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Research Article

An IoT Based Air Quality Measurement and Warning System for Ambient Assisted Living

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Abstract

Indoor air quality parameters are extremely important for creating an efficient and healthy Ambient Assisted Living (AAL) environment, but mostly indoor air quality parameters are well above the values defined as healthy. We spend most of our lives indoors. Detecting air quality problems and improving air quality are only possible by monitoring air quality in real time. Today, smart home automation has become a popular trend and consumers are increasingly aware of new technologies developed in this area, hence the demand for smart homes is growing. In this study, with the IoT-based indoor air quality measurement and warning system, an AAL system was proposed to help especially elderly and children to live safely in their homes. The proposed AAL system consists of a ESP32 controller with a new generation embedded system architecture and low cost different air quality sensors. In addition, the AAL system provides real-time monitoring of indoor air quality parameters such as CO_2, CO, PM_{10}, NO_2, temperature and humidity via the mobile user interface developed with the Blynk IoT platform. The mobile application sends warning notifications to users if the indoor air quality parameters exceeded the specified threshold values. Thanks to these notifications, households can take the necessary measures as soon as possible against the factors that threaten the health of the elderly and children with simple measures such as natural ventilation. The results showed that the proposed measurement system can contribute significantly to AAL systems with its low cost, open source technology, easy installation and mobility.

Keywords: Internet of Things, Ambient Assisted Living, indoor air quality, ESP-32, Blynk.

Özet

İç hava kalitesi parametreleri, verimli ve sağlıklı bir Ortam Destekli Yaşam (ODY) ortamı oluşturmak için son derece önemlidir, ancak çoğunlukla iç hava kalitesi parametreleri, sağlıklı olarak tanımlanan değerlerin oldukça üzerindedir. Hayatımızın büyük bölümünü kapalı alanlarda geçiriyoruz. Hava kalitesi problemlerini tespit etmek ve hava kalitesini iyileştirmek ancak hava kalitesinin gerçek zamanlı olarak izlenmesiyle mümkündür. . Günümüzde, ev otomasyonu popüler bir trend haline gelmiştir ve akıllı evlere olan talep , tüketicilerin bu alanda geliştirilen yeni teknolojilerden daha fazla haberdar olmalarıyla giderek artmaktadır. Bu çalışmada, IoT tabanlı iç mekan hava kalitesi ölçüm ve uyarı sistemi ile özellikle yaşlıların ve çocukların evlerinde güvenle yaşamasına yardımcı olmak için bir ODY sistemi önerilmiştir. Önerilen ODY sistemi, yeni nesil gömülü sistem mimarisine sahip ESP32 denetleyiciden ve düşük maliyetli farklı hava kalitesi sensörlerinden oluşur. Ayrıca ODY sistemi, Blynk IoT platformuyla geliştirilen mobil kullanıcı arayüzü aracılığıyla CO_2, CO, PM_{10}, NO_2 , sıcaklık ve nem gibi iç mekan hava kalitesi parametrelerinin gerçek zamanlı izlenmesini sağlar. İç mekan hava kalitesi parametreleri belirtilen eşik değerlerin üzerine çıktığında mobil uygulama kullanıcılara uyarı bildirimleri gönderir. Bu bildirimler sayesinde hane halkı, doğal havalandırma gibi basit önlemlerle yaşlı ve çocukların sağlığını tehdit eden faktörlere karşı en kısa sürede gerekli önlemleri alabilir. Sonuçlar, önerilen ölçüm sistemin düşük maliyetli, açık kaynaklı teknoloji, kolay kurulum ve taşınabilir özellikleriyle ODY sistemlerine önemli ölçüde katkıda bulunabileceğini göstermiştir.

Anahtar Kelimeler: Nesnelerin İnterneti, Ortam Destekli Yaşam, İç Hava Kalitesi, ESP-32, Blynk.

