Wireless and Location-Based Indoor Air Quality Monitoring System

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Abstract- *Poor air indoor quality can cause health problems. Monitoring of indoor air quality is currently carried out by environmental health officer by carrying a measuring instrument and making measurements directly at the location. Difficulties in monitoring indoor air quality, the limited number of environmental health officer, and the length of time needed to measure the indoor air quality are the main problems in the monitoring, recording and reporting system of indoor air quality. The old method of monitoring, recording and reporting systems needs to be replaced with wireless and location-based indoor air quality monitoring system with data obtained in real time. This study aims to develop a data collection system, provide a database management system, and build dashboards that provide information on monitoring indoor air quality. Systems development life cycle (SDLC) is a process on information system development process that can support business needs, design systems, build and send them to users. Agile development is a method of system development that is done in a simple way, the author of the idea plans the development of an existing system. Collaboration with the developer is carried out to analyze existing systems, designing the system, and implement the system. Wireless and location-based indoor air quality monitoring system can measure six air quality parameters which include dust particles, air temperature, relative humidity, carbon monoxide, and volatile organic compounds. Monitoring these parameters is done in real time and it can be a solution so that the monitoring, recording and reporting systems can be done swiftly with minimum resources.*

Index Terms- *air quality, indoor, monitoring, system*

I. Introduction

In 2016, 91% of the world's population did not breathe clean air, while more than half of the global urban population were exposed to outdoor air pollution levels at least 2.5 times above the safety standard set by WHO. It is estimated that in 2016, outdoor air pollution in both cities and rural areas caused 4.2 million deaths worldwide, while indoor pollution caused a further 2.8 million deaths, a total of 7 million, or one in eight, deaths globally. Housing conditions, in addition to fuels used for heating and cooking, are matters of substantial importance for public health. (1). The WHO Housing and health guidelines highlight that "improved housing conditions can save lives, reduce disease, increase quality of life, reduce poverty, help mitigate climate change and contribute to the achievement of a number of Sustainable Development Goals. Housing is therefore a major entry point for inter-sectoral public health programs and primary prevention. (2).

It has been estimated that people spend about 90% of their time in both private and public indoor environments, such as homes, schools, work places, transportation vehicles, etc. therefore, indoor air quality has a significant impact on health and quality of life in general. For many people, the health risks from exposure to indoor air pollution may be greater than those related to outdoor pollution. In particular, poor indoor air quality can be harmful to vulnerable groups such as children, young adults, the elderly, or those suffering chronic respiratory and/or cardiovascular diseases. (3).

Poor indoor air quality can cause health problems, it is necessary to take continuous measures by all parties. The indoor air quality guidelines aim to provide a reference for homeowners, house occupants, housing developers, the Government, provincial governments, and district/city governments in an effort to improve air quality in the home space. These include air quality requirements, impacts, risk factors, and efforts to improve indoor air quality. Indoor air quality monitoring is carried out by environmental health workers of the health center and district/city health agencies (4). Indoor air quality monitoring system is currently carried out by health workers by carrying measuring instruments and make measurements directly at the location. Based on these conditions, wireless and location-based indoor air quality monitoring system needs to be developed so that it can provide the latest data for health workers. Health workers only need to come once to the location to install the tool and then be able to see the measurement results from the dashboard site provided.

Indoor air quality can be affected by various chemicals, including gases (i.e., carbon monoxide, ozone, radon), volatile organic compounds (VOCs), particulate matter (PM) and fibers, organic and inorganic contaminants, and biological particles such as bacteria,

fungi, and pollen. Among the factors that influence the estimation of human exposure to indoor air pollution, the pattern of human behavior and activity play a fundamental role. (3). The indoor air quality requirements as a reference for healthy air are as follows (4):

A. Physical quality parameters:
   1. Particulate Matter/$PM_{2.5}$ 35 $\mu g/m^3$ (24 hours)
   2. Particulate Matter/$PM_{10} \leq 70$ $\mu g/m^3$ (24 hours)
   3. Air Temperature 18-30 °C
   4. Relative Humidity 40-60 % RH

B. Chemical quality parameters:
   1. Carbon Monoxide (CO) 9,00 ppm 8 hours
   2. Volatile Organic Compound (VOC) 3 ppm 8 hours

These six parameters can be measured by air quality sensors of Arduino based microcontroller. It is important to estimate these six parameters because the evidence on airborne particulate matter (PM) and its public health impact is consistent in showing adverse health effects at exposures that are currently experienced by urban populations in both developed and developing countries. The range of health effects is broad, but are predominantly to the respiratory and cardiovascular systems. The epidemiological evidence shows adverse effects of PM following both short-term and long-term exposures (5).

