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An Internet of Things Technology for Detection and Prevention of Mold

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Abstract: *The susceptibility of building materials to mold growth varies. Some are tolerant to high relative humidity in the ambient air without mold growth occurring, while others are less tolerant, and mold can grow in relative humidity as low as 75%. In the heat of summer, the damages from molds become serious due to the effect of temperature and humidity according to seasonal characteristics. In this study, a smart sensor technology based on Internet of Things for detection of mold growth in indoor/outdoor environment is presented. The developed system comprises a cloud-based web application that communicates with the sensing device, and a sensing device that comprises a case, an electronic circuit, microcontroller and sensors. The mold detection is performed by recording the 24/7 profile of temperature and humidity variations.*

Keywords*: Mold growth, Internet of Things, Temperature, Humidity, Web Application*

I. Introduction

Molds are part of the natural environment and can be found almost everywhere in the environment, both indoors and outdoors. The presence of mold is a major issue for anyone anywhere not only because of the potential property damage, but also because it can pose serious health risks to humans and animals due to production of mycotoxins and microbial volatile organic compound[1-6].

Based on Moller et al.[7], relative humidity (RH), moisture content and temperature content are the most critical factors for the growth of mold or its deficiencies, although the substrate properties and mold species are also important. Most studies have been carried out under the stable laboratory conditions where materials are in equilibrium with a constant atmosphere. Under these conditions, mold growth does not occur when RH is maintained below 75-80%, as most fungi do not germinate and grow below this level. A small amount of growth of some fungus will occur on some susceptible materials under 80% RH, but the growth is very slow. In general, if RH is greater than 80%, the rate of germination of mold is increasing[8-11].

A relative humidity of 40% to 65% is generally considered to be a comfortable and healthy room climate. There are several factors that affect the relative humidity such as domestic activities in home, shower and baths use, and weather conditions. Based on Kolawole[12], the critical point of humidity are when the relative humidity reaches the threshold value of 100%. The starting point for mold to growth is at room humidity of 80%.

Despite significant improvements in sensor technologiesfor detection of mold in indoor environments, these sensors are large, costly and labor intensive. In this study, we propose a low-cost sensor system based on Internet of Things (IoT) that can be easily integrated with an air-sampling unit for on-site monitoring of mold contaminations[13,14].

In the concept of smart home using IoT, many applications are integrated and intelligent. Smart home is bawd on application symbiosis that allows homeowner to monitor and control various useful applications such as better energy efficiency, security control, monitoring and home care. One of common smart application installs in smart home is temperature and humidity monitoring application. There are many monitoring devices in market, but most of them are not portable, costly, some of them did not store data for further analysis, and most applications only provide data display with no alert mechanism. Without proper notification from the system, it is difficult for the users to be alerted so appropriate actions can be taken immediately. For example, a high relative humidity may cause a breeding of mold and fungus in a room. If the homeowner is not concerned or unaware with the humidity condition in the room, this situation may lead to the growth of mold and cause property damage and major health issues. Moreover, there are no existing systems that can alert or notify people in the room in order to help them to control humidity condition to prevent the growth of mold[15,16].

Therefore, this study focuses on solving the above issues in temperature and humidity monitoring system. The aim of the proposed solution is to developan IoT based device, named SmartyLog, which integrates with cloud service that monitors temperature and humidity and alerts user according to a set threshold if growth of mold and fungusare suspected. The study used ARM Cortex-M Series NUCLEO-F401RE microcontroller as the main device, integrated with sensor extension board (X-NUCLEO-1KS01A2 with HTS221) and Thing5peak cloud service. The X-NUCLEO-IKS01A2 and ThingSpeak were used to measure the humidity and temperature condition and store data respectively.

II. Method

Microcontroller: A microcontroller consists of a central processing unit (CPU), a memory unit (random access memory (RAM), read only memory (ROM)), input and output (I/O) peripherals, docks, counters, which are installed in one integrated circuit (IC). The microcontroller can be interfaced effectively to outer peripherals like serial ports, Bluetooth, and Wi-Fi. Most microcontroller utilizes reduced instruction set computer (RISC) design. Figure 1 depicts the microcontroller architecture.

