}$) are those which are less than 35.5 µg/m^3;

moderately healthy air quality conditions (i.e. healthy for the general public, but potentially hazardous for certain sensitive groups) are those between 35.5 $\mu g/m^3$ and 65.4 $\mu g/m^3$; and air quality conditions 65.5 $\mu g/m^3$ or above are considered generally unhealthy [8]. The MQ-135 Gas Sensor® shown above detects air from approximately 10 to 126 ppm [9].

The Microcontroller

The microcontroller is used to process the analog voltage input from the sensor in order to produce a meaningful output for the user. The Arduino Duemilanove® is an open-source, versatile device based on the ATMega328 microcontroller which can be used to implement a variety of input-output functions [10]. The Duemilanove® has six analog input pins (each with 10 bits of resolution) and fourteen digital pins which can be configured either as inputs or outputs (5V, 40 mA maximum operation). The Duemilanove® has a USB port which allows for communication with computers (i.e. to upload code to the microcontroller and to log data). Therefore, the Duemilanove® is an excellent solution to bridge the input from the sensor to the LED output (this process will be described in the section titled *Proposed Design*).

http://www.inmotion.pt/store/product_info.php?cPath=10&products_id=56

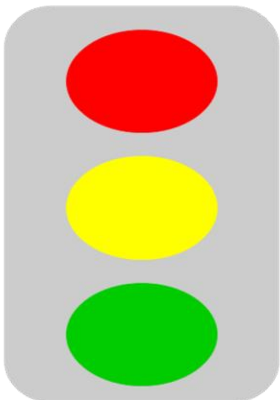
The Power Source

Given that the device (e.g. the Arduino Duemilanove®) requires power to run the peripheral components, a power source must be included accordingly. The Duemilanove® includes a power-supply input socket which can receive inputs from 7 to 12 VDC and includes an on-board voltage regulator to provide 3.3 VDC (50 mA maximum current) or 5 VDC for the analog and digital pins [10]. The Duemilanove can also be powered via the USB input (in addition to the aforementioned programming capabilities via USB). Per the client's instruction, it would also be desirable to provide an alternative rechargeable-battery power supply to run the device when wall power is unavailable. Other design considerations include variations in wall power supplies (i.e. 120 V at 60 Hz versus 230 V at 50 Hz), which will necessitate the selection of a power supply with power transformation capabilities, as well as a switching mechanism from wall power to the rechargeable batteries (this ideally may be automated using the Duemilanove®).

Design Aspect: The User Interface

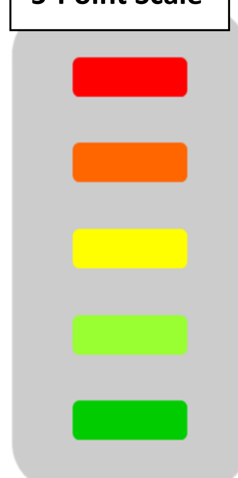
A combination of the client's input and the group members' research resulted in three user interface options titled: stoplight, 5-point scale and 10-point scale. The stoplight, the simplest design of the three, utilizes the common shape visible in most towns. A red light signifies poor air quality, the yellow light signifies air of moderate contamination, and the green light signifies the relative absence of contaminants.

The Stoplight



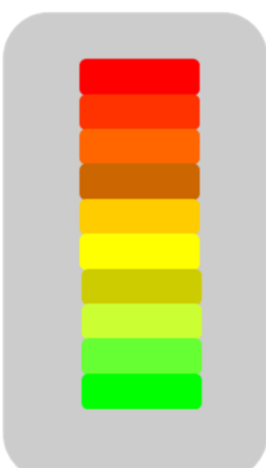
Building on this concept, the 5-point scale merely incorporates two additional intermediates for a higher level of air quality of portrayal. Similarly, the 10-point scale takes this concept to an even higher level, utilizing a 10 light emitting diode (LED) gradient to display the quality of the air. All three models present beneficial aspects and negative aspects, which we investigated using a design matrix.

5-Point Scale



When analyzing each model, the team took into account the complexity, accuracy, and ease of construction of the final device (see the section titled *User Interface Design Matrix*). The "complexity" represents the ease with which the end user may interpret the output of the sensor; the accuracy denotes to what degree the instrument can display the quality of the air; and the ease of construction refers to the distribution of LEDs, the complexity of the code controlling the display, and the formatting of the different color levels on the user interface. The team intended to use the same amount of LEDs for each respective user interface, distributing them evenly among the color levels. With respect to the preceding categories of assessment, the stoplight interface proved the most simple, but the least accurate; it would also be the easiest to construct, requiring the least amount of code and only three levels of LEDs. The 5-point scale seemed to portray a better view of the air quality, but would prove more difficult to construct and have a higher incidence of device failure due to the distribution of the LEDs across 5 color levels. Finally, the 10-point scale seemed to have the most negative characteristics: its overabundance of LEDs in the different color levels would probably lead to a high incidence of device failure (furthermore, this same aspect could also confuse the user). The team would need to further consider how to assign the colors to each level of air contamination so that this model accurately displayed air quality. Like in the 5-point model, by redistributing the same amount of LEDs present in the stoplight model among 10 different colors, if one or two LEDs fail in one bar, it may not light up enough to be visible. If two LEDs fail in the stoplight design, however, the other LEDs present there would be able to compensate.