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1. Introduction

Air pollution is a result of urbanization brought about by modern life and it has a dramatic impact on the global as well as regional scales. Concerns about air quality in indoor and outdoor living spaces continue to increase in the coming years, where population growth and aging problems are expected to be experienced more. Nearly all urban areas do not satisfy air quality limits set by the World Health Organization (WHO, 2016). By raising awareness of air quality conditions in urban areas, it can be ensured that citizens limit their daily activities that cause air pollution. Children, the elderly and people with respiratory and cardiovascular problems are the most affected by the negative effects of air pollution. The US Environmental Protection Agency (EPA), which is responsible for indoor and outdoor air quality regulation in the United States, considers indoor pollutant levels to be 100 times higher than outdoor pollutant levels and bad air quality as one of the five most important environmental problems (Seguel et al. 2017). Today, people spend about 90% of their time indoors, but especially the elderly and newborns most sensitive to indoor pollution they spend almost all their time indoors. On the other hand, activities such as cooking, household cleaning activities, smoking and the use of traditional heating methods (wood and coal stove), harmful gases such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), volatile organic compounds (VOC) and particulate matter (PM) cause many people to be exposed to indoor air pollutants. These dangerous gases cause oxygen deficiency in the lungs and significantly increase the risk of lung cancer. Particularly, CO, leaking from indoor stoves with nitrogen oxide and nitrogen dioxide (NOx), are the most dangerous gases at the home environment (Cho, 2017). AAL systems are designed to provide support to older adults, individuals who have various illnesses or with disabilities, to live as independent as possible in their homes. Such systems can monitor indoor air quality, people's activities, behavior and even health thanks to the intelligent environments created by people in their homes. The main objectives of these systems are to provide independent assistance to their users, to provide timely assistance in emergency situations and to improve the quality of life by eliminating the need for continuous caregiver supervision (Darwish et al. 2017). The Internet of Things is an ecosystem in which physical objects are linked to one another or to larger systems (Bröring et al. 2017). This network collects billions of data from many different devices that we use in daily life and converts them into usable information. Many devices and machines that we use in our era of technology can be monitored and controlled remotely with different device, especially smart phones and tablets (Gupta and Singh 2018).

The world is entering a new era, and in the near future, the majority of the world's population is expected to spend their lives in smart cities and smart homes. In these cities, a multidisciplinary approach is needed to deal with challenges, promote sustainable urban development and improve the quality of life of citizens (Lynggaard and Skouby 2016). Smart Home is the term commonly used to describe a living space that can communicate with each other and has lighting, heating, air conditioning, TV, computer, entertainment, audio-visual systems, security and camera systems (Harper, 2006). Remote control of lighting and electrical equipment, automatic change of the heating system according to regional weather (Kulkarni and Mukhopadhyay 2018), planning of working hours to reduce energy consumption costs of appliances such as ovens, washing machines, dishwashers and air conditioners (Taştan, 2019), health problems which are requiring continuous monitoring the number of IoT-based technology applications that increase the quality and comfort of our lives in many areas such as living a reliable life with wearable medical devices (Taştan, 2018), smart agriculture applications (Keswani et al. 2019), smart environment are increasing day by day. IoT-based smart home technology makes a significant contribution to human life and health by providing connectivity to everyone regardless of time and space. A wireless electronic nose was proposed to detect harmful gases in indoor environments (Hassan et al. 2015) and it was tried to identify the gases in the environment by using coding models. An AQM system based on an Arduino card, a cloud-based platform that manages data from sensors has been introduced (Fioccola et al. 2016). A comparison was made between two cloud computing models and two IoT communication protocols.

However, the proposed system is based on wired technology that limits the mobility and position of the sensors. The AAL system (Makhlouf et al. 2019) recommended for monitoring the elderly in their homes includes monitoring parameters such as fall detection, heart signal and location at home. The results show that falls are detected with an accuracy of 87%, tachycardia 100%, and location 94%. A modular end-to-end indoor air quality monitoring (IAQM) system, consisting of a wireless sensors network, gateways, and an IoT server, has been introduced (Benammar et al. 2018). The system allows monitoring of six gas concentrations in addition to temperature and humidity simultaneously at different locations. The system also has a data back-up mechanism in case of disruption of radio communication or disconnection from the Internet. Developed with the aim of recognizing the most common daily activities of a person at home, the Human Activity Recognition (HAR) system (Bianchi et al. 2019) can detect 9 different activities of the person with 97% accuracy with a wearable sensor.

In this study, an AAL system was proposed to protect individuals such as patients, elderly and children who spend most of their time indoors and who are vulnerable to indoor pollutants. The proposed AAL system consists of air quality sensors, an ESP32 controller module with embedded architecture, and an Android-based mobile user interface built with the IoT platform. The IoT-based AAL system is low-cost, portable, and features real-time monitoring. Thanks to the controller with built-in WiFi module, all measured indoor air quality data is displayed with the mobile application and this data is saved to the cloud server. The proposed AAL system sends warning notifications to users via mobile application if the gas concentrations, temperature and humidity values reach the limit values that threaten human health. As a result of the notifications sent to the users by the AAL system, it was found that the manual natural ventilation contributes to the creation of a healthier living space by reducing the exposure time to unhealthy indoor weather conditions.

2. Material and Method

Low air quality is a major health threat for children, elderly and patients who spend most of their time indoors. Indoor harmful gases are part of daily life, but most buildings do not have real-time air quality monitoring. In this study, an IoT-based AAL system was proposed for real-time, low-cost air quality monitoring. The proposed AAL system monitors the climatic parameters (temperature, humidity), pollutant gases (CO_2, CO, NO_2) and particulate matter (PM_{10}) in real-time. Developed using the ESP32 microcontroller module with IoT architecture and IEEE 802.11 b / g / n network protocol, the AAL system provides a completely wireless solution. The IoT-based AAL system provides real-time air quality monitoring, providing users with uninterrupted information on pollutant gas and PM concentrations in the environment. When the limits of air quality parameters are exceeded, AAL system sends warning notification to users via mobile application. These notifications about the air quality of the living environment ensure that the air quality is improved as soon as possible by taking the necessary actions of the users.