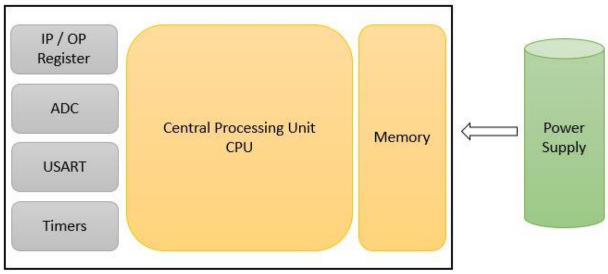

Figure No. 1: Microcontroller Architecture

There are several microcontrollers that are commonly used by researchers and inventors such as ARM-Corte, Arduino, Raspberry Pi, and BeagleBoard. For example, a work by Ling et al. (2015), utilizedmicrocontroller that is associated with Zigbee communication to monitor human body temperature. This system provides body temperature estimation without being intrusive and uncomfortable. It is an optical measurement using electromagnetic radiation (infrared radiation). The instrument utilizes the infrared signal to decide the temperature. However, due to familiarity constraint, this proposed work used ARM-Cortex in the implementation of the IoT device.

Advanced RISC Machine (ARM): ARM-Cortex microcontroller is the most mainstream microcontroller in the computerized embedded framework world and most of the industries incline toward ARM microcontrollers since they are cost effective and are used for different applications. Figure 2 shows the NUCLEO-F401RE Development board for STM32 which was used in this study.

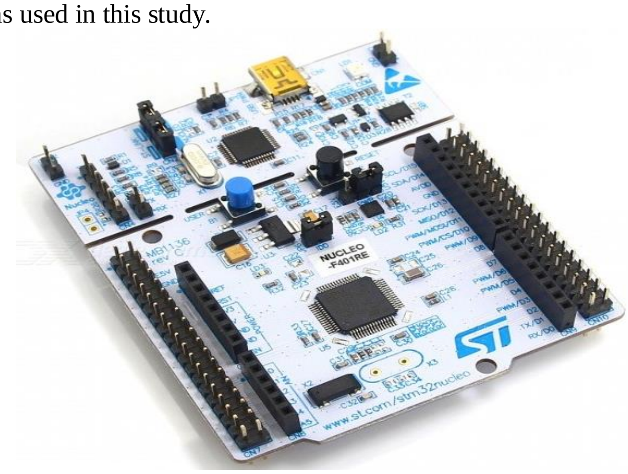

Figure No. 2: NUCLEO-F401RE Development Board for STM32

The ARM design offers isolate information and direction transports for communication with the ROM and RAM memories. It comprises a 3-stage pipeline to fetch, decode and execute the direction successively. The cortex processor is a cost sensitive gadget, which is utilized to lessen the processor zone and has broad enhancing intrude on dealing with framework troubleshoot abilities. Figure 3 illustrates ARM Microcontroller Architecture.

