2016 President's Cup – Final Report

Large Scale Early Warning System for Deadly Environmental Elements

AERITY

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Abstract

Our project, *Aerity* (Air and Purity), was initiated to protect people and prevent unnecessary deaths due to the increasingly imminent danger of various invisible elements that exist in our daily life. We have developed a network of sensors that are located around the country that detect the levels of lethal elements: smoke, harmful gases and radiation. These sensors provide real-time data which is uploaded to the Internet through the use of Raspberry Pi. The public can then access this information through an interactive map on a user-friendly website. On top of that, *Aerity* keeps users aware and alert about their immediate surrounding as it will generate a warning alarm whenever there is a dangerous level of smoke, gases and/or radiation that is beyond the safety threshold. Due to its affordability, communities within and outside Hong Kong will be able to access such vital information and take immediate action to keep themselves and their families from harm.

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1. Background

There are many invisible airborne elements that threaten our day-to-day health: smoke, gases, and radiation. These elements can be found in the very air we breathe, and they are often by-product of industries or factories. Not many people are aware of the danger that these elements pose, and this can prove to be very fatal.

For example, the 2015 Southeast Asian Haze was an air pollution crisis that caused a significant deterioration in air quality across several countries in Southeast Asia (Euan McKirdy, 2016). Millions of people had no choice but to inhale the dangerous particulates from the smoke which caused hundreds of thousands of cases of acute respiratory disease. Nineteen people died from chronic heart and lung illnesses. 4 out of 5 team members come from Indonesia, and have had friends and families who were directly or indirectly affected by the smoke.

In addition to smoke and particular gases, radiation also plays a major role in causing deaths. For example, up to 2014, the official number of fatalities caused by the Fukushima nuclear disaster in 2011 had reached 1,232 (Guiterrez, 2015). Fukushima habitants are now facing various deadly health problems associated with the nuclear meltdown.

1.1 Invisible Dangers in Our Daily Life

Both smoke, particular gases and radiation are dangerous to humans' health; they are somewhat omnipresent in our daily lives. Yet, not as many people are aware of the presence of such elements in their environment and how they present a major health risk. Knowledge about these elements are vital to understand the dangers we face:

1.1.1 Smoke and Gases

Smoke is a collection of airborne solid particulates and gases emitted when a material undergoes combustion. Inhalation of toxic smoke caused by incomplete combustion of fuel gases or any organic compound could be acutely dangerous to health. Smoke which mainly consists of soot (carbon) and tiny particles is problematic not only for health but also for the environment. Every year, there are 700 to 900 deaths due to smoke inhalation (NFPA, 2016). Combustible gases such as Liquefied Petroleum Gas (LPG), Alcohol, Propane and Butane are very volatile; they are easily inhaled. They are very harmful for the lungs; they replace oxygen and cause breathing difficulty.

1.1.2 Radiation

Radiation is the transmission of energy in the forms of waves and particles through space. There is an accepted limit of radiation exposure that a body could tolerate, however the body does not really register until the damage started to build up. As a result, symptoms of acute radiation syndrome (ARS) may go unnoticed without appropriate medical diagnosis. Patients of acute radiation syndrome face an increased risk developing cancer later in life. In Hong Kong, a possible cause of radiation is from Daya Bay Nuclear Power Station located in Shenzhen, 50 km away from the center of Hong Kong area. It poses a huge risk to the Hong Kong residents if there was a leak from the station. Our proposed project, *Aerity*, would inform the local residents immediately if there was a leak, thus allowing them more time to take action without having to wait for announcement from the government or through the media. For example, China has a history where the air pollution had been reported in a misleading way, blocking the public understanding and enabling official inaction (Andrews, 2014). Therefore it is extremely important that the residents have access about this data from a neutral third party.

1.2 Objectives of Our Project

The purpose of this project is to create a network of detectors that display pollution levels in different regions; users can check the data in various locations of their choosing, whether it is at residential neighborhood, office districts or for travel.