Temperature and humidity also have a strong and significant impact on the perception of indoor air quality, the perceived air quality decreases with increasing air temperature and humidity (6). Various studies have been conducted on the health risks of dampness and fungi in houses, and few studies in work places and schools. The paper by Lanthier-Veilleux et al. shows independent contribution of residential dampness or mold to to asthma, allergic rhinitis, and respiratory infections among students at the Université de Sherbrooke, Quebec, Canada (7).

Household air pollution (HAP) from the combustion of biomass fuels are still commonly used in developing countries and release many air pollutants, such as carbon monoxide, free radicals, and PM, in particular $PM_{2.5}$, which may be linked to several health complications, including low birth weight, cardiovascular disease, tuberculosis, and cataracts (3). The study of Kurti et al. determined HAP exposure was associated with reduced lung function and respiratory and non-respiratory symptoms in Belizean adults and children (8). The research conducted by Medgyesi et al. shows the effects of exposure to biomass fuel cookstove emissions on women in rural Bangladesh, associated with acute elevated $PM_{2.5}$ concentrations and decreasing pulmonary function (9).

II. RESEARCH ELABORATIONS

Data and information on air quality will be very useful if put together and organized on the database. The database is a collection of organized facts and information. Telecommunications is the transmission of electronic signals that transmit data so an institution can carry out their works through a computer network. Networks connect computers and equipment in buildings, across the country, or throughout the world. The internet is the largest computer network in the world that freely exchanging data and information (10). Data and information that is exchanged freely is managed in a database management system (DBMS). The DBMS is a collection of programs that manage database structures and control access to data stored in the database. Manipulating database includes retrieving certain data, updating databases, and generating reports from data (11).

The data manipulation language in the DBMS is used to add, change, delete, and retrieve data in the database. This language contains commands that allow users and programmers to extract data from the database to fulfill information requests and develop applications. The most widely used data manipulation language today is Structured Query Language or SQL. HTML commands are used to communicate with network servers that forward requests for data to software that translates HTML commands to SQL. The DBMS accepts SQL requests and provides the required data. Computer devices transfer information from the internal database to the network server and sending it in the form of dashboard site to users (12). Relational DBMS uses SQL to translate user requests into instructions for retrieving requested data. The entity relationship (ER) model is the current standard on database implementation. An entity represents a certain type of object in the real world which means that the entity can be distinguished so that each entity event is unique and different, a location for example, while an attribute is a characteristic of an entity. Relations between entities or relations models come from mathematical concepts known as relations which are considered as a structure consisting of intersecting rows and columns (tables) (12).

Dashboard site is a visualization instrument that provides information of data extracted from the database. Dashboard can be used for increased awareness, trends, and comparisons between existing plans and actual conditions, visualized in a nicely simplified user interface (13). User experience is one of the main features of the dashboard. Users are consumers of information presented on the dashboard (14). Dashboard criteria are classified into 7 main categories including user customization, knowledge discovery, security, information delivery, warnings, visual design, and system integration and connectivity (13).

DBMS and dashboards are established by following the cycle of systems development life cycle (SDLC). SDLC is a process to determine how an information system can support business needs, design systems, build and send them to users. SDLC follows four basic stages in the form of planning, analysis, design, and implementation. The agile methodology focuses on streamlining system development processes by eliminating a lot of modeling and documentation and the time spent on those tasks. Careful planning ensures that Agile

system development can be carried out properly. Through the simple stages of system development, the plan is included in analysis, design, and implementation. (15).

Establishing wireless and location-based indoor air quality monitoring system is done by developing a data collection and monitoring system, providing database management system, and building a real time and location-based dashboard that provides information on air quality monitoring system. Agile system development is used to create a database management system and information visualization dashboard for wireless and location-based indoor air quality monitoring system in accordance with regulations in Indonesia. Database management system is based on relational DBMS that uses SQL to translate user questions into instructions for retrieving requested data. SQL makes it possible to extract data with far less effort in the database environment. The relation model is the current standard database implementation. The database application relationship with SQL contains (11):

1. An interface that allows end users to interact with data that is presented in the form of information.
2. Collection of tables stored in the relational database.
3. SQL engine that is hidden from the end user, SQL engine executes all requests or data requests.

