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To cite this article: A Nor Azhar *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **551** 012047

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IOP Conf. Series: Materials Science and Engineering **551** (2019) 012047 doi:10.1088/1757-899X/551/1/012047

Indoor Air Quality (IAQ) Sensing Device Prototype: Software-Hardware Architecture and Performance

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Abstract. In a green environment, air quality is among the prominent aspects to be considered to prevent pollution and in turn maintain safe air. Sick Building Syndrome (SBS) and Building Related Illness (BRI) are the problems that must be encountered by building occupants. Existing devices are quite expensive, and more attention is needed on monitoring air quality. Therefore, this paper discusses a software-hardware architecture proposal to overcome the existing IAQ data retrieval performance problem. The objective of this work is to analyse the most recent IAQ sensing device developed by the researcher, to evaluate the performance attribute, and to implement the software-hardware architecture based on the Performance-Driven Software Architecture Refactoring (PDSAR) method. In order to assess the overall performance of the architecture proposed, the prototype of the Indoor Air Quality (IAQ) sensing device was developed. The testing was performed during a period of six months. The results demonstrate that the average performance for 540 readings is 76.67%. This shows that the architecture can be accepted as a generic IAQ sensing device development structure. The device act as an alternative, cheaper and safer device which can be employed by all building owners in the future.

1. Introduction

Air quality inside a closed room concerns many people. Many government bodies, especially science and technology, urge industries and building managers to increase the building health through Green Building Initiatives. However, this effort is far from being accomplished, primarily due to cost constraints. Indoor Air Quality (IAQ) detection is among the approaches used to overcome Sick Building Syndrome (SBS) and Building Related Illness (BRI). Recent research adopted educational [1], factory [2], vehicle [3] and residential premises [4] as domains. In this paper, we discuss the sensing device focusing on architecture and its performance. We also propose a novel architecture, and report on how it performs, while the IAQ device is running. IAQ was defined as an environmental issue in a confined space which comes from pollutants, and it harms occupant's health. These harmful pollutants (gasses, volatile organic compounds (VOCs), and pollen/dust) all contribute to SBS, resulting in an uncomforted feeling while in that space. Sensing devices are cheaper and more reliable through-out the year. However, the performance of this architecture has not been tested well.

Based on [5], Performance-Driven Software Architecture Refactoring (PDSAR) can be defined as a discipline that collects approaches, methodologies, and tools aimed at introducing performance

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assessment in the context of software architectures. It focuses on the top end of the architecture of software, and on the performance itself. Most of the architecture in research on IAQ sensing devices lacks these attributes.

2. Related Works

Several researchers compare overall strengths, characteristics, and performance. Since we focus on performance, the data transfer is needed for performance analysis. We also put in mind the economic value of the device, since it would reduce the reliability factor. This ensures the effective usage of energy based on eco-design methodology [6].

We selected six most recent sensing devices to compare performance. Several criteria were chosen, related to performance analysis. Sensor main device is the "brain" of IoT devices, controlling all sensors connected to them. For every device, we compare the architecture, since it is important to make sure the structure of the developed solution can be implemented successfully in other domains. The performance results were also chosen as among the attributes to be compared in determining the best solution. The data transmission protocol and time frame were chosen to determine how good the devices managed to sense the environment and store the data.

Table 1. Comparison between six recent IAQ sensing devices

Criteria	**IEQ Toolbox** [7]	**Proactive IAQ** [8]	**SPIRI** [9]	**IAQ IOT** [10]	**Cloud IAQ** [11]	**WSN IAQ** [12]
Sensors main device factor	9 Arduino, XBee	1 PIC microcontroller PIC16f877a, ESP8266	10 Raspberry Pi Zero W	3 IDT smart gas sensor, Raspberry Pi	5 Grove, GSM Module	6 Arduino UNO
Top down approach architecture	Partial, Wireless Mesh Network	No	No, 6LoPAN	No, Based on IDT Architecture	No, Based on GSM	No
Performances	Good	No Discussion	Good	No Discussion	Bland-Altman statistical analysis model	Success
Data transmission protocol	Calibration with National Instrument DAQ card	Wi-Fi	Ripple (RPL), CoEP (Constrained Extensible Protocol)	Wi-Fi and Bluetooth	GPS and GSM	Wi-Fi. WSN, SD Card
Data transmission timeframe	1 minute	Not stated	1 minute	Not stated	3.6 seconds (Average)	1 second

Table 1 summarizes the findings of most recent works by prior work. It seems that only SPIRI fulfills the performance based architecture, and cloud IAQ separately does the after session performance analysis. Architectures in these works complement with software-hardware architecture, but none of them have a top-down approach to rely on device performance over time, due to problems in cloud computing devices, as stated by al-Sharafi [13].