Our specific objectives include:

- To design a network of smoke, gas and radiation sensors that are spread out over a large area and able to display real-time data, integrated with Google maps, on a website accessible to all.
- To inform the users about the level of danger and allow them to take action.
- To minimize and prevent casualties if events such as the nuclear meltdown or massive haze shall occur.

1.3 Our Logo

Figure 1 Aerity Logo

The name, *Aerity*, is derived from the words ‘Air’ and ‘Purity’. As a visual cornerstone of our project, a logo has been designed to create a unique identity of *Aerity* that provides essential information about the core values of our project. Please refer to Figure 1.

The logo reflects the vision of this project. It is visualized by a chain of connected circles and earth in the middle. The connected circles represent the network of our sensors that detects radiation as well as the harmful gas and smoke particles.

The font of *Aerity* portrays simplicity and futurism. It is simple yet impactful which resembles the project as perceived by users.

The color green represents the nature, freshness and safety. The color blue represents the sky, stability and trust. *Aerity* is a trusted, reliable system that helps keep people safe.

2. Design and Methodology

The idea of having a network of sensors or detectors that will send data to a website was actualized by the use of a Raspberry Pi computer and pollution sensors. The MQ-2 Smoke sensor, and Geiger radiation sensors are used to collect levels of smoke and radiation respectively. These data come out as the output of the sensors, and sent to the Raspberry Pi. Raspberry Pi is a low-cost, credit-card sized, single-board computer. One Raspberry Pi and the sensors make one unit of 'pollution monitoring station'; these stations will be then located in various regions in the area.

The data is processed in a program in Raspberry Pi in Python language to transform them to a `JSON` file. This file will be then transmitted to the *ihome* server. On the website, the `JSON` file will be read and processed into displayable data. These data also provide the safety status of the particular region concerning each pollutants. The users can check the hazard level of certain locations, which will be shown on the map.

2.1 Overview

Our data flow consists of three main parts: recording sensor inputs, reading and processing sensor inputs, and analysing and displaying the data on website. In the first part, the smoke/gas, and radiation levels are detected by a MQ-2 sensor and a Geiger-Muller tube sensor, respectively. The data collected is then stored using a Raspberry Pi 2 Model B. Furthermore, we extract the data from `current.JSON` by using a Python program and the data will determine whether the area is safe. The current data recorded is stored in `record.JSON` file, which consists of previous current data. In the last part, the data is extracted from `current.JSON` and displayed on the website through graphs and charts. Refer to Figure 2 for a detailed data flow chart. For the device set up, please refer to Figure 3 on page 8.