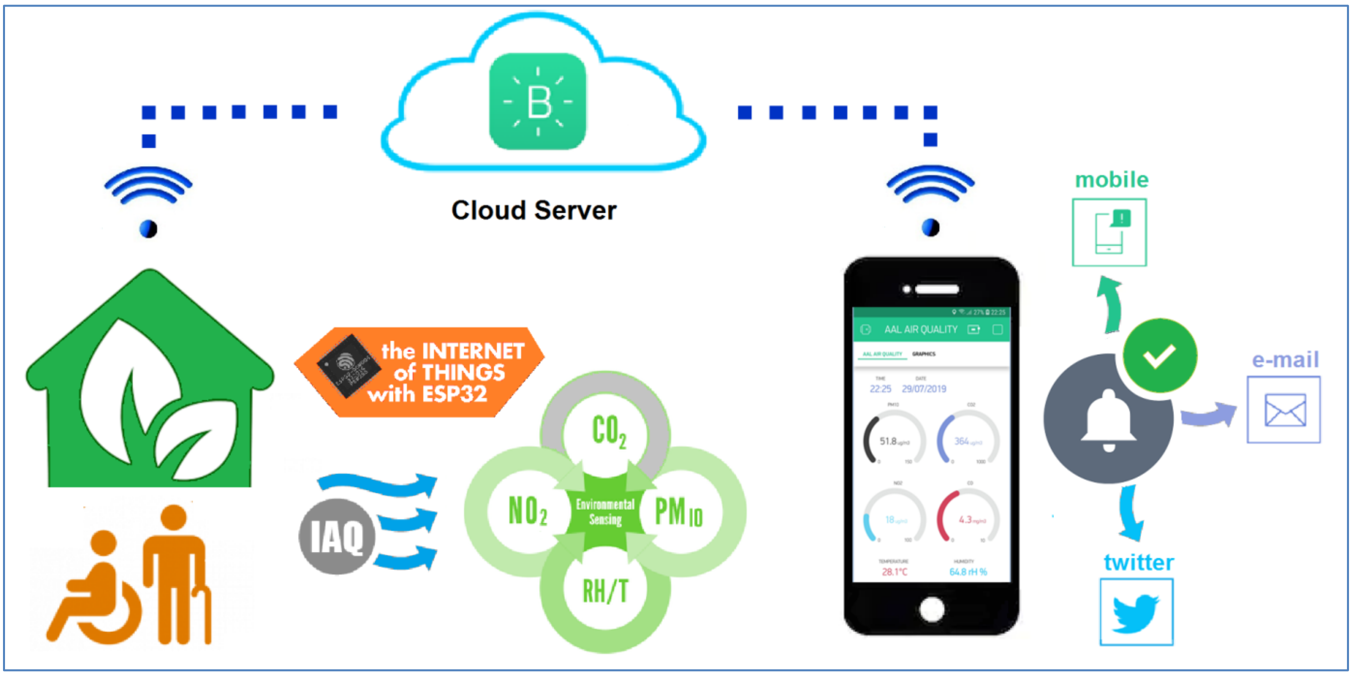


***Figure 1**. Architecture of the proposed IoT-based AAL system.*

The IoT-based AAL system shown in Figure 1 consists of an ESP32 microcontroller module from Espressif Company with wireless Wi-Fi communication and a range of air quality sensors. The ESP32 incorporates a Harvard Tensilica Xtensa LX6 32-bit Dual Core processor capable of operating up to 240 MHz. The ESP32 module has internal wireless modules, such as WiFi and bluetooth, for smart home and IoT applications (Espressif Systems, 2019). The detection unit includes GP2Y1010AU, MH-Z14, MICS-4514 and DHT22 sensors.

***Table 1.** Electronic features of the sensors in the IoT-based AAL system (Taştan and Gökozan 2019).*

Equipment Name	Types	Electronic Features
CO_2 gas sensor	MH-Z14	Detection range 0-10000 ppm; operating voltage: 4-6 V; accuracy: ± 50 ppm ±5%; resolution: 5 ppm; output Voltage: 0.4-2 V; operating temperature: 0-50 °C
NO_2, CO gas sensor	MICS-4514	Detection range 1-1000 ppm (CO); 0.05-5 ppm (NO_2); operating voltage: 4.9-5.1 V; operating temperature: -35-85 °C; heating current: 58mA
Dust sensor	GP2Y1010AU	Operating voltage: 5V; output voltage: 0.9 (no dust)–3.4 V; operating current: max 20mA; operating temperature: -10-65 °C, accuracy ± 15%
Temperature and Humidity sensor	DHT22	Temperature range: -40°C to 80°C; humidity range: 0% to 100% ; operating voltage: 3.5-5.5V; operating current: 60uA; output : serial; resolution: 0.1°C and ±1 rH% ; accuracy: ± 0.5°C and ±1 rH% ; resolution: temperature and humidity both are 16-bit.

