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A novel IoT architecture for measuring and visualizing influence of common factors on house dust concentration

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Abstract

The house dust mites are considered to be an allergen source and a main cause of allergic rhinitis and allergic asthma. House dust mites, their feces and other allergens which they produce are usually major constituents of house dust. Any stir in the air causes settled dust, and therefore allergen source found in it, to become airborne and thus easier to be inhaled by people, possibly causing different kinds of allergic reactions (sneezing, for example). In this paper, the correlation between common home activities (walking around, bed making, vacuuming etc.) and airborne dust concentration is examined. In order to do so, a novel Internet of things architecture is proposed that is capable of establishing that correlation. This proposed system not only collects dust concentration but it also visualizes it in an easy to understand and interpret way.

Keywords: Internet of things, IoT, Airborne dust, Dust measurement, Data visualization.

1. INTRODUCTION

As shown in [1]-[4] and numerous other papers, there is a consensus that an association between house dust and allergy/asthma has been proven. Those papers also show that a major allergen in house dust is related to the presence of house dust mites [13]. Many researches have proven that this problem is not localized to a certain geographical areas but is spread through the whole world, as shown in [2] and [5]. The types of house dust mites vary with geographical factor, but researches show that the most common species throughout the world are Dermatophagoides pteronyssinus, Dermatophagoides farinae and Euroglyphus maynei ([2] and [14]). The main motivation for this paper is the fact that house dust mites are a cause of health issues and that it would be beneficial if their presence in the air and concentration could be easily measured and visualized in a modern, easy to understand way.

In the house, place with the highest concentration of house dust mites is usually the bed, specifically, the mattress ([2] and [3]). Other than that, house dust mites can be found everywhere where there is dust: pillows, carpets, upholstered furniture, curtains etc. ([6] and [7]). As shown in [6], there is a clear association between indoor air humidity and the concentration of house dust mites in the dust. Indoor relative air humidity below 50% for extended periods of time will remove most of house dust mites [15]. If relative air humidity is above that level for only a couple of hours per day, it will allow house dust mites population to thrive [16].

Many works have examined theory behind dust becoming airborne and settled again (for example, [17]), so the aim of this paper is to provide an IoT (Internet of Things) system to empirically visualize which common activity causes most airborne dust particles. There are numerous methods for estimating the concentration of house dust mites in the dust, but most of them involve physical collection of samples from specific area of the house [7]. As the purpose of this paper is to measure influence of common factors like vacuuming, walking, running, bed making etc. on indoor dust concentration, it is not practical to manually collect samples from different surfaces. From the evidences found in [1], [3], [7] and other, for the purpose of this work we assume the following: if there are any house dust mites in the house, they will be also present in the dust. Therefore, whenever there is dust, there will also be mites in it, of course, if previously mentioned conditions are met. It is also true that if there are no mites in the house, there will also be no mites in the dust. In this way, instead of detecting mites, we detect dust: more dust means potentially more mites, and vice versa.

Many papers have examined concentrations of mites in the dust, both settled and airborne ([8] and [9]). As it can be understood from [10], allergic reactions are mainly triggered by inhaling airborne particles containing house dust mites' byproducts. This paper comes from a standpoint that dust when settled is not contributing to the allergic problem and settled dust concentration is not in the scope of this paper. When different common factors like vacuuming, walking, running, bed making etc. cause settled dust to become airborne, then it becomes the issue and comes in the scope of this work. After some time, airborne dust will settle and will go out of the scope again. Therefore, this paper aims to show an association between several common factors and dust concentration in the air and, by extension, the house dust mites that can be inhaled and cause allergic reactions.

In order to achieve its goal, this paper must provide a way to measure dust concentration in the air and correlate it with common factors. Many papers have conducted a research that included measuring airborne dust concentration and it comes down to detecting particulate matter less than 10 µm (PM10) and less than 2.5 µm (PM2.5), as shown in [10], [11] and [12]. This paper will propose an IoT architecture to measure airborne dust concentration and correlate it with common factors and to visualize concentration of those particulate matters. The aim is to show which common factor contributes how much to stirring dust and making it airborne. The following set of common factors is examined: bed making, venting the room, children running and jumping, vacuuming with regular vacuum cleaner, vacuuming with autonomous robot, using air-condition.