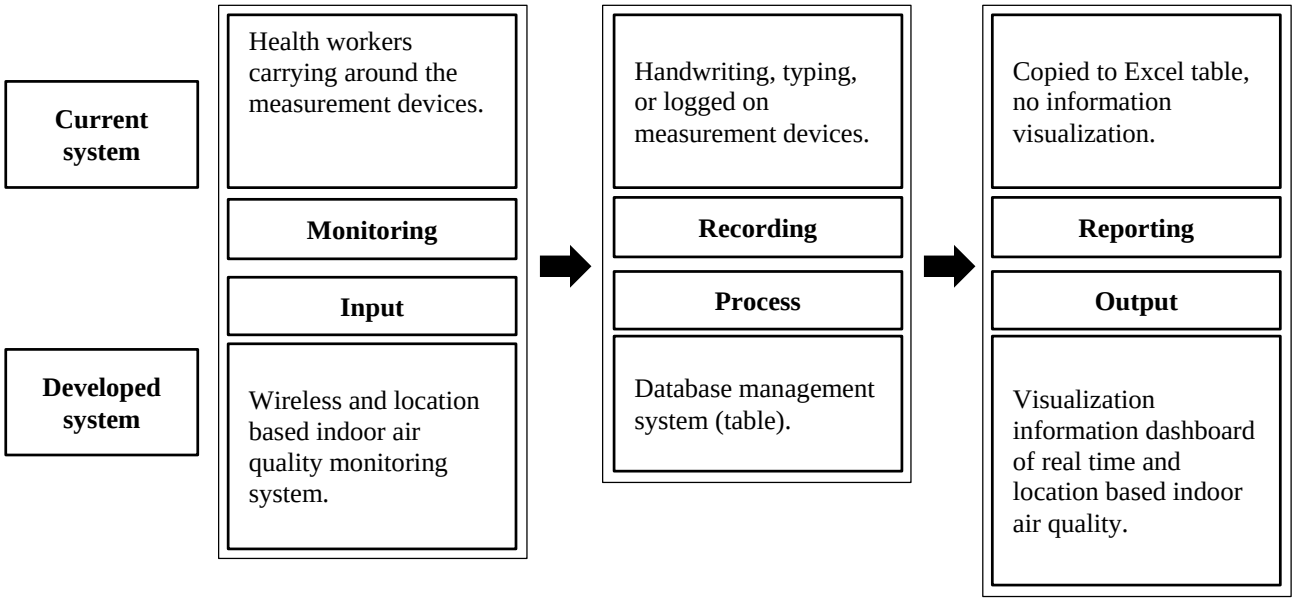
The dashboard is created as a visualization instrument, using HTML and PHP, that provides information visualized in a nicely simplified user interface. The indoor air quality dashboard contains information of six parameters of indoor air quality (particulate matters, air temperature, relative humidity, carbon monoxide, and volatile organic compound) at the place where instrument is installed with the map as a main display.

III. RESULTS OR FINDINGS

The measurement of indoor air quality is currently done by environmental health workers carrying instruments and measure directly at the location. The limitations of the current system are as follows:

1. Input
   Indoor air quality is measured directly by the measuring instruments, recording is done by hand writing. Selected test reports randomly carried out by agencies that have indoor air quality measuring devices. The limited number of environmental health workers and measuring time ranging from 8 to 24 hours is a limitation of current indoor air quality monitoring system.
2. Process
   Tables in the form of handwriting converted into Microsoft Excel format. Unstructured and scattered reporting processes randomly create data of indoor air quality.
3. Output
   Scattered data of indoor air quality makes it difficult to identify environmental health impacts on health. The scattered data must be sorted and searched one by one, this is time consuming and there is possibility that the data is incomplete so the information obtained is only partial.

Figure 1. Analysis of Current Systems and Developed System



Difficulties in monitoring indoor air quality, the limited number of environmental health workers, and the length of time in measuring indoor air quality are the main problems in the monitoring, recording, and reporting system of indoor air quality. The old method of monitoring, recording, and reporting systems needs to be replaced with wireless and location based indoor air quality monitoring system through data obtained in real time.

Data flow diagram (DFD) of indoor air quality monitoring system is divided into internal and public system. Both are divided by making different sub domains with DNS, access will be transferred between the two. Internal system administrators can access the entire system directly by using token/username and password to different server IPs. Public users can access the dashboard and download tables of indoor air quality data.