The GP2Y1010AU is an analog output dust sensor with optical detection system. An infrared light emitting diode (IRED) and a photo transistor are arranged transversely to each other. The IR light reflected from the dust entering the sensor's air chamber detects the photo transistor and generates a voltage.

The MH-Z14A CO_2 sensor module uses the principle of non-dispersive infrared (NDIR). The MH-Z14A sensor measures 0-5000 ppm, 5 ppm resolution and ±50 ppm accuracy. MICS-4514 is used for measuring gas concentrations such as NO_2, CO and hydrocarbons. It has two sensor chips with independent heaters and delicate layers. One sensor chip detects oxidizing gases (OX) and the other sensor detects reducing gases (RED).

DHT22 temperature and humidity sensor consists of two parts: capacitive humidity and thermistor temperature sensor. There is an 8 bit microcontroller on it. It has relative error values of ± 0.5 ° C in temperature measurement and ± 2 rH in humidity measurement.

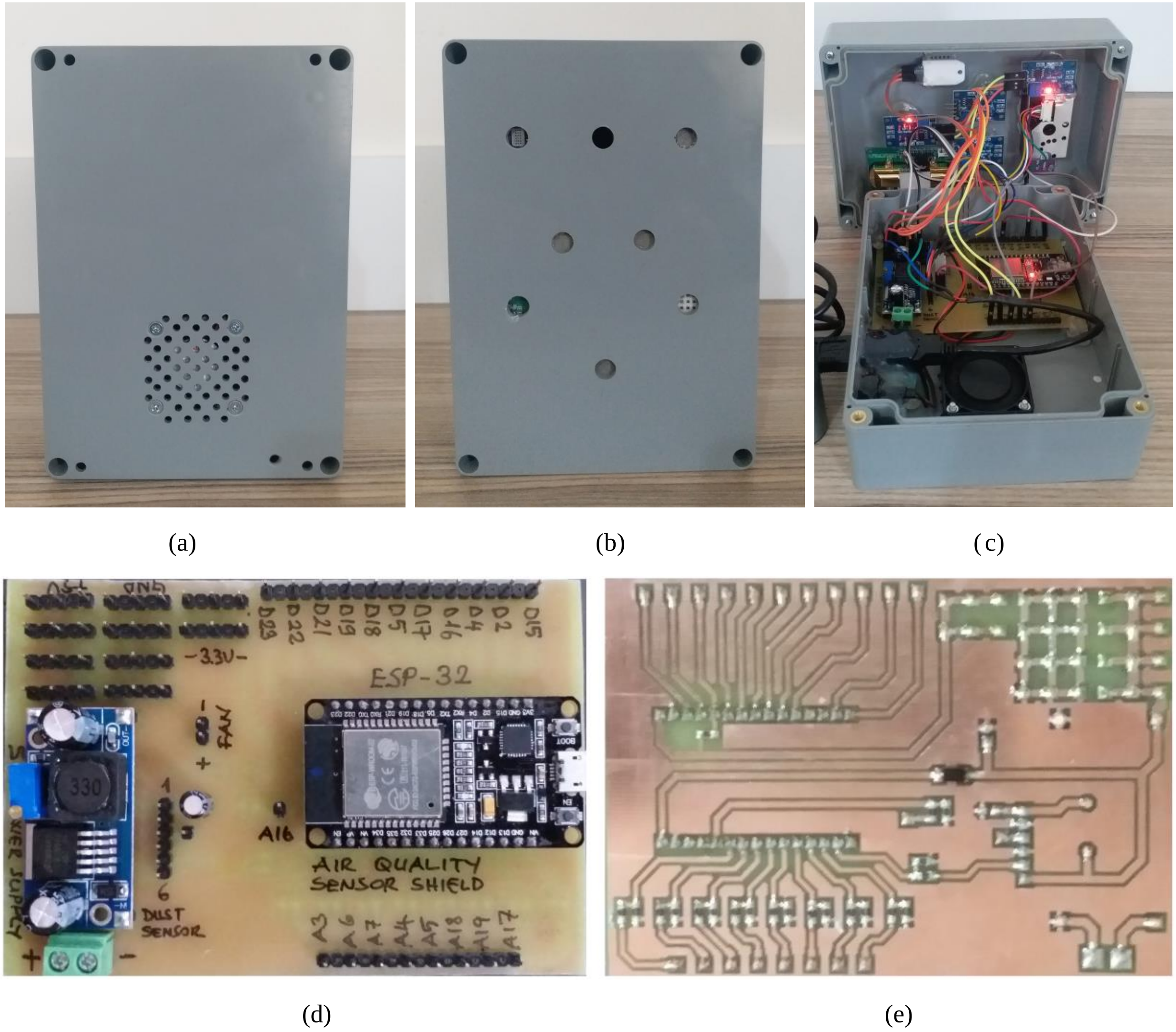
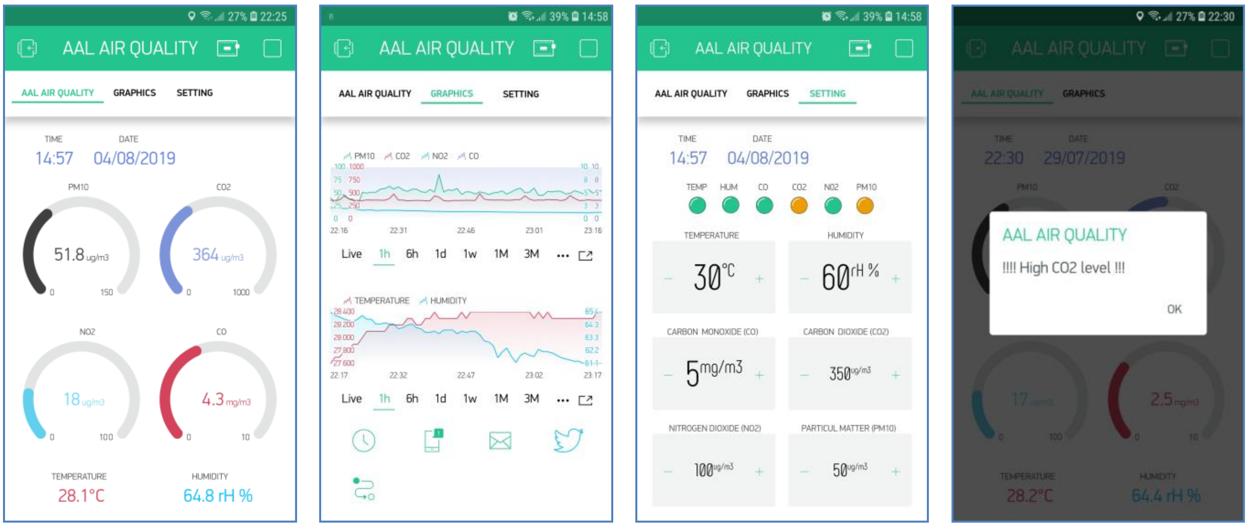


