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Implementing Consumer-based, Internet of Things-based Environmental Monitoring Systems within Smart Spaces

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Abstract**—**Internet of Things (IoT) based Air quality measurement systems within smart cities have long been researched to find the most efficient way of collecting data for mitigation purposes in various areas. One of the biggest issues is the balance between flexibility and size for consumer-based measuring devices. This paper talks about a customized design of such a device, measuring nine different parameters that are considered crucial in any environment (CO2, CO, PM 1.0, PM 2.5, PM 10, temperature, humidity, pressure and altitude). This data is then communicated from the microcontroller through the Wi-Fi module attached to be able to access the data at a Graphical User Interface (GUI) made on GReS Studio's website or also through other third-party services such as ThingSpeak. Analysis of a sample of the results obtained is also discussed.
Keywords-Internet of Things, Smart City

I. Introduction

In 2016, IEA (International Energy Agency) reported that a whopping 6.5 million people die annually due to air pollution [1]. Patients who have chronic disease are forty percent more likely to receive a heart attack in heavily polluted areas than in lightly polluted areas. This all has been the result of why environmental sensing has become one big area where the Internet of Things (IoT) technology has revolutionized convenience for the user accessing their data. The problem seen is that currently we do not yet have a functioning, efficient system in place for such a variety of air pollution measuring needs. According to BCC research, the global environmental sensors market and monitoring business itself will grow to a whopping $17.6 billion in 2019 [2], showing just how much industries are starting to really utilize this type of sensing. One of its main applications is within the B2B (Business to Business) market, where it is used mostly in workplaces. However, due to most people paying attention towards the outdoor applications of such technology with the belief that most of the said air pollution is worst in those environments, they ignore fact that households are also generating more and more dangerous air pollution. The aforementioned household environments have turned out to also be a big market, as it applies to everyday awareness of consumers, for it is already seen within the horizon with new evolutions of technology, thus widening the field, akin to one device that the author has worked on. Implementation of said devices are what brought about the concept of "smart spaces".

Proper definitions of what a smart space is vary, but an appropriate, accredited definition in the context for this paper is one from Aalto University [3], "a built environment with embedded services for mobile users". Much of the environmental sensing are used to monitor air pollution within the environment, making sure that the specified gasses do not go over the threshold dangerous level. Hence, connected to this, due to the requirements of the action with it always building up, the features that the device needs to offer is always increasing as well, including but not limited to: durability, accuracy efficiency in transmitting data and redundancy. Many efforts have already been made to achieve climate microclimate maintenance through various Wireless Sensor Networks (WSN), but a truly sophisticated, efficient, consumer-friendly system that can be widely adopted by users is still to be seen.

This paper will discuss a proposed design architecture on building an air pollution monitoring system for the smart space that maximizes the possible outcome from the trade-off between flexibility (features within the device) and size. This is considered through eight different parameters that can be measured through the device as opposed to the traditional three or four often seen in bulky sizes, in order to keep tabs effectively and efficiently on how the air quality is doing, and is a big leap ahead on the development on such technology within Jakarta, Indonesia, where the author has implemented it.

This paper is organized as follows. Section II describes the architecture of the system being used and the benefits of using that set-up. Section III talks about the methodology of how the system will work. Section IV will show an example of the implemented system within a spot at GReS Studio’s workplace. Section V puts into context some challenges that will be faced in adopting the system. Finally, section VI summarizes everything that has been already discussed as well as some possible future research areas to consider.

II. System Description

As seen on the block diagram in Fig 1, the ESP 8266 Microcontroller act as the brain of the system. The Microcontroller has a Wi-Fi module attached to it, allowing communications to be done easily that way.