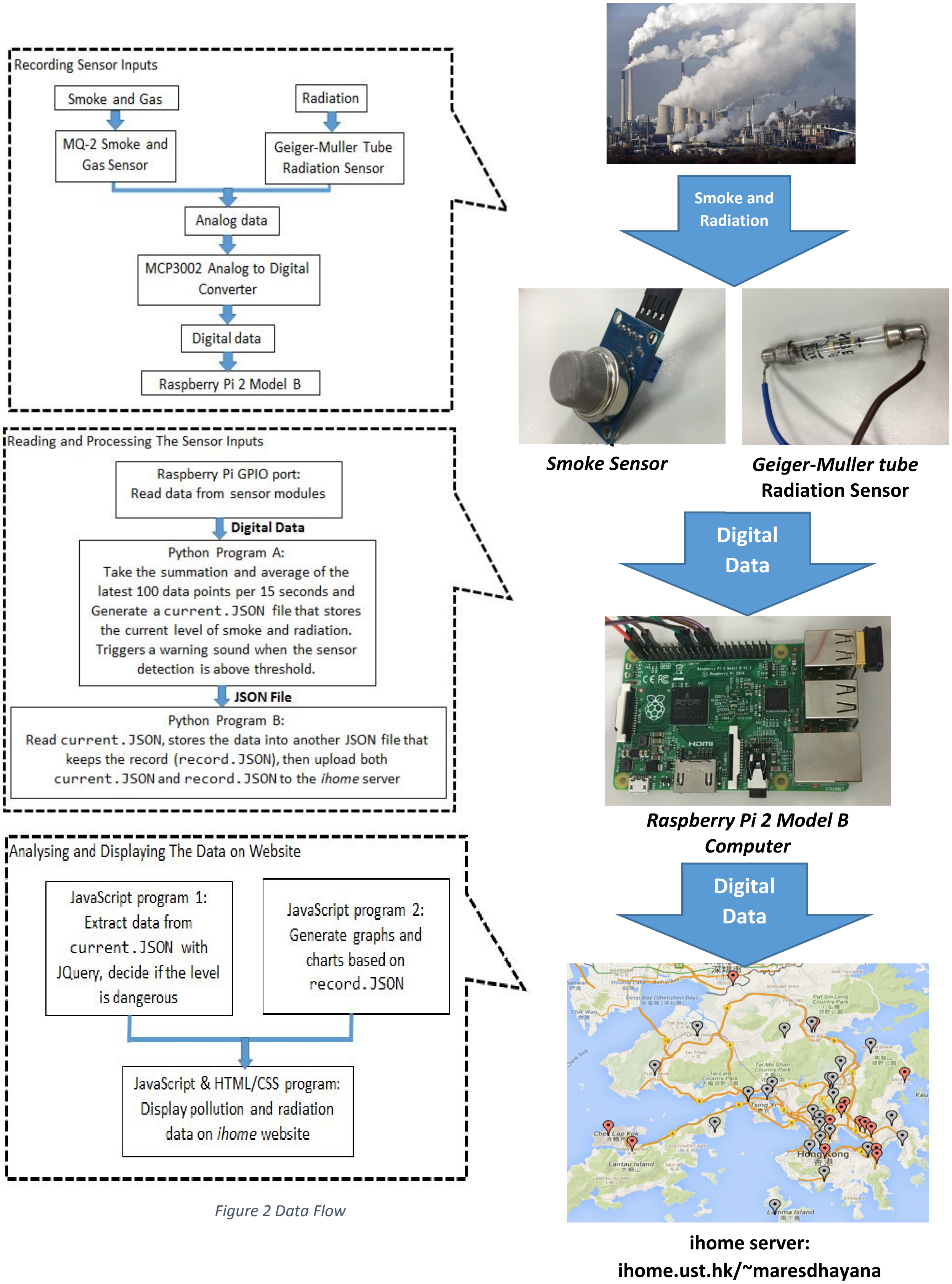

Figure 2 Data Flow

2.2 Hardware Development

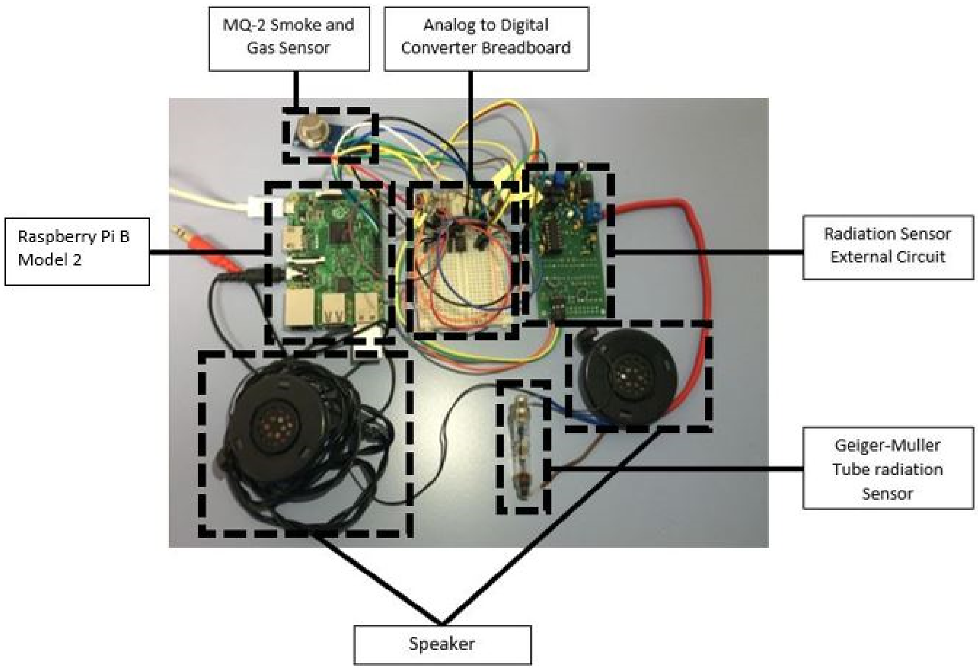

Figure 3 Hardware Components

2.2.1 MQ-2 Smoke and Gases Sensor

MQ-2 sensor detects the concentration of smoke and combustible gas in the air. It operates at temperatures between -20 to 50 degrees Celsius. It measures the concentration from 200 to 20000 ppm. The sensor outputs the readings to the Raspberry Pi as an analog voltage. The sensor has low conductivity in clean air, and the conductivity will rise with higher concentration of gas. MQ-2 has high sensitivity to combustible gas in wide range as well as LPG, isobutane, Propane, Methane, and Hydrogen. With its wide detecting scope, fast response, and high sensitivity, this sensor is suitable for our project.

Symbol	**Parameter name**	**Technical parameter**	**Remarks**
Rs	Sensing Resistance	3K Ω – 30K Ω (1000ppm) isobutane	Detecting concentration scope: 200ppm-5000ppm LPG and propane 300ppm-5000ppm butane 5000ppm-20000ppm methane 300ppm-5000ppm Hydrogen 100ppm-2000ppm Alcohol
α (3000/1000) isobutane	Concentration slope rate	≤ 0.6	
Standard Detecting Condition	Temp: 20°C ± 2°C Humidity: 65%±5%	Vc: 5V±0.1 Vh: 5V±0.1	
Preheat time	Over 24 hour		

Table 1 MQ-2 Smoke Sensor Specification

2.2.2. Geiger-Muller Tube Radiation Sensor

Geiger-Muller tube consists of a sealed metallic tube filled with argon or other noble gas mixed with a small amount of Bromine. The argon gas is considered the detecting gas and the bromine is considered the quenching gas. A thin metal wire runs through the tube, the gases inside the tube are kept below the atmospheric pressure. The metal wire acts as the Anode and the tube acts as the Cathode. There is an electric potential for up to one kilovolt between the wire and the tube.

When there is a radioactive particle enters the tube, it ionizes the detecting gas. Electron that results due to the ionization would accelerate towards the metal wire. The electron experiences an increasing electric field strength which in turns apply a greater accelerating force on the electron. This electron will collide with other atoms and ionize them, and it creates an avalanche of electrons striking the metal wire. The stream of electrons in the tube creates an electric discharge which will show as a measurable voltage in the external circuit of the Geiger-Muller tube, which in this case is put on the PCB.

Once the radioactive particles are detected and the electric discharge was created, the quenching gas absorbs the positive argon ions. It thus prevents future ionization which leads to inaccurate reading of radiation level.