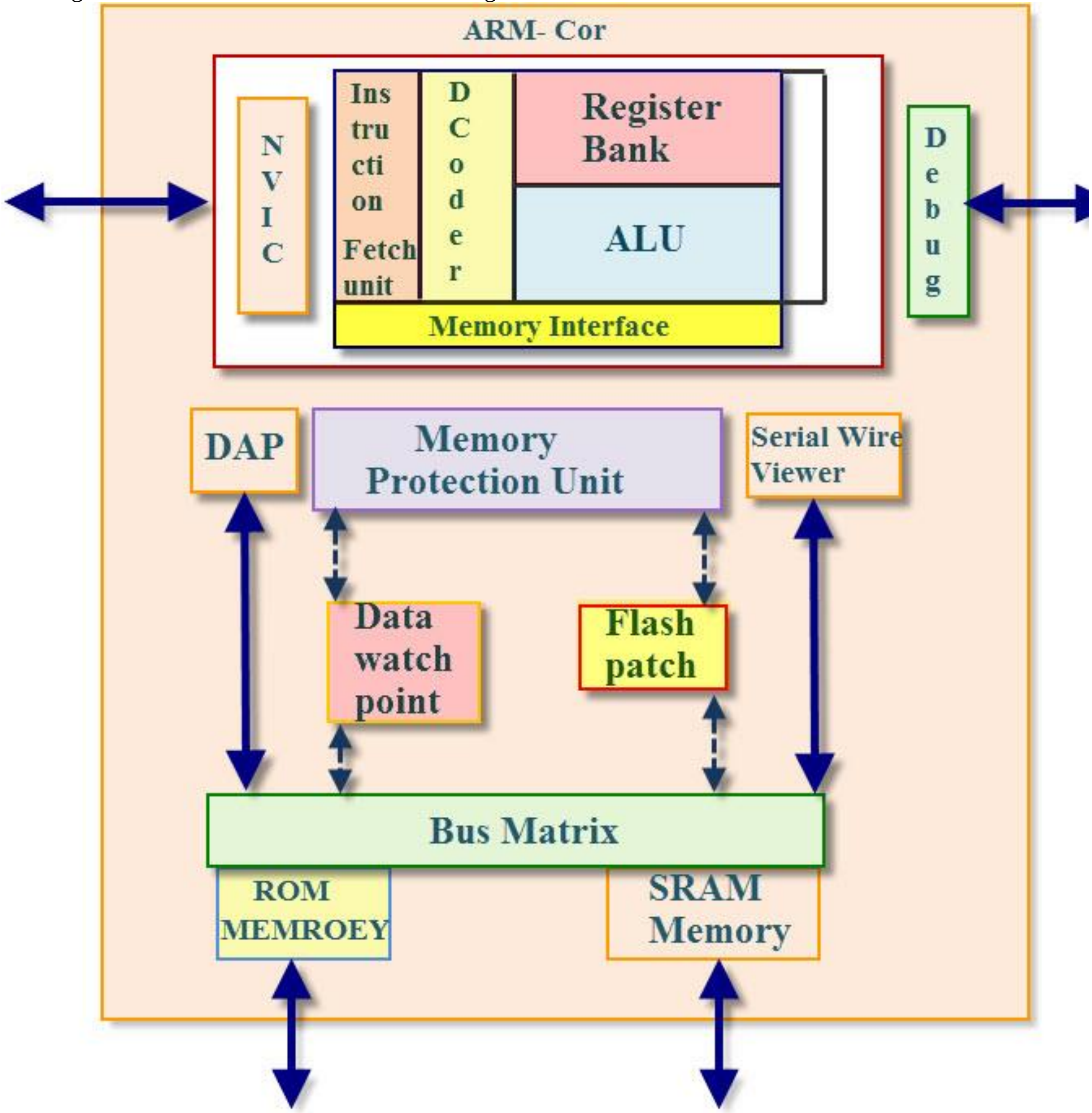

Figure No. 3: ARM Microcontroller Architecture

This study aims at preventing deer-vehicle collisions, as the collision is a great degree of risk, and can harm drivers. The prototype consists of seismic sensor, ARM microcontroller, buzzer and digital to analog converter. In order to prevent the collision, this device alerts the deer of approaching vehicles.

Mold: Mold is a group of certain relatively mild fungus that can often be colorful and may appear as spot or blurred masses. Molds are everywhere and widely used for benefited purposes in the food industry, in medicine and science. The mold growth process on the inner surface generally includes germination, growth and sporulation. The basic requirements for mold growth on the inner surface are spores of mold, oxygen, fat and dust on the surface, temperature and humidity available (either on its own surface or as high relative humidity). If these conditions are present in the formation, mold growth can occur on the inner surface.

Cloud Storage: Cloud storage services may be accessed through a co-locate cloud computer services. According to Nakhuva and Champaneria (2015), there are numerous IoT cloud platforms. These cloud platforms are compatible with any type of microprocessor or microcontroller. The cloud service gives the client to control and monitor intended parameters from any place.

ThingSpeak is an application platform for development of IoT systems. It can help to fabricate the application, which works based upon the information gathered by sensors. ThingSpeak is an open information platform for IoT application development. ThingSpeak is an ideal complement to a current enterprise system to take advantage of the IoT. It gives the capacity to incorporate information with an assortment of third-party platform, systems and technologies. Some features of ThingSpeak are as follows:

- **Collect:** Sends sensor and gadget information gathered from it to thecloud with the goal that the information can he further analysed.
- **Analyse:** ThingSpeak can analyse the information got from sensors orgadgets and can derive the virtual portrayal of the information.
- **Act:** Considering the analysis, it will trigger the activity to empower functioning of IoT system and application.