A. *Sensor Architecture*

ESP8266 Microcontroller [4] will read the MH-Z19 CO2 Sensor [5] and PMS7003 PM Sensor [6] through serial communications (using Software

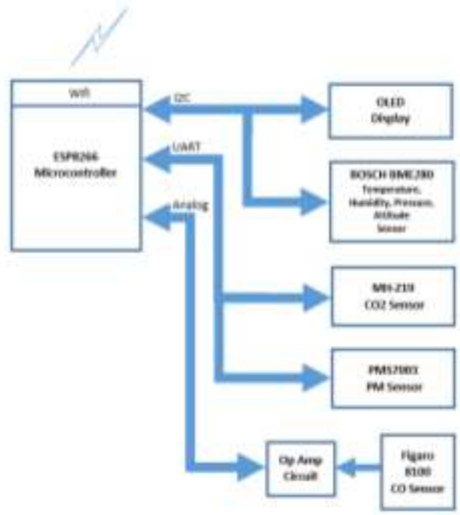

Fig 1. Proposed Sensor Device Setup

Serial Library since ESP8266 only have 1 Serial port available for the communication to the sensor).

ESP8266 Microcontroller will read the Bosch BME280 [7] through I2C communication (using I2C address 0x76). While for Figaro 8100 CO Sensor [8] output, which has linear relationship between CO gas concentration and sensor output, after amplifying by the Op Amp circuit, is read through the Analog input of ESP8266 Microcontroller.

After doing data reading and processing, ESP8266 will display the sensor result to the OLED (Organic Light Emitting Diode) Display through I2C communication (OLED Display I2C address is 0x3C). Through the internal Wi-Fi module, ESP8266 will send result data to the cloud via the Internet Gateway.

The general process of the device goes through three main phases: record, sleep, and sense, depending on user preference. Various devices can have various settings. This is for the consideration of saving power,

TABLE I. CURRENT OF SENSORS

Module	*Mode*	*Current*
Sensor (BME280)	Active Sleep	3.6 µA
Sensor (PMS7003)	Active Sleep	<100 mA <200 µA
Sensor (MH-Z19 NDIR)	Active	<18 mA
Sensor (TGS5141)	Active	15 µA

power usages as shown in Table I. This is also taking information from [6], [7], [8] and [9], as it would be unnecessary to keep the device operating needlessly collecting data every second. However, this is again to be taken into the context of how the device is being used; if it being used in situations that need fast response such as when cooking is being done, it can be set to much shorter intervals or even every nearest possible time, as per second, but if it is not that needed, then we can just set it to longer intervals, especially if the device is not being plugged in to a power source. Despite this, it is important to add the fact that not all sensors can collect data between short intervals; some must have a 'buffer' time before recording again between recordings. Moreover, each developer may need to take into account the power usage before they adjust the settings for each sensor that is being used.

III. METHODLOGY AND TRANSMISSION

B. *Transmission to Cloud Service*

Sensor data read by Device will be sent to the Cloud every preset period (default is 3 minutes) through the Internet Gateway. Communication from the Device to the Internet Gateway can go through the Wi-Fi or Bluetooth connection (Bluetooth Low Energy is preferable since it consumes very low power). Currently Device supports MQTT (MQ Telemetry Transport), a lightweight communication protocol designed for constrained devices and low-bandwidth devices, as the communication protocol to the cloud.

C. *User Data Presentation and Parameter Settings*

The data collected and stored in the Cloud Database will be used to display information to the user through mobile phone application (support iOS and Android) or through Device Server. The information can display the recent text based sensor data result collected by Device, or graphical time-based historical data collected by the Cloud.
There are 2 types of connections to get user data presentation from the Device. The first is through direct wireless connection to the device. This can be seen in Fig 2 below, in an example design made with the consideration of simplistic user experience.

In this process, users can connect wirelessly to the device through Wi-fi or Bluetooth to get the latest data reading from the device. The second is through cloud data presentation, whether they be through a mobile app or through the device website. One can connect to the cloud to get historical data and present it in text or graphically on the phone screen for the presentation on the mobile app, or to simply browse the device website and login there to get the historical data. The data can be displayed as graphics or text styles. We have been able to see that IoT-based systems have also already proven to work in the past, such as in [9]. ThingSpeak API (Application program interface) is being integrated with the website to be able to upload the data, hence making ThingSpeak the actual cloud.