The Geiger-Muller tube that is being used in the project is the SI-3 BG Geiger-Muller tube. The specifications of the tube are as follows:

Working Range of Dose Power	300R/h
Working Voltage	380-460V
Working Current	0,015-0,02 mA
Plateau Length/ Inclination	80V/0,25%/V
Sensitivity to Gamma Radiation	188 - 235 Pulses/s/R/h
Own Background	0,2 Pulses/s
Working Temperature Range	-50 +60 C
Length	55mm
Diameter	10mm

Table 2 Specifications of Geiger Muller Tube

2.2.3 Raspberry 2 Model B Computer

Raspberry Pi is a powerful credit-card sized computer which acts as a processor, RAM, and similar hardware ports such as USB2.0 and Ethernet ports. *Raspbian* is the main operating system for Raspberry Pi; it is a Linux distribution based on *Debian*. In addition, the main programming language used in this computer is Python besides C, C++, Java, Perl and Ruby. It is small in size, low power consumption, yet still capable of performing tasks like an expensive computer but in a relatively lower price. Hence, it is the best fit for our project due to its cost-effectiveness.

Following are the technical specifications of Raspberry Pi 2 Model B:

- Broadcom BCM2836 Arm7 Quad Core Processor powered Single Board Computer running at 900MHz
- 1GB RAM
- 40pin extended GPIO
- 4 x USB 2 ports
- 4 pole Stereo output and Composite video port
- Full size HDMI port
- CSI camera port for connecting the Raspberry Pi camera
- DSI display port for connecting the Raspberry Pi touch screen display
- Micro SD port for loading your operating system and storing data
- Micro USB power source

Apart from the aforementioned items, there also some other hardware materials needed for operation of the pilot devices as follows:

- DuPont Wires
- Breadboard
- MicroSD card 8GB
- WiFi USB Adapter
- 5V 2.5A Power Supply for Raspberry Pi

2.3 Software Design

2.3.1. Transferring Data from Sensors to Raspberry Pi

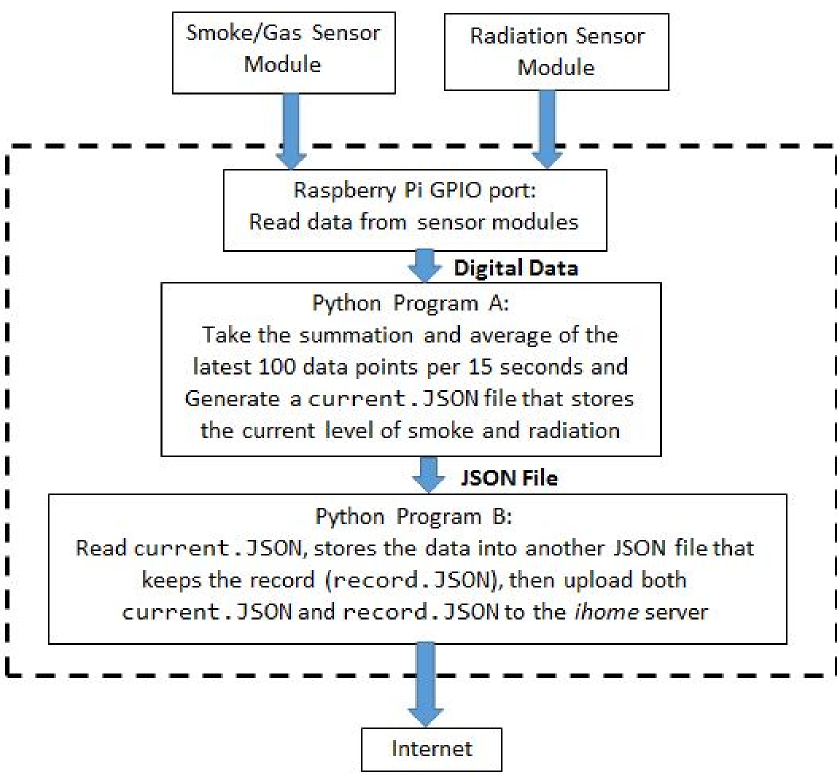

Figure 4 Data Flow - Sensors

Python Program A

There are two programs written in Python in the Raspberry Pi; they are the ones necessary to extract data from the sensor. Python program A is the Python program which takes value from the GPIO pins i.e. value from the sensors. Python program A works for both the MQ-2 and the Geiger sensor. It takes the summation of the most 100 recent readings per 15 seconds, and find the average level. Every time a new level is read, the oldest data is deleted. Therefore, in any point in time, there are only one hundred readings in the program. Based on this average; the program would decide if the area is dangerous or not.