SmartyLog: The Proposed Solution: This section lists out the details of the proposed technology, named SmartyLog, which is temperature and humidity monitoring system consisting of multiple components. The main board is ARM-Cortex NUCLEO-F401RE microcontroller, the second board is the X-NUCLEO-IKS01A2 with HTS221 sensor that collects the environment humidity and temperature data, ThingSpeak is the open source cloud service and alert notification using e-mail. Figure 4 shows the proposed design for the proposed IoT device.

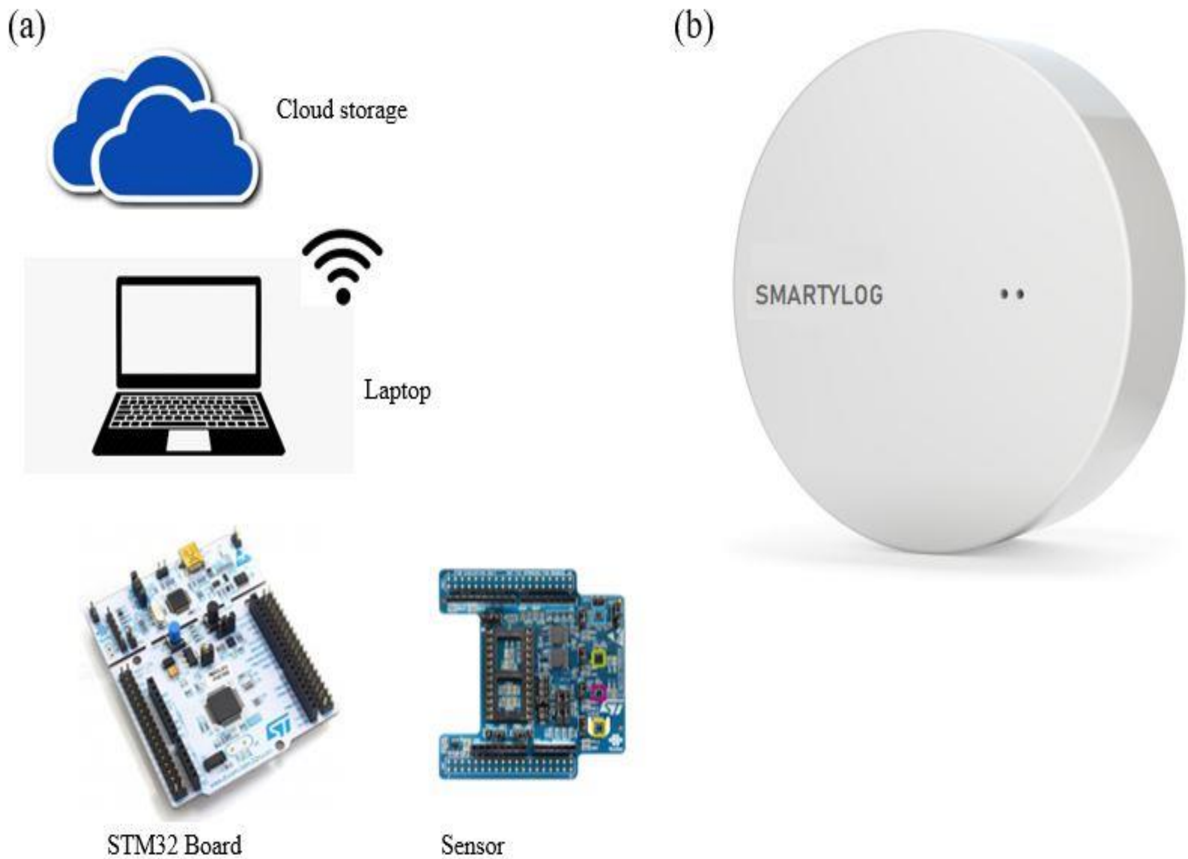

Figure No. 4: SmartyLog – (a) Proposed IoT device for Temperature and Humidity Monitoring System, (b) SmartyLog Prototype

The methodology used in this study is Rapid Application Development (RAD) that is an alternative to commonly used waterfall development model, which focuses largely on planning and sequential design practices.