Fig 2. Example of UX on Device

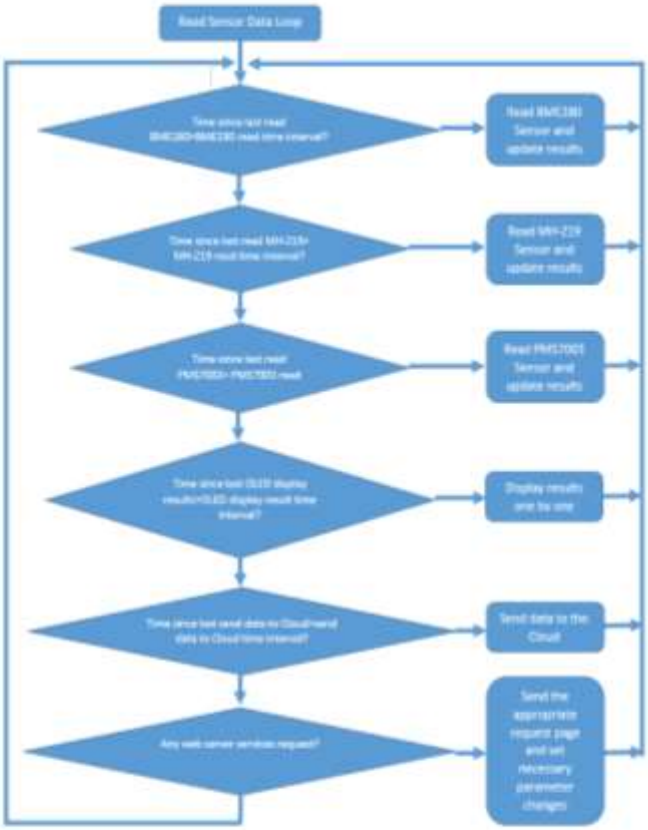

Fig 3. Sensor Data Loop Reading Diagram

The first is the Wi-fi parameter settings for connection to the Internet Gateway. This will enable Wi-Fi connection to the Internet Gateway so Device can send sensor data to the internet.

The second would be Cloud account settings. This parameter is necessary to make successful Cloud connection from the Device. These will include user name (email address), password, and encryption type. Finally, the most important consideration to set up are sensor data thresholds. These parameters will be used to determine whether a sensor data result will trigger an alert should it passed the threshold. If an alert happened, then the next action need to do should be set (sending alert through email/sms, produce alert sound or blink display screen on the Device).

D. *Sensor Data Read Loop*

To enhance user experience in reading the Device displayed data on the OLED screen, instead of using normal sequential task execution (doing one task, and then the other task sequentially), in the programming the Device using time-base execution for each task, shown in fig 4. Each task will be assigned individual time intervals between task executions. The microcontroller internal timer is used as the reference execution timer. For instance, reading temperature, humidity, and pressure, once every 15 seconds, reading CO sensor will be done every 30 seconds, reading CO2 once every 1 minute, reading PM sensor once every 2 minutes, sending data to the cloud every 5 minutes, and display one sensor data result 5 seconds before changing to the other sensor data results.

By doing this programming trick, the user will see as if the Device smoothly displaying all the sensor data parameter results (temperature, humidity, pressure, CO, CO2, tVOC) sequentially with 5 seconds interval without interruption (or little delay only). Although the Device actually reads sensor data or updates data to the cloud, the user will not have noticed that.

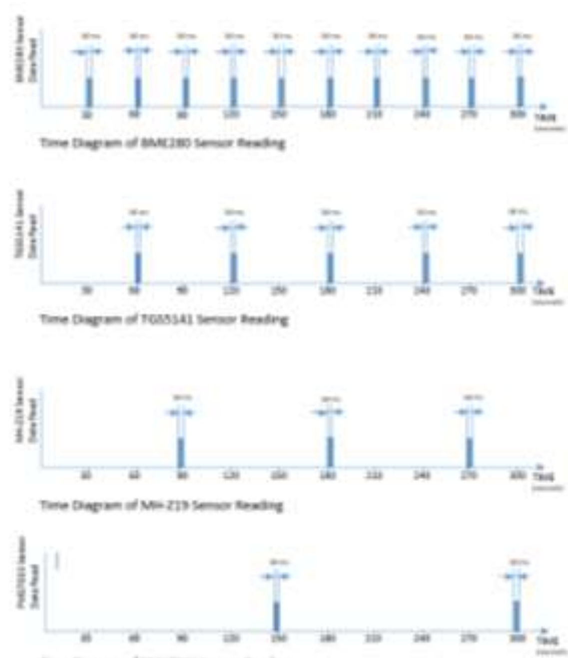

Fig 4. Scheduled timed task executions on the proposed system

For every task, when it runs, the Device will store the execution time of the task, and compare the time difference between current time and that recorded previous execution time with the preset period of that task, and when it is bigger (meaning the period exceeded), the task should be executed.