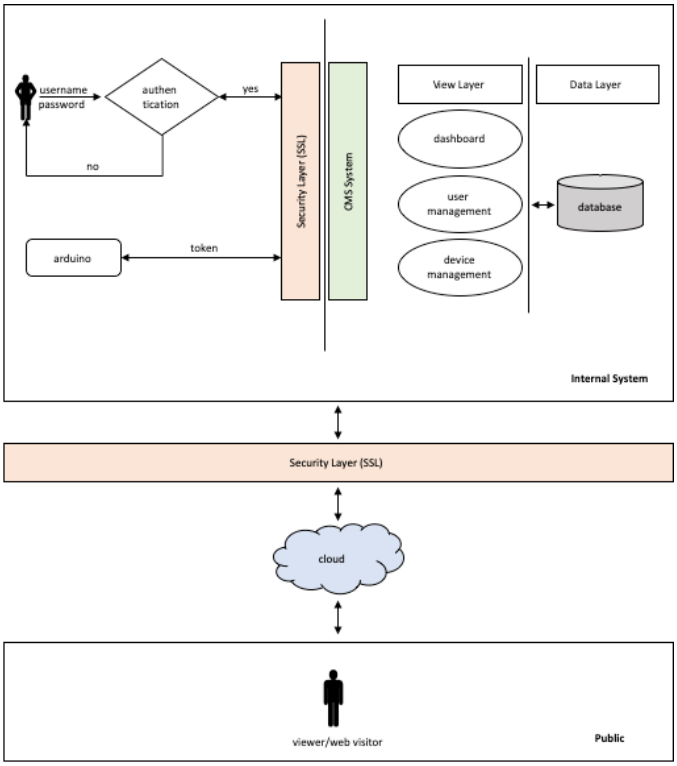


Figure 2. Data Flow Diagram Indoor Air Quality Monitoring System

DBMS tables consist of user table as data storage of CMS system user, device table that serves as a data storage for monitoring devices, measurement table as data storage for measurements and units, transaction table as data storage for all measurement results, and history table as data storage if there is a change in value on each table. All tables of data are stored in the DBMS server and can be accessed only by the site administrator. The programming language used is PHP and the table structure created using mySQL. These data tables are used to display information on the site dashboard.

The dashboard design is a simple modern design that makes it easier for users to navigate and explore the site. Mockup is made as a reference guide in creating a user interface. The results of the mockup are made into dashboards that can be accessed using a computer connected to the internet.

Figure 3. Dashboard Mockup of Indoor Air Quality Monitoring System

Data obtained from indoor air quality monitoring devices is stored with the DBMS method in table form. Downloadable table contains data of location, time, parameters, and measurement values. Data tables can be used as basic data as well as a system of recording and reporting for relevant agencies. The table is also useful for viewing the history of indoor air quality and associating it with activities that occur at a particular time. Data tables can also be used to observe the indoor air quality trends so that it can be used as a reference in policy making and to change people's behavior toward healthy life.

Table 4. $PM_{2.5}$ Parameter of Indoor Air Quality Monitoring Data

Parameter: $PM_{2.5}$

Threshold: 35 μg/m^3

Location: Public Health Faculty, Universitas Indonesia, Depok

Number	Time	Value	Threshold
1	09.00	36	Unsafe
2	09.10	31	Safe
3	09.20	27	Safe
4	09.30	24	Safe

The dashboard can be accessed by visiting the address airwatch.id and the dashboard display will be adjusted automatically on bigger or smaller screen. Overall the dashboard consists of one main page with the largest display is a map. There is a flag icon on the map where the indoor air quality monitoring device is installed. The information displayed when the user selects the flag icon is the initial information of indoor air quality. Users can change the initial information by selecting the parameters that will be displayed in the upper right panel then full parameter will be displayed at the bottom.