2. METHODOLOGY

In this section, the approach taken to solve a problem is described. Overall, the process can be described with three phases: designing and programming the IoT system capable of measuring and visualizing, performing actual measuring test runs to collect data and visualizing and interpreting the results.

There are many papers that describe the possible approaches to building an IoT system for dust concentration measurements, for example [18], [19] and [20]. Based on approaches taken by those papers, current industry standards in IoT and specific requirements of this project, this paper presents a slightly different approach. As a contrast to approaches that just collect data and store it in the database, this paper proposes a complete system that is designed and built to collects measurements, store them in the database and visualize them in an easy to understand and intuitive way.

An overall architecture of the proposed system is shown in Figure 1.

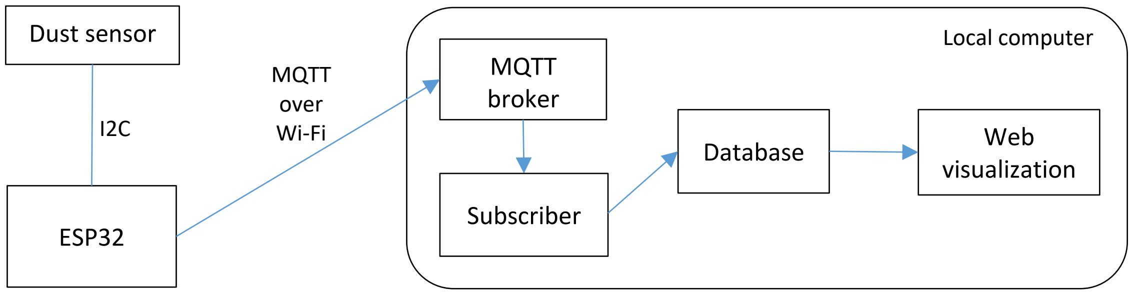

Figure 1: The architecture of the proposed system

The heart of the system is an ESP32 microcontroller board that includes 802.11b/g/n HT40 Wi-Fi transceiver. Microcontroller board is connected to a temperature and humidity sensor and also to a Honeywell HPM series particulate matter sensor. This dust sensor uses laser scattering on the particles where laser light is scattered on the particulate matter in the air, producing certain effect on the photo-detector in the sensor [22]. Electric signal from the photo-detector is amplified and processed internally using the Mie theory for scattering of an electromagnetic plane ([21] and [22]). As shown in [22], it is required to humidity correct readings of such a low-end dust sensor. However, since this is an indoor system and relative humidity never goes above 80%, the correction factor is 1.0 so measured value and corrected value are the same. The programming code running on ESP32 takes measurements every 1 second and uses standard MQTT protocol to deliver them to MQTT broker running on local computer. A subscriber in the form of Python program is subscribed to a defined set of topics so whenever a new telemetry is received on the broker, Python program receives it and stores it in relational database running on local SQL Server. Then, a C# web application running on the same computer is used to retrieve measured values from the database and visualize them, allowing end user to simply use Internet browser to access visualized data. The visualization in web application can be tuned by choosing data range and also by choosing sampling rate. Initially, data from last hours is displayed with sampling equal to 60, meaning, we take average value from 60 measurements in one minute and display it.

The advantages of this system are: measurement device is compact and Wi-Fi based so it is very easy to move it around the house; no external connection is required as all communication is done locally between measurement device and a computer; any changes to visualizations are easy to make because web application is custom made and not limited in functionality.

Actual measurements are described next. Since we are interested in airborne dust that can cause allergic problems, we want to measure dust in the approximately same height where human face might be. Therefore, Table 1 shows placements in the room and heights of dust sensor depending on the common factor measured.