There are several time-based periodical tasks running on the Device. These, in consequent order, are the BME280 sensor reading interval, MH-Z19 sensor reading interval, PM7003 sensor reading interval, OLED Display result interval, sending data to the cloud interval, and ending finally with the Web Server request.

The program will keep looping through each periodical task, and when it found the time duration after last task execution already exceeded the task interval, the appropriate task will be executed, otherwise it will be skipped.

By doing this, it will avoid having to wait for a long time to read all the sensors data and other task sequentially, which will make the display freeze for a long period of time.

IV. Proposed Device Deployment

To ensure the functionality of the proposed system, it was placed around the GReS Studio workplace for a start. Fig 4 shows the deployment of the system on July 2017 on a period of 6 hours, from 6:00 AM to 2:00 PM.

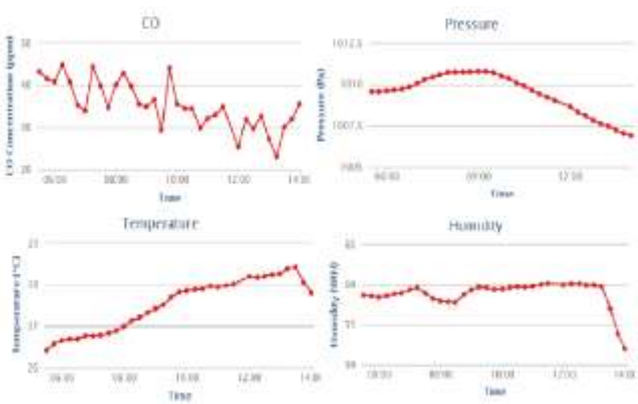

Fig 5. CO, Pressure, Temperature, and Humidity Data for GReS Studio Data Taking

These results are set to show data that is based on 15-minute averages of the 100-last data taken by the device. Out of the mentioned measurable quantities, now for this case study I focus on four of the measurements, which are CO, pressure, humidity, and temperature.

As seen, the CO varies between 44.38ppm and 23.02 ppm, the pressure from 1010.82 Pa to 1006.97 Pa, temperature between 28.42^{o}C and 26.65^{o}C, and finally humidity between 60.16% and 51.96%. As seen clearly from fig 5, the data was continuously monitored wirelessly through ThingSpeak from being sent through the microcontroller's Wi-Fi module being connected to the internet. Such results are also easily accessible through other possible connected third-party services such as Amazon Web Services or also just through the device directly. Similar wireless methods such as that seen in research from [10] has also proven to be effective in being able to transmit data for mitigation purposes quickly.

V. The Future Challenges of Implementation

There are still many challenges in environmental monitoring devices gaining widespread use. One is that many people, despite the clear evidence that air pollution is a big issue to the environment that causes many casualties, still do not believe that it is relevant to them, and hence would ignore the thought that they may need these devices for their household use. Previously, mostly businesses could not get their hands on these kinds of technology because they were expensive and very bulky. Nowadays, however, more and more of the smart environmental monitoring devices are being more consumer friendly due to their pocket-size and sold much more cheaply, meant for the consumers, as well as offering multiple features within one device. Furthermore, mostly only businesses who do deal with activities creating a lot of air pollution feel that it is necessary to have these devices, such as businesses with data centers or those who work in coal mines. The biggest issue is still, of course, connectivity, since some areas may not have a resilient connection compared to others. Therefore, offline capability is still needed as a redundancy measure for putting the data in storage within the device and uploading it back to the central server when the connection comes back on, which is one feature that most of these devices still do not have, hence making it a concern to consumers whether to buy it or not. Finally, what needs to be considered is the working conditions of the device, as it may work in certain temperatures, for example, since if it goes past its threshold, it may end up being inaccurate.