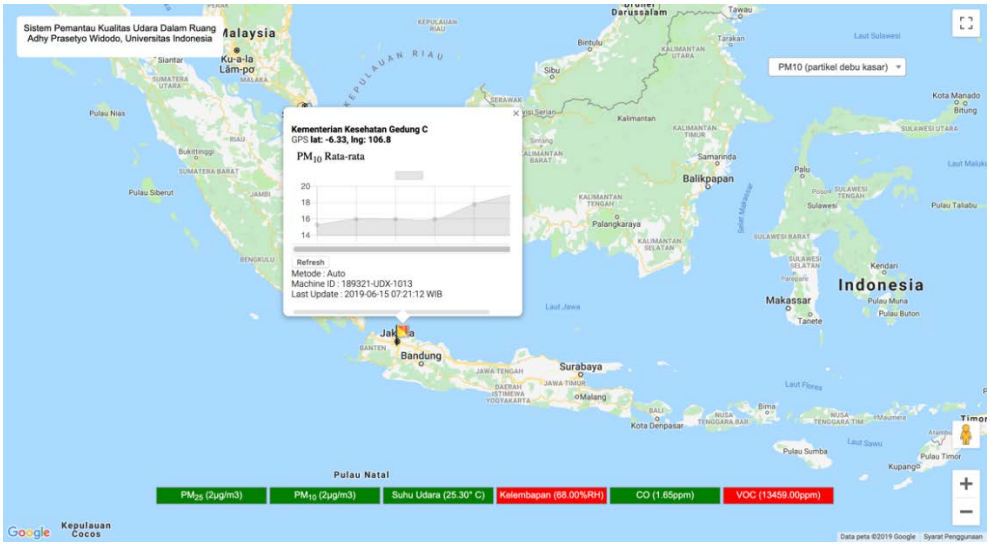


Figure 5. Dashboard of Indoor Air Quality Monitoring System

Device used on indoor air quality monitoring systems is based on Arduino microcontrollers with air quality measuring sensors and modules. Indoor air quality sensors are for the measurement of particulate matter, air temperature, relative humidity, carbon monoxide, and volatile organic compounds. The module consists of a GPS module to determine the location where a device is installed and a Wifi module to access data wirelessly via the internet. Data collected by sensors is displayed in the form of indoor air quality parameter information on the dashboard site.

The programming platform used to develop the system is PHP and mySQL. This is a native version of PHP so there will be limitations in scalability. Compared with other programming platforms, PHP is classified as lacking in performance and operational input/output. This can be a potential problem if accessed by many users and site visitors at the same time. The advantages of the PHP programming platform are its instant characteristic and PHP have a huge library support. PHP is also easy to understand, so it can be easily integrated with other systems. The mySQL database manipulation program is still the best relational DBMS for site applications. The mySQL database programming platform can be used on a small and large scale program.

The cost of the developed system can be reduced because there are several sensors in one device compared to the device currently used. The cost of measurement is cheaper because it can be done remotely without transportation expenses. The air quality monitoring

equipment is quite practical because it only requires access to electricity (DC current) and internet (Wifi network) for its operation. Everyone can access the information from dashboard whenever and wherever they are. Data storage of measurement results is made automatic and real time. The developed system can be upgraded and adjusted to the regulation threshold or new regulation threshold. Long-term monitoring can be done easily because the device only needs to be installed, it doesn't have to be held continuously like currently available devices. Reading the results is easier because it can use a bigger screen, it can be done automatically in real time and history can be saved to be accessed later.

Air quality monitoring can be easily carried out in a home room, workspace, or public space such as a place to eat, lodging, school, industry, health care facilities, and other public spaces in accordance with applicable regulations. The environmental health workers only need to come to install and carry out supervision and maintenance of the installed devices. Environmental health workers have been trained and have facilities to transmit data and access environmental health information digitally. This makes the Health Agencies and Health Centers ready to implement indoor air quality monitoring system. The data and information obtained can be integrated with the existing environmental health quality monitoring system.

The most important thing in the dissemination of information today is the need to ensure that information is considered as a communication and participation, not just simple actions in presenting data, regardless of their usefulness or relevance to the recipient (16). The indoor air quality monitoring system can be used as a decent decision support system as an intervention to improve health. Monitoring pollutant levels indoor is important for environmental health efforts and energy efficiency (17).

Indoor air quality measured in an industrial environment provides consistent data flow for reliable management of building automation systems and provides a platform for informed decision making (18). Easy intervention that can be done by the homeowner or the person in charge of the building can have a tremendous positive effect on indoor air quality in many situations. This is an important practice that can be instructed to the person in charge or manager of the house or building through the dashboard on indoor air quality (19).

IV. CONCLUSIONS

Automatic indoor air quality monitoring system can be a long-term measurement solution and a solution to the limited number of environmental health workers. Wireless and location based indoor air quality monitoring system equipped with a database management system (DBMS) can support environmental health workers in carrying out monitoring, recording, and reporting of indoor air quality. The indoor air quality monitoring dashboard can measure and monitor six air quality parameters including dust particles, air temperature, relative humidity, carbon monoxide, and volatile organic compounds in real time and location-based.

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