The RAD model as illustrated in Figure 5 involving four main phases that are requirement planning, user design, construction and testing and cutover.

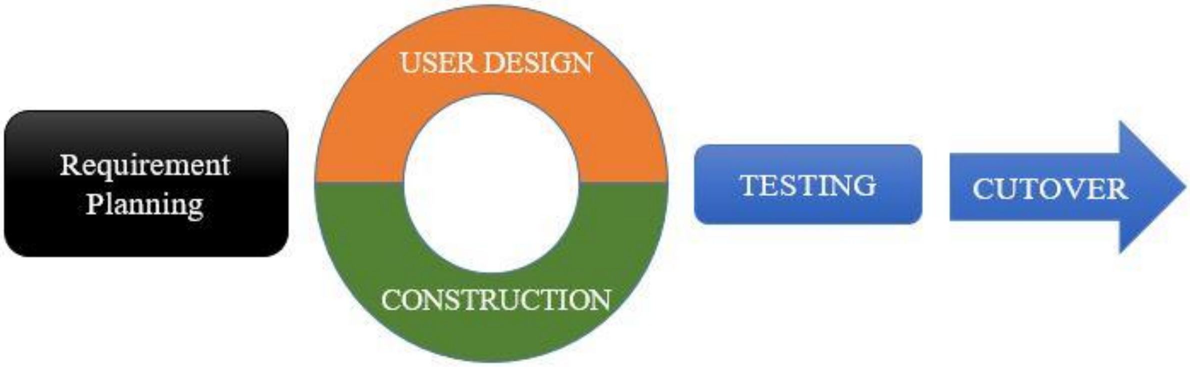

Figure No. 5: Rapid Planning Development Model

Figure 6 illustrates the flow chart of the system. Firstly, the X-NUCLEO-IKS01A2 sensor measures and displays the data of the current humidity condition in the room. After that, the collected relative humidity data are sent to the ThingSpeak cloud storage and are analysedto determine if the currentrelative humidity is above the configured threshold. If so, the systems notifies user via email/text message.