These data would then be compiled into `JSON` files which would then be processed with the Python program B.

Python Program B

Python program B reads the `JSON` file generated from Python program A; it stores the entries into two different `JSON` files. The first `JSON` file stores the current situation, whether the area is safe in that particular moment in time. The second `JSON` file stores a record of the previous sets of information. It is useful to see the trends of the pollution levels, and this set of data can be displayed in graphs and charts later on. Both `JSON` files are then uploaded to the *ihome* server to be displayed in the website.

Figure 4 on page 11 shows a brief illustration regarding the data flow.

2.3.2. Displaying Data to Website

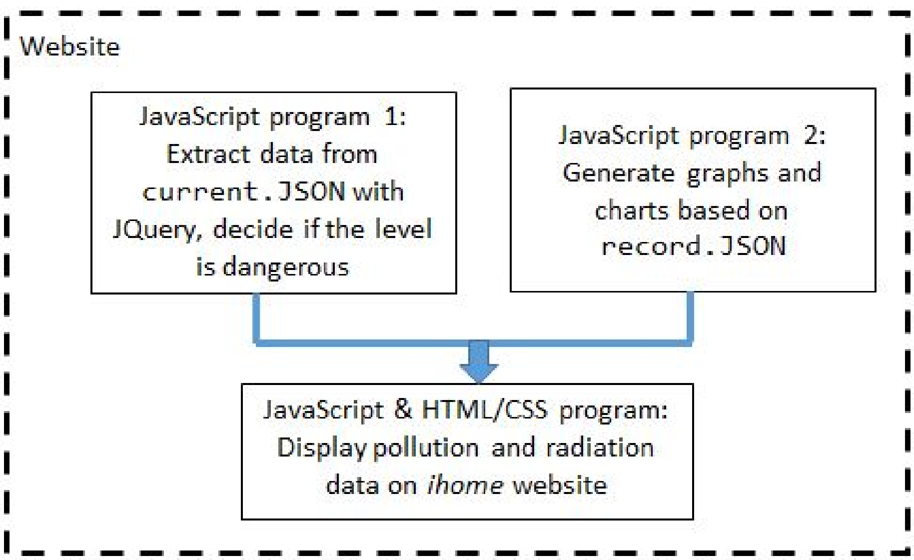

Figure 5 Data Flow - Website

JavaScript Program 1

The website is built using several languages: HTML, CSS, JavaScript and PHP. JavaScript program 1 is a program which receives the uploaded `current.JSON` file. It then uses the JQuery library to extract the data within these files and decide whether the level of smoke and pollution is dangerous or not.

JavaScript Program 2

JavaScript program 2 is the program which generates graphs and charts based on the `record.JSON` file. The users can then see the trend of the levels of smoke and radiation in the area within a longer period.

Website Display

Hong Kong

After the data is extracted in JavaScript program 1 and the graphs and charts are generated in JavaScript program 2, these data would then be displayed in the website, using several languages such as PHP, HTML and CSS. One of the most important features of the website is to see where the dangerous or safe areas are and the specific levels of pollution in each. Using Google Map API, the data can now be shown on the online map, as shown below in Figure 6.

There are several specific pointers in the map; they will show pollution levels in that area when clicked. When the users click on these markers, they can see the level of smoke and radiation as well as the indicator whether that particular level is safe for human bodies or not. The pointer will flash different colors when the pollution levels in that area have reached a dangerous level i.e. the users are strongly advised not to go there.