The consciousness regarding the problem of air pollution is increasing, and eventually we're at a point where the general consensus still believes that it is truly a problem, as seen especially with the dangers of air pollution and how it is measured being thought in the education systems of today. Aside from that, awareness from environmental groups such as the EPA (Environmental Protection Agency) is being drummed up, seen from their initiatives, including their air quality awareness week which starts on May 2 this year, has been able to contribute to the campaign for the problem we have now [11]. The same goes for certain policies set by some countries; the United States' decision to withdraw from the climate change agreement is a critical example of how the problem can rise to even greater heights, hence even forcing consumers to get the awareness themselves eventually as more effects around them are seen. Decisions such as this make it clear that the effects of air pollution will not diminish anytime soon; the IEA has even already warned that premature deaths caused by outdoor air pollution is set to rise to 4.5 million people from the 3 million people annually now by 2040, whereas those that are caused by indoor air pollution is set to drop from 3.5 million to 2.9 million [1]. A big cause of this is that possibly, people have been getting more aware of the situation that they are facing and as time progresses, their industrial spaces will be "smarter", creating idealized living environments that inform users regarding such data for their mitigation purposes. This has been also seen in research from [12], in which urban locations have been the main target locations of the growth of these devices.

On the other hand, we are seeing more rapid improvements within the IoT architecture. One of the biggest trends that we are seeing now is the evolution of smart spaces collectives that have been designed by various companies. These such collectives have been designed to work together, and eventually more companies are transitioning to include such environmental monitoring devices to complete their smart spaces pack. Furthermore, there have been developments as well that have allowed such appliances from one companies to work with those of another's, fulfilling the criteria of cross-platform development, and that is one thing that we will see for sure being used as a standard in the future, hence eliminating the need to buy the same brand just to create a smart space. As modernization continues, we are sure to see even more appliances become fully adapted to the IoT concept.

Another evident trend is the transition of 4G networks to 5G networks. By 2020, it is expected that the 5G network will be ready to support 50 billion connected devices as well as 212 billion connected sensors, one of the greatest contributions to the even more surprising access to 44 zettabytes of data that it will enable [13]. With 5G networks, environmental monitoring devices will gain more widespread use, especially for technical people, such as those who worry about latency or network agility. The time is takes to transfer data can be reduced from the 50 to 80 milliseconds to today towards just a few milliseconds, improving the overall user experiences, especially in situations where high response rates are needed, such as if a specific air pollution threshold is triggered to act quickly to mitigate it. Such networks will revolutionize network agility as it promises high broadband speeds and allows more competent back-end services, allowing content to be processed quickly, making computing more efficient, more economical, and storage costs will be reduced significantly. This is all done through the enlisting of back-end data centers and cloud services, allowing even more complex tasks to be performed by smaller devices, something we have not seen today.

VI. Conclusion

In conclusion, despite the myriad of benefits that the use of IoT within environmental sensing has upon creating smarter, better maintained environmental conditions, clearly there is still a long way to go for companies that provide these services before they can get reach the mass market consumers stage. Many adopters are still in the process of identifying the potential of this type of application in IoT, and thus more are coming into the market to make use of it, as shown by the increasing market share of this sector over time. The author's experience of being in the environmental monitoring system devices market has already made him sure that this is so, as well as the transitioning of customers to even "smarter" spaces with such devices. This will play a big role in the smart city vision of cities of today.

On the other hand, the author also has proposed a feasible device architecture, which has been proven through implementation within the market. We can see that as time progresses, newer network protocols such as 5G will replace the current ones and more sensors, perhaps those that are more accurate and consume less power will be created to fit more consumers' needs. The growth of the said monitoring systems can be guaranteed at this point, as the trend that the average air quality in many parts of the world have shown that it will only continue to worsen over time, given policies such as the United States' withdrawal from the climate change agreement. We are sure to see these devices being essentially crucial to public use one day due to the deterioration of air quality in many cities as of today.

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