10-Point Scale

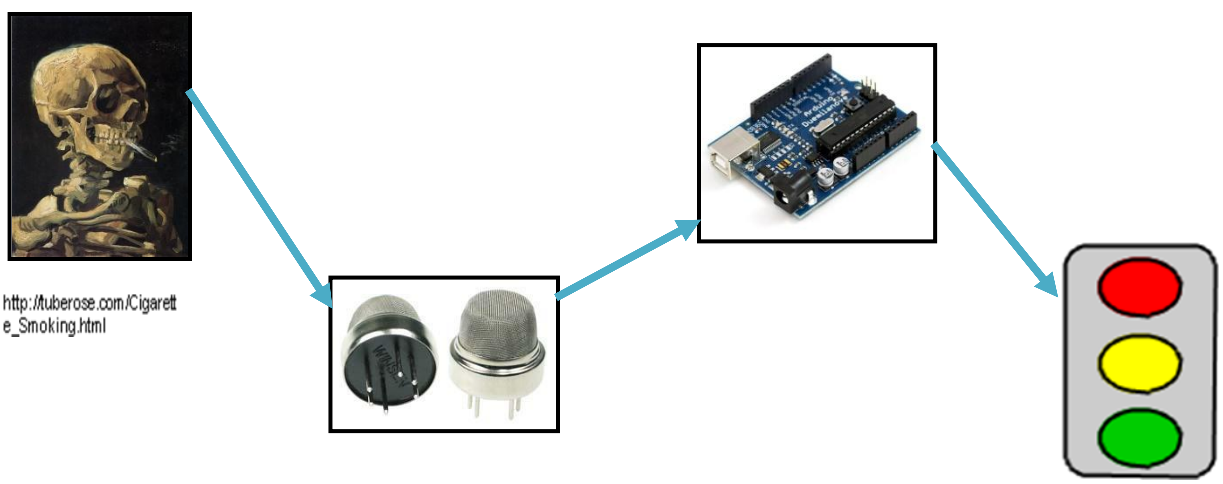


User Interface Design Matrix

Design	Complexity	Accuracy	Ease of Construction	Total
Stoplight	10	4	8	22
5-Point Scale	8	7	6	21
10-Point Scale	2	10	2	14

Proposed Design

The design matrix (above) summarizes the team's considerations. Each category donated 10 points so that the final total was taken out of thirty. With its simple design, low distribution of LEDs, and ease of construction, the stoplight model was chosen to portray the quality of air sensed by the final product. The final design will thus utilize the stoplight LED display to portray the output of a particulate sensor, utilizing an Arduino Duemilanove® microcontroller to integrate the various inputs and outputs. The team still needs to select some of the various circuit components, such as: the power source, the case, resistors, a toggle switch, a breadboard, and 22 gauge wire.



http://tuberose.com/Cigarette_Smoking.html

Future Work

In the future, the team must begin to construct its design. One main problem foreseen involves hooking up the sensor to the microcontroller and causing the LEDS to light up according to the current level of air quality. As the sensor will give a voltage signal proportional to the level of contaminants that it detects, we may need to calibrate the sensor output. Also, we need to determine how we will effectively log the input voltage data (sensor output) that the microcontroller receives from the sensors. We have effectively programmed the microcontroller to light up the LEDs at given voltage thresholds (received from the output of the sensor) (see the *Appendix* section titled *Microcontroller Code*). However, we will have to do some additional programming to instruct the microcontroller to sample and collect data once per minute, then store this data in the attached memory. Another key component of our future design involves incorporating the power source. While we have an idea of how we will do this based on similar set-ups from other electronic devices, we still need to acquire the components for this aspect of our design and incorporate them into the final prototype. Once we have ensured that all the key components are effectively working, we will need to physically assemble all of the parts into a compact project box. Lastly, we have to test our device, using more sensitive and/or accurate particulate sensors to determine if our sensor is lighting up the LEDs at the correct threshold levels.

Ethical Considerations

As mentioned in the *Background* section, the team needed to take into consideration that this project is intended for educational purposes. It needs to accurately describe air quality for individuals teaching pupils that do not speak the same language. This outreach project thus carries some ethical considerations. The team must define air quality through the use of the final product.

References

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10. Arduino Duemilanove. (2010). Arduino. http://arduino.cc/en/Main/ArduinoBoardDuemilanove

Appendix

Product Design Specifications (PDS)

Project: Indoor Air Quality Monitor

I. Function

This design project is aimed at designing a device which can monitor indoor air quality. The device will be used to improve indoor air quality in low-income areas of countries such as India and Rwanda. Our client requires that the device indicate the level of air quality in a simplistic manner. Also, the device should specifically detect pollutants and particulates in the air which are the direct result of tobacco smoke and biomass fuel burning. The device should have some means of storing the data which it collects. The stored data should be easily downloaded for further research.