Figure 2. *IoT Based AAL System.*

The IoT-based AAL system shown in Figure 2 has an IoT-based structure that contains different sensors for measuring indoor air quality. Figures 2-a and 2-b show the front and back views of the measuring system, Figure 2-c shows the connections of the system, and Figure 2-d and 2-e show the pcb images of the measuring system. Blynk Cloud server is used for data recording in AAL system which performs air quality measurement.

This data saved to the cloud server can be sent to the user via e-mail. The values of climate parameters and gas concentrations are calculated by averaging 12 measurements taken at 5-second intervals. In this way, the effect of a fake measurement by the sensors is minimized. If the threshold values for gas concentrations and climate parameters are exceeded, the system sends notification to the users.



(a) (b) (c) (d)

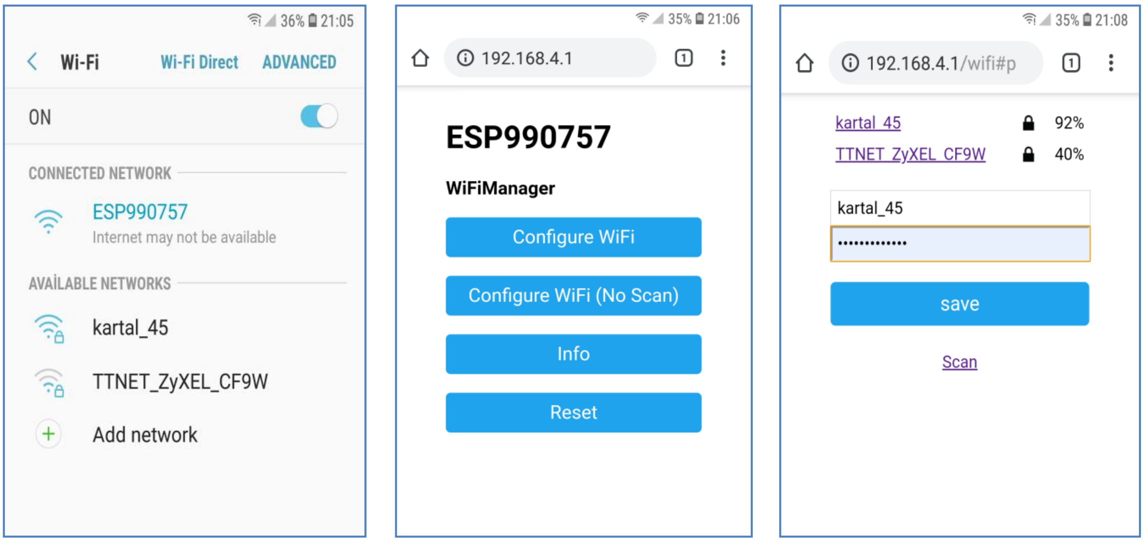
Figure 3. *User interface; a) Numerical panel b) Graphical panel, c) Setting panel, d) Notification screen display.*

The front panel views of the mobile user interface developed in Figures 3-a, b and c are given. Figure 3-d shows the notification screen for CO_2 gas concentration exceeding the limit value. Blynk is a hardware-agnostic IoT platform with customizable mobile apps, private cloud, device management, analytics, and machine learning. The data is stored on the Blynk cloud server for up to 1 year without deletion and can be easily accessed at any time.