3. Proposed Architecture and Implementation

Inspired by PDSAR architecture, we developed the architecture for the focused domain. In Figure 1, the flow of the data transfer is presented. The sensor reads the environment/contamination value, while the data performance rate is calculated. The lower the value of data performance, the better the IoT device would be. On the other hand, any error in the data leads to performance issues, which contributes to the reliability of the architecture. It is an indicator of how well the sensors communicate with the database. If the performance of data errors is high, the architecture should be readjusted. This approach is inspired by agent-based works in cloud computing [14]. The PDSAR has demonstrated a good sign in real time software architecture, which is able to perform top-down approach checking, while compromising with the performance of the devices. This generic architecture supports the dual/more architecture running simultaneously to create a high-reliability performance in software-device architecture. We propose a top-down architecture inspired by PDSAR, as shown in Figure 2. The performance is compromised based on the current architecture, and it then changes with time, based on the variables in Figure 1.

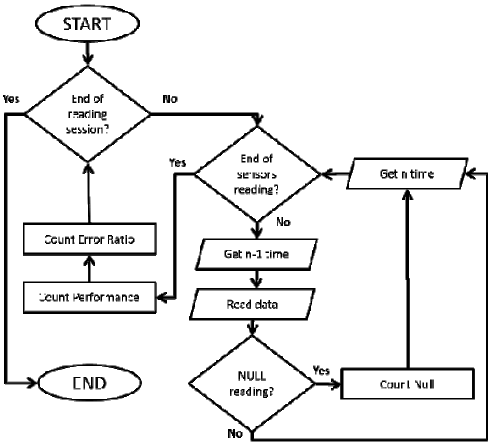

Figure 1. Flowchart for IAQ sensor device – Data Management

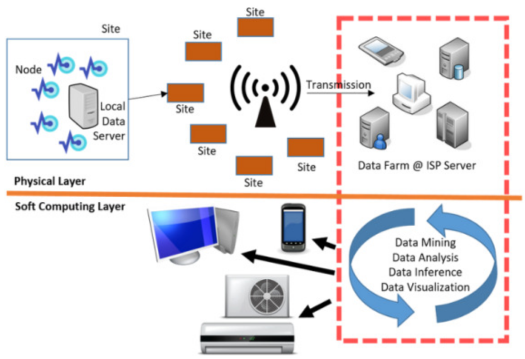

Figure 2. Proposed architecture and implementation

In this general architecture, we performed simultaneous sensor data processing through separate entities from the storage. This is due to a report from a recent IAQ device researcher, mentioning that the board or the main factor of the device could potentially reduce the performance. To reduce the burden on the sensing device main board, sensor data from nodes are transferred and accumulated to the local data server. During this stage, the burden of the device was reduced significantly. Figure 1 shows the flow diagram of the proposed architecture. The performance of data transfer was counted based on three factors: null, unacceptable and data transfer rates. Two sessions of the data performance log were set up, namely, from sensors node to local server, and from the local server to data farm.

This action was followed up with interchangeable architecture, which is based on the data performance. The device works to capture the data, and not to accumulate them. Local data server does the work, as shown in Figure 3. The data reading gap is optimized, especially in reading and analysing. We had five architectures working. We tested simultaneously, and performed modifications based on the performance of the readings. These five architectures were changed based on the performance of the data transfer throughout time. It is controlled by local (site), and data farm servers. The redefined flowchart is shown in Figure 4. The changes factor compromise on several occasions: (a) lack of power, or the ability to transfer data slowly because the device cannot accumulate the data in the timeframe; (b) failure of sensor nodes, which affects the other nodes due to incomplete data; and (c) Failure of the server, which affects the reliability of IAQ reading.