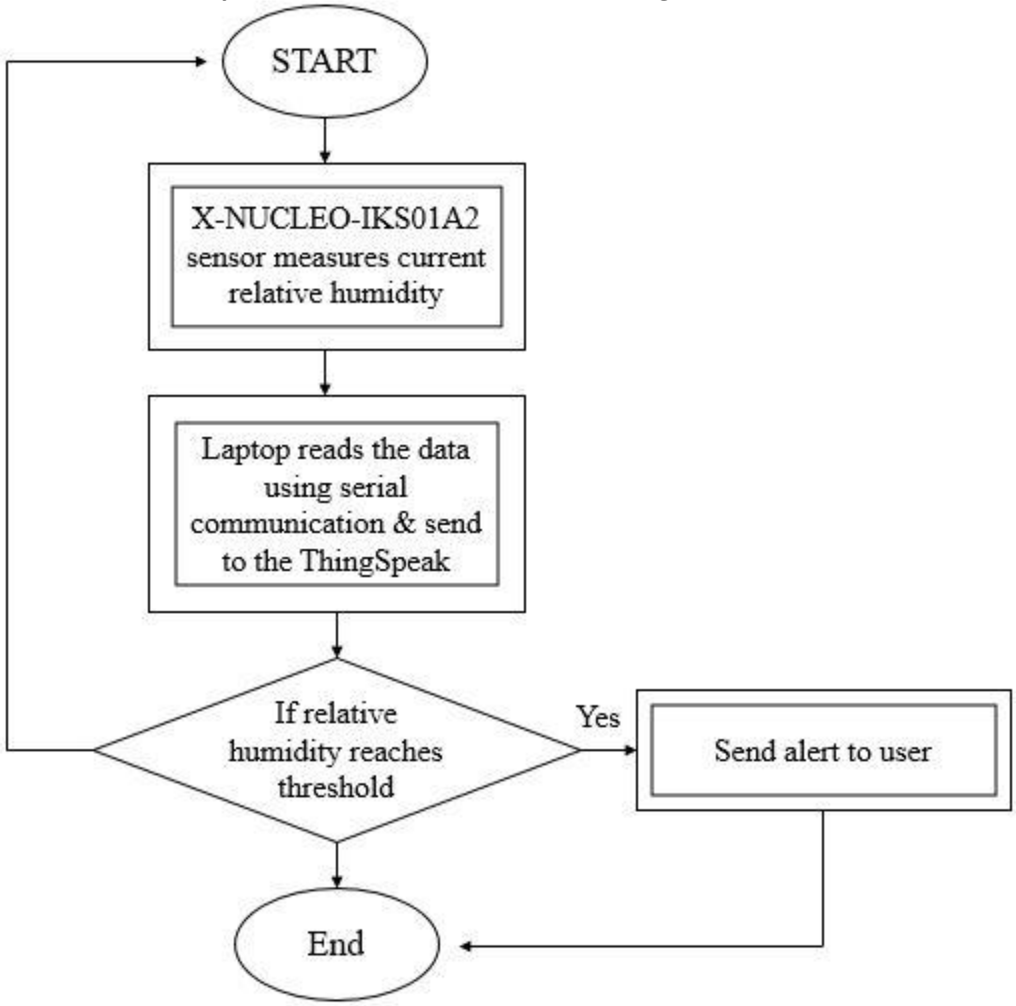

Figure No. 6: Flowchart of the System

Implementation of SmartyLog: The proposed system is divided into three phases, whichare data acquisition phase, machine phase and data storage phase. Each subsection describes setup environment for each phase respectively.

- **Data Acquisition Phase Setup:** In this phase, two hardware were used, namely NUCLEO-F401RE and X-NUCLEO-IKS01A2. NUCLEO-F401RE is the main board use to run the program. X-NUCLEO-IKS01A2 is the environmental sensor boards. Figure 7 shows the X-NUCLEO-IKS01A2 integration to the NUCLEO-F401RE main board. Then, the main board is connected to the laptop using the USB cable (COM4).

Figure No. 7: Block Diagram of Data Acquisition Phase

- **Data Collection and Mold Indicator:** The humidity data and temperature data from read using NUCLEO-F401RE and X-NUCLEO-IKS01A2 sensors and used for prediction of mold growth. The basic version of the mold growth model was based on large laboratory studies with pine sapwood[17]. The mold growth intensities were determined at the constant conditions using mold indexes (Table 1). Based on the studies under varied and fluctuated humidity conditions the mold growth model presented by Hukka and Viitanen[18] was used in this study.

Table No. 1: Mold Index for Experiments and Modeling

Index	Description of the growth dare
0	No growth
1	Small amounts of mold on surface (microscope), initial stages of local growth
2	Several local mold growth colonies on surface (microscope)
3	Visual findings of mold on surface, < 10 % coverage, or < 50 % coverage of mold
4	Visual findings of mold on surface, 10 - 50 % coverage, or >50 % coverage of mold
5	Plenty of growth on surface, > 50 % coverage (visual)
6	Heavy and tight growth, coverage about 100 %

- **Data Storage Phase Setup:** This phase describes the data storage phase setup as depicted in Figure 8. The cloud storage is used to store the humidity and temperature data in the cloud. A popular cloud based platform in IoTsystems is ThingSpeak as it is an open source platform and enables user to view the collected data in a real-time.

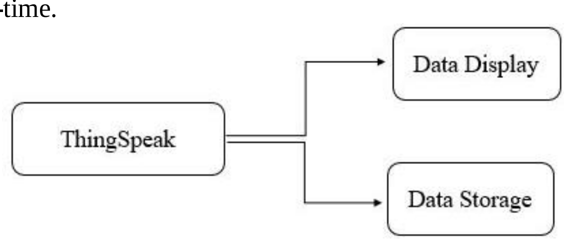

Figure No. 8: Block Diagram for Data Storage Phase

Testing of SmartyLog: The SmartyLog was deployed in a damp area for testing and validation setup in order to test its functionality including connectivity of sensor and cloud service, and alert notifications testing (Figure 9).