Table 2. *Air quality standards of European Environment Agency (EEA, 2018)*

Pollutant	Concentration	Averaging period	Permitted exceedences each year
PM_{10}	50 µg.m^{-3}	24 hours	35
	40 µg.m^{-3}	1 year	n/a
NO_2	200 µg.m^{-3}	1 hours	18
	40 µg.m^{-3}	1 year	n/a
CO	10 mg.m^{-3}	Maximum daily 8 hour mean	n/a
CO_2	250-350 ppm	Outside air	Normal level
	350-1000 ppm	Indoor air	Acceptable level

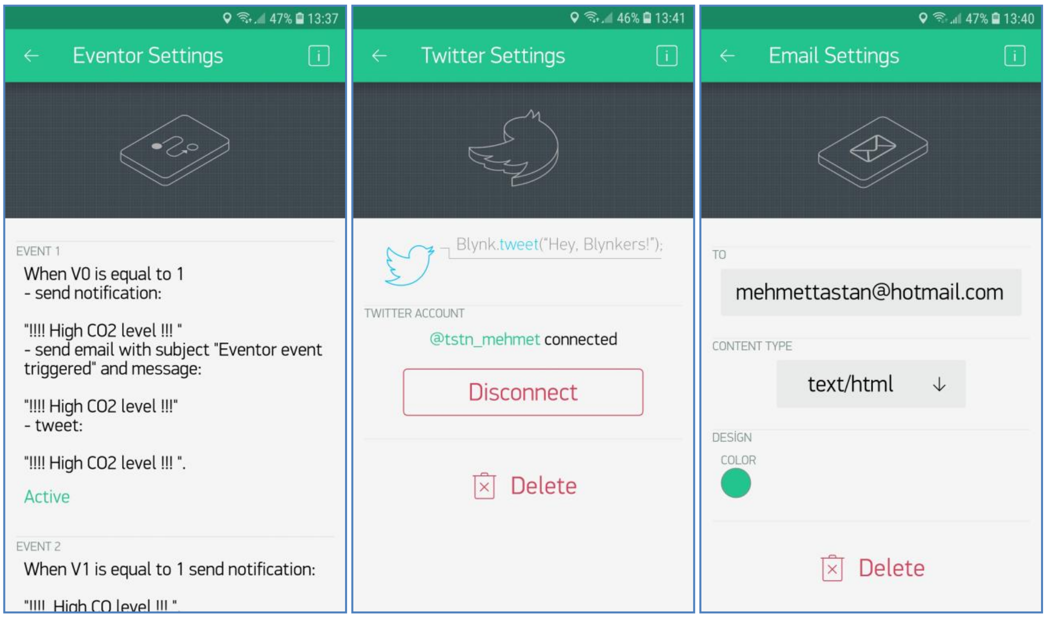
Table 2 shows the air quality standards set by the EEA. For PM_{10}, the 24-hour average value is 50 µg.m^{-3}, the annual average value is 40 µg.m^{-3} and the permissible annual number of exceeds is 35. The hourly average value for NO_2 is 200 µg.m^{-3}, the annual average value is 40 µg.m^{-3} and the permissible annual number of exceeds is 18. It is recommended that the 8-hour average for CO does not exceed 10 mg.m^{-3} and 1000 ppm for CO_2.



(a) (b) (c)

Figure 4. *WiFi configuration of AAL system.*

Figure 4 shows the Wifi configuration settings for the AAL system. When the ESP32 module operates, it is shown in the list of wireless networks as ESP990757 as shown in Figure 4-a. After connecting to this network, enter "192.168.4.1" in the address bar and switch to "Wifi Manger" page shown in Figure 4-b. When you enter the "Configure Wifi" tab, the list of "Wireless Networks" shown in Figure 4-c is displayed. By selecting the network to be connected from this list, the "user name" and "password" of the network are entered and connection to the wireless network is made. After this connection is made, the ESP32 microcontroller checks the wireless network connection at intervals of 10 seconds, and in case of a disconnection, re-connects to the wireless network using the recorded network information.