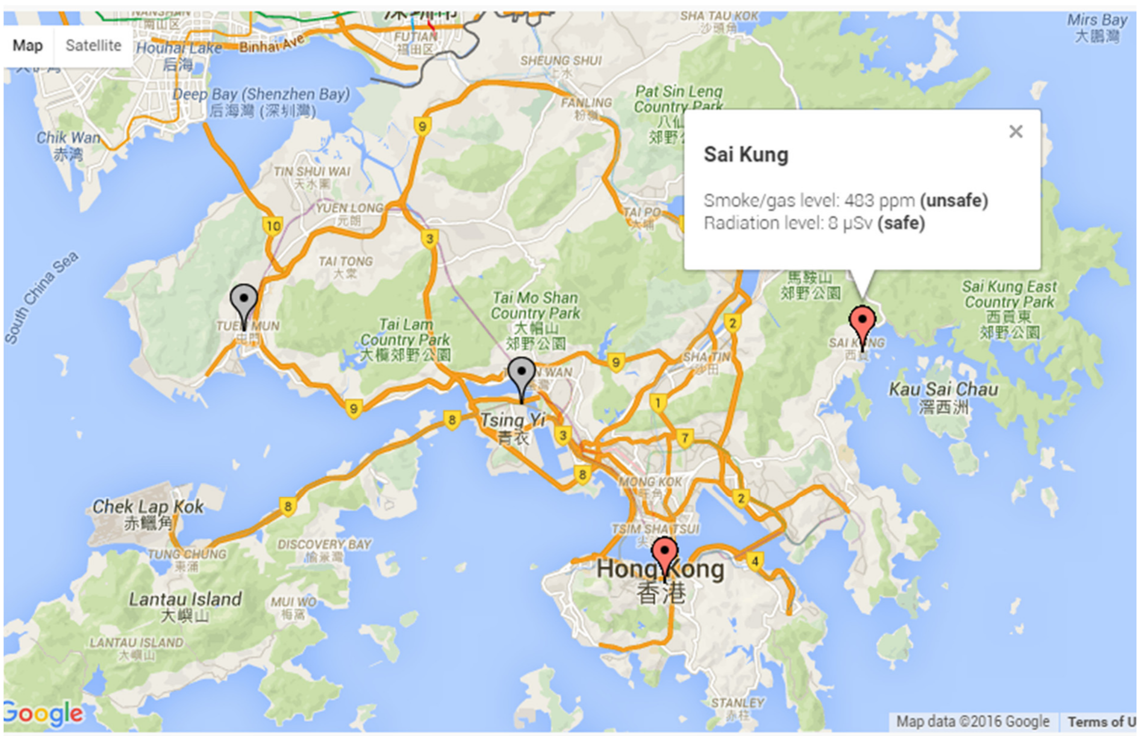

Figure 6 Hong Kong map showing two safe locations and two dangerous locations in Wan Chai and Sai Kung (indicated by orange/red flashing markers)

Indonesia

Figure 7 Southeast Asian Haze October 2015 Scenario (flashing orange/red markers on polluted islands)

In the Figure 7 above, it is shown what it would have looked like on the website if the system had been applied in Indonesia during the 2015 Southeast Asian Haze. The haze had been incredibly disruptive to the lives of men, women, children and animals. Schools were closed, transport was disrupted; the haze was so bad that it was dubbed a "crime against the humanity" by Indonesian Meteorology, Climatology and Geophysics Agency (Euan McKirdy, 2016). Had the Indonesian population the access to the map or the data, they would be able to take extra measures in order to avoid falling ill, such as wearing masks, avoiding outdoor activities, drinking more water and closing any openings at home or office, before the smoke spreads across the islands where they live. They would be able to reduce the effects of the haze and possible reduce the numbers of victims by preparing before the smoke arrives.

Japan

Figure 8 Fukushima Nuclear Disaster Scenario (Five flashing orange/red markers around Fukushima)

Figure 8 above is what it could have showed on the website had the system been established by the time of the Fukushima nuclear disaster. Had the Japanese residents been able to see that there was a wave of radiation coming, they could have prepared for the evacuation immediately, and prevent the tragic abandonment of homes, and pets which was unfortunately the case. Thousands of abandoned animals are now forced to scavenge for food, endure frigid nights, ward off predators, and are constantly exposed to noxious radiation (White, 2015). The system would have allowed more time for the evacuees instead of being informed by the army as they were forced to leave the prefecture.