Figure No. 9: Deployment of SmartyLog in Damp Area for testing and validation

The main program is Node.js script that was executed by using command node P5M.js COM4. The humidity and temperature data collected from the X-NUCLEO-1KS01A2 with NUCLEO-F401RE sensor were used for calculation of Mold Index and mold growth notifications (email and text messages) were generated if Mold index was greater than 200 (Mold index values generated from formula presented in [18] were multiplied by 100 to present it as a percentage). Figure 10 shows the developed web platform for monitoring Mold index and user alert notification.

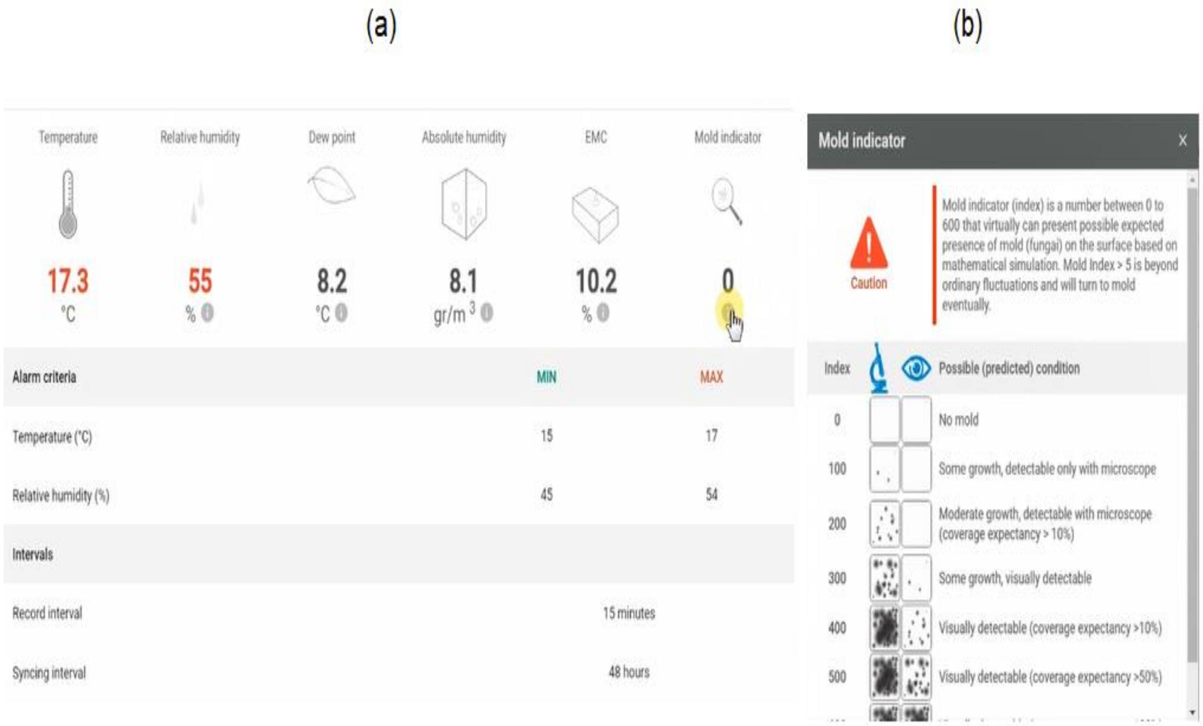

Figure No. 10: (a) Snapshot of Developed Platform for Monitoring Mold Growth and Alerting User, (b) Mold Growth Criteria

III. Conclusion

This paper proposed an IoT device using NUCLEO-F401RE and X-NUCLEO-IKSO1A2 sensor board to detect mold using humidity and temperature data. The monitoring system aimed to ensure the level of humidity is not exceeding a pre-defined threshold, which is generally 80%. This is the main step to prevent the mold growth. The mold releases elements that can harm the human/animal health if exposed for a long period. The monitoring system provides a web-based cloud application to display the percentage of humidity and temperature reading in real-time and store the collected data for further analysis. The system also alerts users viaemail/text message if the percentage of humidity reaches the threshold so that necessary actions can be carried out to ensure mold growth is prevented.

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