II. Client Requirements

- The device must monitor indoor air quality specifically related to tobacco smoke and biomass fuel burning
- The device must indicate the current air quality in an extremely obvious and clear manner
- The device should have some internal memory to which it can record data
- This data should be easily downloaded to a computer for further studying and analysis
- The device should be primarily powered through the wall outlet
- The device should have a rechargeable battery which will serve as a “back-up” power source
- The device should be sufficiently small and lightweight
- The device should be able to function for a significant amount of time without breaking down

III. Design Requirements

1. Physical and Operational Requirements

a) **Monitoring Capabilities:** The device must monitor current levels of air pollutants, specifically volatile organic compounds (benzene, carbon tetrachloride, chloroform, and dichloromethane), carbon monoxide, and particulates.

b) **User Interface:** The device will indicate the current air quality to the user in a simplistic manner. The device will use different colored light emitting diodes (LEDs) to tell whether the air quality is poor (red), fair (yellow), or good (green) in a manner analogous to a stoplight. The various LEDs will light up based on danger threshold levels for hazardous air pollutants.

c) **Data Storage:** The device must be able to frequently store the information which it is monitoring to an internal hard-drive. The data should be easily downloaded via a USB port.
d) **Safety:** The device should be safe and pose no immediate risk to the user (s).
e) **Power Supply:** The device will be powered through a common electrical wall outlet. However, the device will have an internal rechargeable battery which will charge during normal use and supply power during an outage.
f) **Operating Environment:** The device should be able to function correctly at various temperature humidity levels. Specifically, the device should work properly at all humidity levels and between 10 and 40 °C.
g) **Size/Weight:** The device should be approximately 8x10x8 cm and have a mass no greater than 2 kg.
h) **Materials:** The device will consist of sensors for the various compounds being monitored, various circuit components, a project box, LEDS, a programmable microcontroller such as that in Arduino ®, a plug for going into a wall outlet, and a rechargeable battery.

2. Production Requirements

i) **Quantity:** Initially, only one functional device will be constructed. However, it is expected that several more of these devices may be manufactured and put to work as early as this summer.
j) **Budget:** The initial prototype should not take more than $1000 to construct.

3. Miscellaneous

k) **Standards and Specifications:** The device should be able to detect levels of particulates and pollutants at certain threshold levels. The device should be tested by seeing whether or not the LED lights change at given particulate or pollutant levels indicated by more exact instruments.
l) **Customers:** Our customers will be those conducting studies on indoor air quality in India and Rwanda, as well as those running Project Quit Tobacco, a U.S NIH funded project.
m) **User-Related Concerns:** The main concern here is that the device is accurate enough to indicate to the user a potentially dangerous air quality situation. Also, the device should pose no significant electrical shock risk to the users and researchers.
n) **Competition**: There are several similar devices on the market. However, none of these seem to monitor exactly the same pollutants as our device will. Also, most of these devices have a somewhat more complicated user interface.

Microcontroller Code

```
// Digital LED Output to Analog Sensor Input
//
// Setup:
//   - Potentiometer (i.e. 'sensor") with Outer Leads to '5V' and (Analog/Power) 'Ground', and Wiper to 'Analog In 0'
//   - Red LED connected from 'Digital Pin 5' to (Digital) 'Ground' (resistor side to Ground)
//   - Yellow LED connected from 'Digital Pin 6' to (Digital) 'Ground' (resistor side to Ground)
//   - Green LED connected from 'Digital Pin 7' to (Digital) 'Ground' (resistor side to Ground)
//
// by: Indoor Air Quality Monitor Team (BME 301)

int sensor  = 0;// analog pin 0 used to connect the sensor
int  sensor_val;// variable to read the value from analog pin 0

int LEDpinR  = 5;// digital output 1 (red)
int LEDpinY  = 6;// digital output 2 (yellow)
int LEDpinG  = 7;// digital output 3 (green)

void setup()
{
 pinMode(0, INPUT);   // sets sensor as an input
 pinMode(5, OUTPUT);  // sets red LED as an output
 pinMode(6, OUTPUT);  // sets yellow LED as an output
 pinMode(7, OUTPUT);  // sets green LED as an output
}

void loop()
{
   sensor_val =analogRead(sensor);         // reads the value from the sensor input (i.e. value between 0 and 1023, if using 5V input)
  if (sensor_val >= 0 && sensor_val < 341)// green LED lights up for values 0 to 340 (from analog sensor input)
  {
    digitalWrite(LEDpinG, HIGH);
    digitalWrite(LEDpinY, LOW);
    digitalWrite(LEDpinR, LOW);
  }
  else if    (sensor_val      <      682)//  yellow  LED  lights  up  for  values  341  to  681  (from  analog  sensor  input)
  {
    digitalWrite(LEDpinG, LOW);
    digitalWrite(LEDpinY, HIGH);
    digitalWrite(LEDpinR, LOW);
  }
  else                                     // red LED lights up for values 682 to 1023 (from analog sensor input)
  {
    digitalWrite(LEDpinG, LOW);
    digitalWrite(LEDpinY, LOW);
    digitalWrite(LEDpinR, HIGH);
  }
}
```