(a) (b) (c)

Figure 5. *a) Eventor, b) Twitter and c) email notification configurations of Blynk application.*

Figure 5 shows the configuration settings of the notifications for the Blynk application, an IoT platform. Figure 5-a shows the settings for the notifications received via the mobile phone. The alarm is triggered in the Blynk application for the virtual pin value "V0=1" sent from the controller. Then, the display shows "!!!! High CO_2 level !!!" message is written. Figure 5-b shows the twitter account and Figure 5-c shows the e-mail account settings.

3. Results and Discussion

In the IoT-based AAL system, air quality measurements are sent to the cloud server in 1 minute intervals. There is no air purification system in the household where the measurements are taken. The ventilation of the indoor environment is carried out by natural means by manually opening the doors and windows. In Figure 6,7 and 8, weekly change graphs of climate parameters and gas concentrations are given.

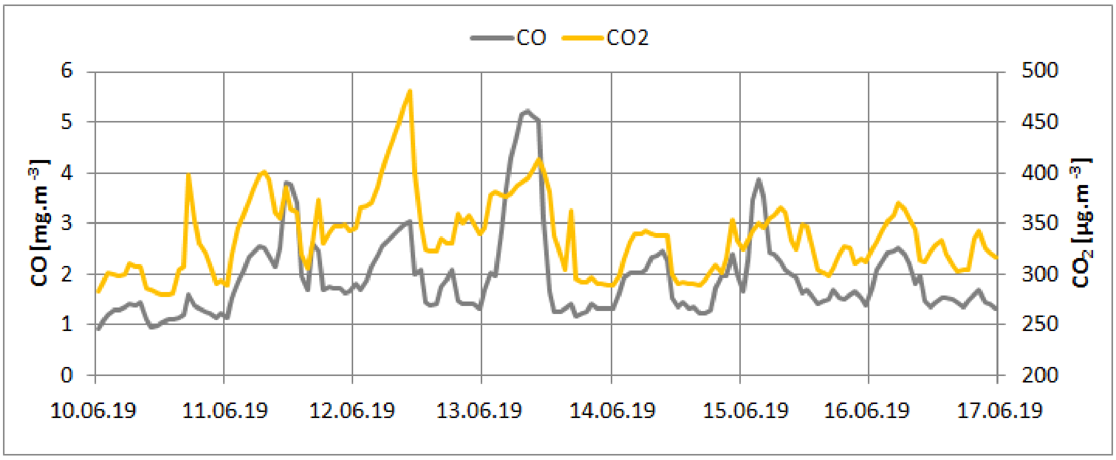


Figure 6. *Weekly CO-CO_2 change graph.*

Figure 6 shows the weekly change graph of CO-CO_2. When the graph of CO is examined, it is seen that the concentration value varies between 0.93-5.23 mg.m^{-3}. When the graph of CO_2 is examined, it is seen that the concentration of this harmful gas varies between 280.2-480.6 µg.m^{-3} on a weekly basis. It was observed that the concentration values of both gases reached maximum values during the night hours and decreased due to the ventilation during the day.

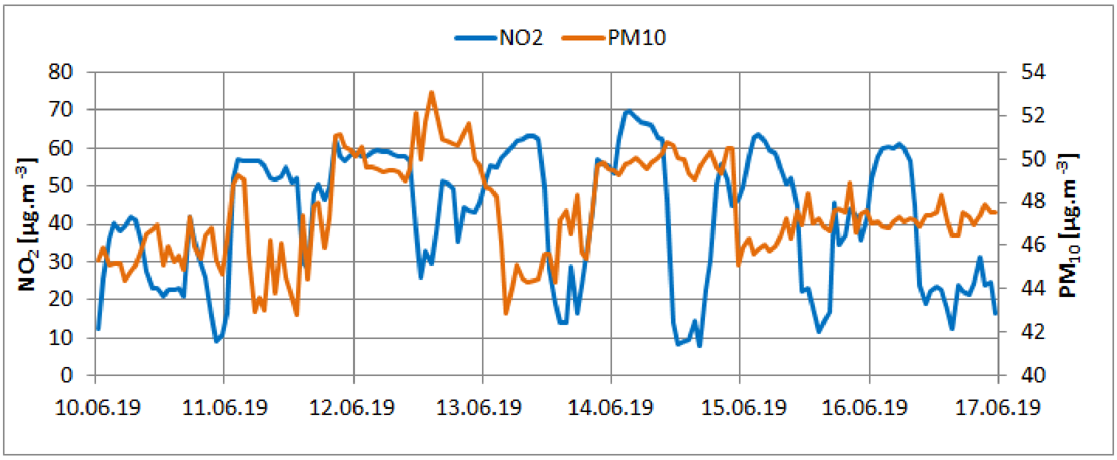


Figure 7. *Weekly NO_2-PM_{10} change graph.*

Figure 7 shows the weekly change graph of NO_2 and PM_{10}. When the one-week change is examined, it is seen that NO_2 value varies between maximum 69.9µg.m^{-3} and minimum 7.8 µg.m^{-3} values in this period. According to the 7-day change graph of PM_{10}, particulate matter showed changes between 42.8-53 mg.m^{-3}.