There are two types of switch conditions: (a) NULL wise, a signal for single or multiple sensor errors; and (b) performance wise, based on the transmission rate calculation. If the rates arrive at the threshold, switching will occur. We tested 20 nodes of sensors, which have five nodes on each server. The sensors are temperature, humidity, environmental, dust sensor PM2.5, carbon monoxide and sound/noise. The main board we chose is Lolin NodeMCU, which is based on the ESP 8266 chip. For the Bluetooth connection, HC05 was chosen due to the capability to read and write in real time. The time frame for sensor readings was set every 8 hours to the server farm. However, in a local site, the timeframe is five seconds.

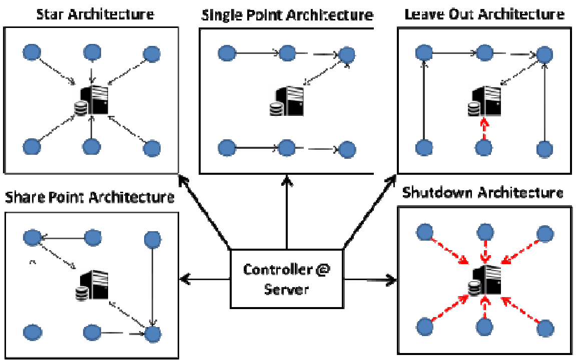

Figure 3. Transition architecture for data transmission

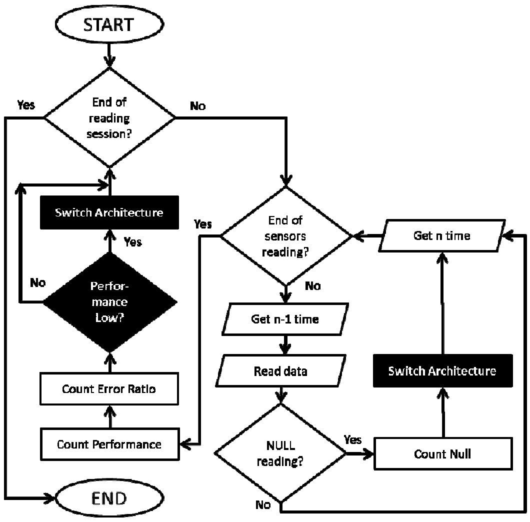

Figure 4. Redefine flowchart for IAQ sensor device – Performance Based

4. Result and Discussion

Simulations of the device were developed to evaluate the preliminary performance test. Later on, we tested the device on-site, to assess the architecture proposed. The testing was performed during a period of six months. An interruption on a sensor was performed to the sensor to check its reliability. Every time the architecture makes a transition, it accumulates the changes. The same goes to the null switch counter (when the sensors give over 5 null or zero values). Table 2 shows the summary of sensors log as the result of the IAQ device performance. The average performance count was on the percent of perfect readings versus the readings counted. With a result of 76.67% accuracy by the device, the proposed architecture can be accepted as one of the ways of measuring the performance, and ensures the quality of data sensing.

Table 2. Architecture performance log

A	1 – 3 month period				4 to 6 month period				Overall
	B	C	D	E%	B	C	D	E%	F%
1	18	10	16	83.70	43	33	12	67.41	75.56
2	30	12	23	75.93	21	22	40	69.26	72.59
3	21	34	18	72.96	13	54	30	64.07	68.52
4	19	20	27	75.56	22	22	16	77.78	76.67

*Legend : A : Local server; B : Architecture switch count; C : Null switch count; D : Performance switch count; E : Σ(switch_count)/270*100; F : Σ(switch_count)/540*100*

5. Conclusion

The architecture of the IAQ sensing device was proposed to obtain the optimal WSN performance in IAQ. The testing done shows the performance and reliability of accuracy of the prototype. This can be an alternative solution that is cheaper and more affordable for very confined space owner.

Comparing to [5] test subject, the implementation of PDSAR prove the effectiveness of search based architecture, compared to a metaheuristic approach. This result also proves the freedom of architecture results in better output, and also is also suitable for sensing devices. The performance of the sensing device concludes that, similar applications need a search based architecture to enhance their reliability.

Acknowledgments

This work is sponsored by Universiti Malaysia Pahang Internal Research Grant (RDU170305) under the umbrella of HeDoo innovation product.

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