Table 1: Details of common factors measured

Common factor	Sensor placement in the room	Sensor height
Bed making	50 cm away from the bed	1.0 m from the bed
Venting the room	Center of the room	1.5 m from the floor
Children running and jumping	Center of the room	1.5 m from the floor
Vacuuming with regular vacuum cleaner	Center of the room	1.5 m from the floor
Vacuuming with autonomous robot	Center of the room	1.5 m from the floor
Using air-condition	Center of the room, away from direct stream of air from air-condition	1.5 m from the floor

The following protocol was used for measurements. First, a baseline value was established by having absolutely no movement in the room for 1 hour. Because the dust concentration varies during the day based on external factors, it is necessary to establish the baseline before each measure and then use difference between measured value and baseline value to get dust concentration that become airborne because of observed activity. Since our measuring interval is only several minutes long, we assume that baseline value will not change in that period. After we get the baseline value, we perform the actual measurement by sampling dust concentration every 1 second. The actual length of the measurement depends on the time it takes airborne dust to settle and return to baseline value. Then, we give 1 hour of time to get completely settled dust and that airborne dust concentration returns to baseline value.

3. RESULTS

Figure 2 shows results when measuring dust concentration during and after bed making. As usual, one hour warm-up period was used before actual measurement to define baseline values for current external factors (only a part of that period is shown for clarity; all values < t_1 belong to warm-up period). Warm-up period finished at t_1 when bed making activities have commenced. These activities lasted for no more than one minute (time point t_2) and after that, settling period has started and lasted until t_3. Time point t_3 represents a point in time when average value in time slot was roughly the same as during baseline establishment.

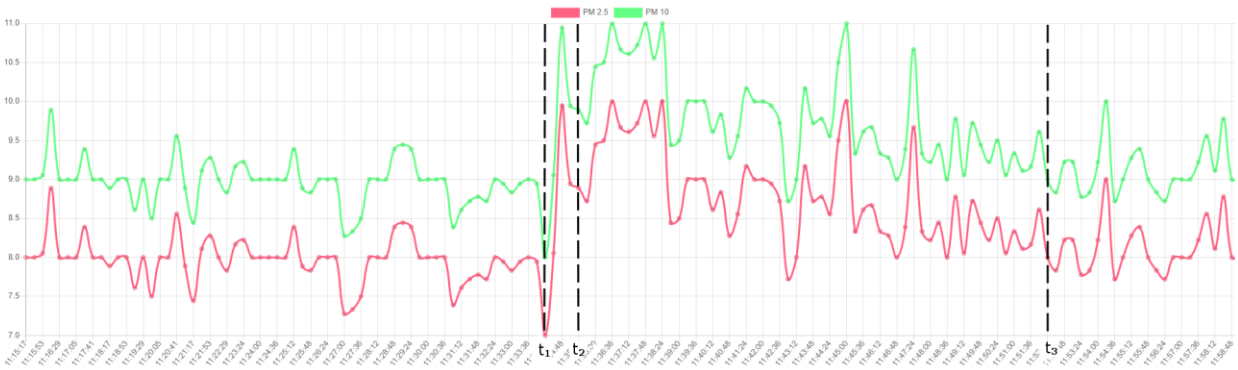

Figure 2: Bed making results

The purpose of the second test was to measure dust concentration during and after venting the room for the duration of 5 minutes. The whole setup was the same as with first test, resulting in Figure 3. Figures 4 through 7 show correlations between remaining common activities and dust concentration in the air. Figure 4 shows results of children playing in the same room as measuring device. There were three children, playing catch on the wooden floor without any carpeting. No other carpeted elements (pillows, carpets, upholstered furniture, curtains) were present in the room. Figure 5 shows results of vacuuming the same room as measuring device. The vacuum cleaner used is 10 years old model with regular vacuuming power and with HEPA filter. Figure 6 shows results of using Roomba autonomous robot for vacuuming and Figure 7 shows results of using air-condition.