3. Cost Analysis

Aerity - Cost Breakdown of Final Product

Item	Unit Cost (in HKD)	Qty	Total Cost (in HKD)
MQ2 Smoke and Gas Sensor	17.6	1	17.6
Geiger-Muller Tube Radiation Sensor	43.8	1	43.8
Radiation Sensor Circuit	139.7	1	139.7
Raspberry Pi Zero	40	1	40
DuPont Wires	7	7	49
3x3 inches PCB	4	1	4
MCP3008 Analog to Digital Converter	12	2	24
MicroSD Card 16 GB	38	1	38
Wifi USB Adapter	80	1	80
5V 2.5A Raspberry Pi 2 Power Supply	20	1	20
Speaker	10	1	10
		Grand Total	**466.1**
		Equivalent to USD*	**60.06**

*USD1=HKD7.76

For the development of the product, Raspberry Pi 2 Model B was used. However, the final product would use Raspberry Pi Zero which costs much cheaper and could perform the same task. In addition, breadboard would be changed to printed circuit board (PCB) as the design would be finalised. Also, PCB can be mass-produced and be purchased at a lower price. According to the cost analysis, one set of *Aerity* will cost HK$ 466 or approximately US$ 60.

Our product is very affordable. It democratizes our air quality monitoring platform to be widely used for the larger user base be it from the underprivileged neighborhood or the well-off community.

4. Future Project Development

There are still many improvements that can be made in order to increase the impact of *Aerity* to different communities across the globe. Currently, the users need to access the data through the website. In order to provide a more personalized data relevant to a particular user, we are planning a mobile application that will run both Android and iOS. This mobile application would thus be able to warn anybody who owns and carries a smart device in their pocket, and keep them from harm wherever they go.

We are also planning to expand the features of *Aerity* in order to detect a greater types of deadly elements in the environment. Our initial plan had included the sensors not only for Smoke and Radiation, but also for Carbon Monoxide gas. Carbon Monoxide, also called "Invisible Killer", replaces the Oxygen in the blood and kills off cells. Its odorless, tasteless, and colorless nature causes people to die without ever knowing what hit them. Surviving victims would suffer from a range of permanent problems such as brain damage, heart problems, and major organ dysfunction. We had realized that we would not be able to integrate the sensor within the time constraint of the project, however, it is vital to increase the capacity of *Aerity* to be able to detect more deadly elements in the environment. We are thus planning to integrate the sensor in our system in the future.

In order to encourage the use of our product in low-income communities, we are planning to further reduce the cost of production of our product by using Raspberry Pi Zero. Raspberry Pi Zero is at least five times cheaper than the previous models, pushing the cost of our product down by quite a significant amount. Various governments and NGOs can adapt our system easily in low-resource settings. This allows not only the middle-upper class, but also the low-income families to keep themselves from harm.

5. Conclusion

Our project, *Aerity,* was developed in the intention of saving people's lives from the imminent danger of various, often invisible, elements in the air which pose a threat to the environment and human health. The result of this project is a network of sensors that are spread across different locations which detect the level of lethal elements: smoke, harmful gases and radiation. These sensors collect real-time data and upload them to the internet through the use of Raspberry Pi computers. The public can make use of this information through an interactive map on the *Aerity* website. Besides, the system will generate a buzzing alarm if the local area has smoke, gas, and/or radiation levels beyond the safety standard. It enables users to be vigilant of any potential environmental hazard and take quick action to save their lives. Due to its affordability, basically everyone, from the low-income neighborhoods to the more affluent areas, will be able to access such vital information and keep themselves and their families safe from harm.

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