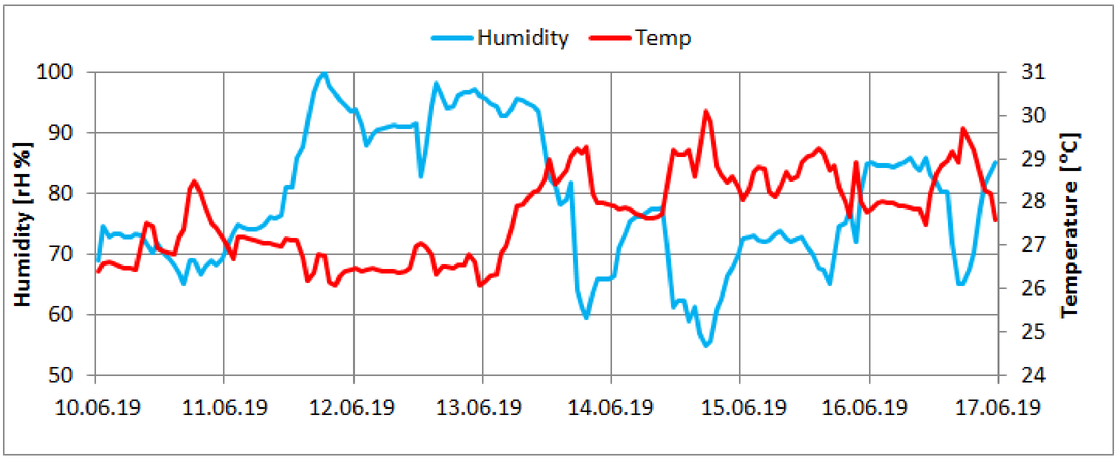


Figure 8. *Weekly Temperature-Humidity change graph.*

Figure 8 shows the weekly change graph of indoor climate parameters. One-week temperature and humidity change graph shows that the temperature varies between 26.1-30.1°C and the humidity varies between 55.1-99.9 %. When all graphs are examined, it is seen that the indoor CO, CO_2 and NO_2 concentrations decrease rapidly as a result of natural ventilation by opening windows and doors in the morning. As a result of natural ventilation performed on 13.06.2019, CO concentration decreased from 5.23 $mg.m^{-3}$ to 1.36 $mg.m^{-3}$, NO_2 concentration decreased from 62 $\mu g.m^{-3}$ to 16 $\mu g.m^{-3}$ and CO_2 concentration from 420 $\mu g.m^{-3}$ to 301 $\mu g.m^{-3}$. Increased gas concentrations in closed and unventilated environment for a long time resulted in a 74% decrease in CO, 75 % in NO_2 and 28 % in CO_2 as a result of natural ventilation. When the results are evaluated, it is seen that indoor air quality changes according to individual activities in the household. However, the natural ventilation process through the notifications sent to the users through the AAL system has caused significant increases in indoor air quality.

4. Conclusion

In this study, an AAL system was proposed to create a healthy living environment in smart houses which are part of smart cities. The proposed AAL system provides a complete wireless solution consisting of a mobile application that includes data collection hardware, data consultancy and notifications, especially to protect children and elderly individuals from indoor pollutants. The proposed low-cost IoT-based AAL system monitors climate parameters such as CO, NO_2 and CO_2 gas concentrations, particulate matter PM_{10}, and temperature-humidity in real time, causing indoor air pollution. This system incorporates four sensors, but other sensors can be added for specific parameter monitoring. The AAL system informs users about the level of pollution through the mobile application. If the threshold values for pollution levels are exceeded, the application sends notifications to them. In this way, users can minimize the exposure time to polluted air and take measures to reduce the pollution level as soon as possible. Indoor air quality is known to vary depending on the daily activities of household members such as sleeping, cooking and cleaning.

Low air quality is undoubtedly an important parameter that directly affects our health. Even simple measures such as opening only doors and windows to reduce the concentration of harmful gases in the environment can significantly improve indoor air quality. This study clearly demonstrated this situation. The results showed that the AAL system has a feature that can contribute to a healthier living environment. Compared to other systems, the proposed AAL system has many advantages such as low cost, open source technologies, easy installation and easy configuration. However, in many AAL systems, there are still many open issues such as scalability, quality of service issues, security and privacy. Furthermore, further testing is needed to improve the calibration and accuracy of the proposed AAL system. The proposed AAL system has an effect that can increase the air quality awareness of individuals, especially in homes where elderly and children live. The AAL system will cause households to improve their ventilation habits and contribute to a healthier living environment.As a result, AAL and IoT may be the key to solving the independence problems of older adults. Combined with smart homes, smartphones, wearable technology and IoT technologies, AAL systems offer many opportunities to solve problems related to emergencies, disabilities and diseases.

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