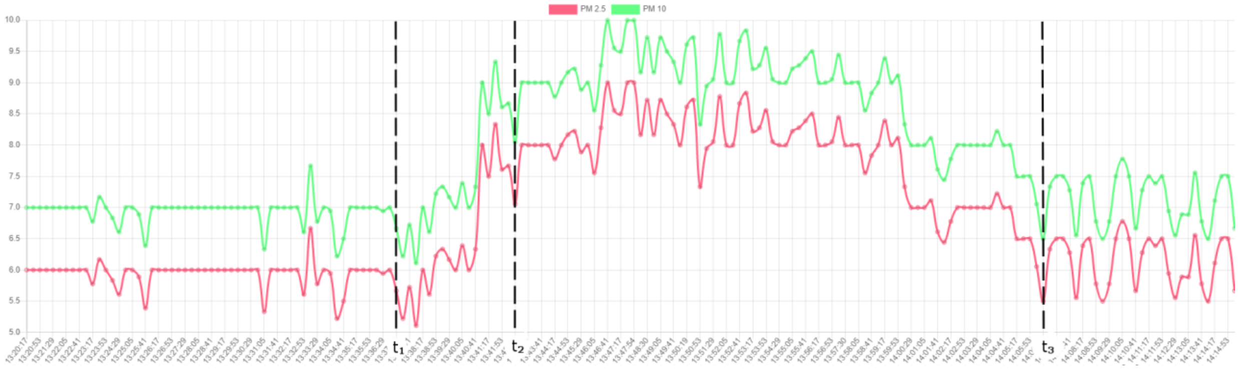

Figure 3: Venting the room results

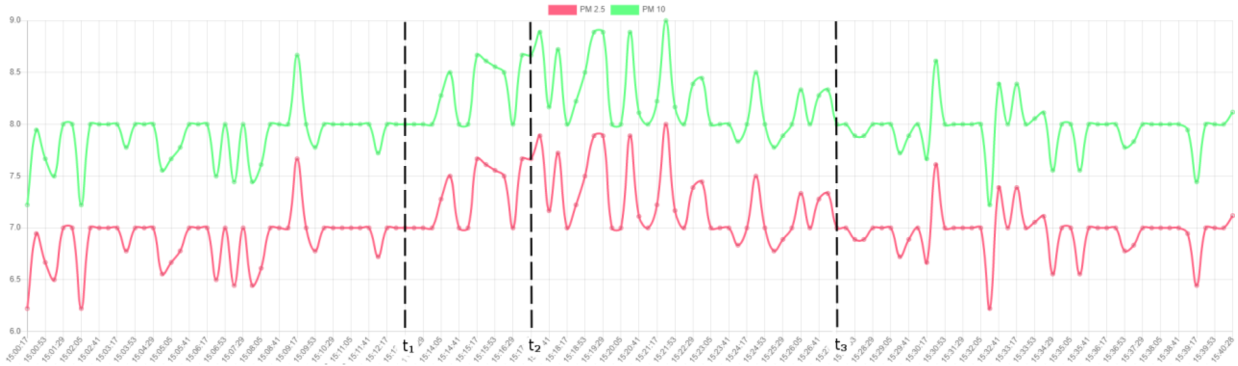

Figure 4: Children playing and running results

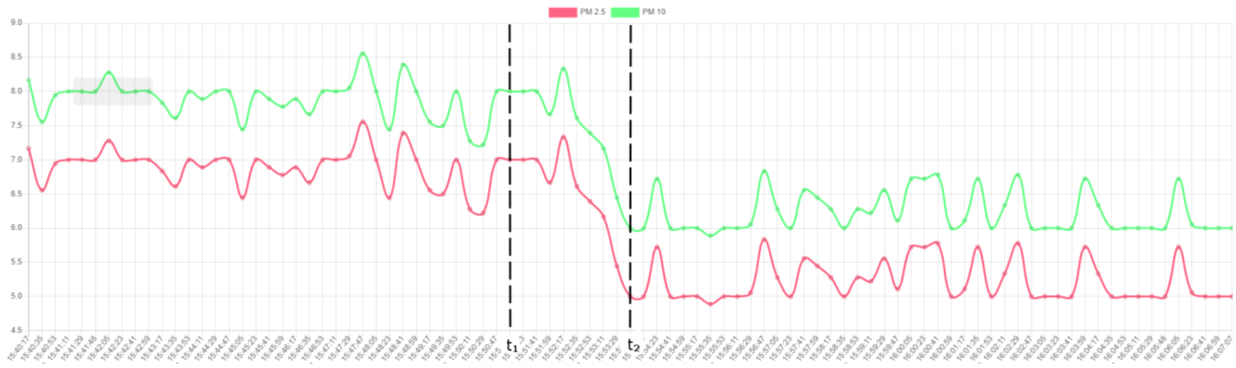

Figure 5: Vacuuming results

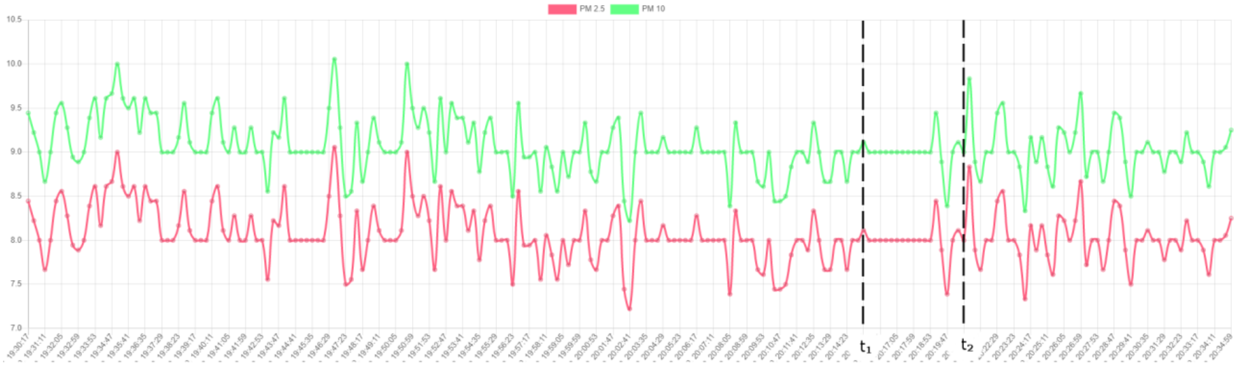

Figure 6: Autonomous robot vacuuming results

Figure 7: Air-condition results

4. DISCUSSION AND CONCLUSION

In this paper, a novel architecture for an IoT dust measuring and visualizing system was proposed. In order to test this new architecture, six test were defined, each modelling common household activity: bed making, venting the room, children running and jumping, vacuuming with regular vacuum cleaner, vacuuming with autonomous robot and using air-condition. For each test, multiple test runs were executed on different days, in different times of the day and in different rooms. Shown figures present one test run for each test. Different tests and test runs have different baseline values, which is expected due to external factors.

Main hypothesis was to prove that proposed novel architecture can be used to measure and visualize measured results in an intuitive and easy to understand way. Shown figures represent visualizations shown to end user and it is apparent that they are easy to understand: green values represent PM10 measurements, red values represent PM2.5 measurements, *x* axis showing time and *y* axis showing measured values in µg/m3.

First three activities shown expected results. Even short duration of bed making caused significant increase in dust concentration. Then, it took roughly 17 minutes for the dust to settle down and return to baseline values. Venting the room for five minutes shown similar expected results. Five minutes of venting caused significant increase in dust concentration with settling period of about 24 minutes. Then, children playing and running for a few minutes caused smaller increase in dust concentration with also a shorter settling period of only 9 minutes.

Regular vacuum cleaner test showed that the concentration of dust in the air was significantly reduced, even though the vacuum cleaner in question was 10 year old model with HEPA filter ready to be replaced. The results suggest that executing this activity regularly would lower the concentration of dust in the air, but additional experiments might be beneficial to better understand this phenomenon. Similar results were achieved in air-condition test. The concentration went down, although not so steeply. The results might be interpreted in a way that using air condition is good for removing the dust from the air, but also additional experiments should be carried out. Finally, using autonomous robot for cleaning the wooden floor showed no increase in dust concentration in the air, although this robot uses rotation brush for picking up dirt from the floor. The reasons for these results require additional investigation.

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