Erciyes Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 40, Sayı 1, 2024

Erciyes University
Journal of Institue Of Science and Technology
Volume 40, Issue 1, 2024

Fuzzy Logic Based Low Cost Mobile Alert System for Asthma and COPD Patients

Mustafa YURDAKUL *[1], **Şakir TAŞDEMİR**[2], **Sümeyra Büşra ŞENGÜL**[3]

*[1] Kırıkkale University, Faculty of Engineering and Natural Sciences, Computer Engineering, KIRIKKALE
[2] Selçuk University, Faculty of Technology, Computer Engineering, KONYA
[3] Selçuk University, Faculty of Technology, Computer Engineering, KONYA

(Alınış / Received: 30.01.2024, Kabul / Accepted: 21.03.2024, Online Yayınlanma / Published Online: 30.04.2024)

Keywords
Asthma,
Fuzzy Logic,
Air Quality,
COPD,
Alert System

Abstract: Respiratory diseases are infections caused by microorganisms. The two most common respiratory diseases are Chronic Obstructive Pulmonary Disease (COPD) and Asthma. Although these diseases cannot be completely cured, their effects can be reduced with precautions. Patients should improve their indoor air quality and avoid exposure to occupational dust and chemicals. However, patients may not be aware of the air quality in their environment. Therefore, patients may face situations such as attacks, use of rescue drugs and emergency hospitalisation. In this study, a portable mobile air quality warning device was developed that can automatically measure indoor and outdoor dust concentration, air quality, humidity, temperature and carbon monoxide (CO) levels. In order to enhance the evaluation of the air quality index, a fuzzy logic approach was used. Additionally, the device transmits sensor data to a server via wifi. The mobile application allows for monitoring of measured values and provides audio and visual warnings in potentially dangerous situations for the patient.

Astım ve KOAH Hastaları için Bulanık Mantık Tabanlı Düşük Maliyetli Mobil Uyarı Sistemi

Anahtar Kelimeler
Astım,
Bulanık Mantık
Hava Kalitesi,
KOAH,
Uyarı Sistemi

Öz: Solunum yolu hastalıkları, mikroorganizmaların yol açtığı enfeksiyonlar olarak bilinir. Kronik Obstrüktif Akciğer Hastalığı (KOAH) ve Astım en yaygın solunum yolu hastalıklarıdır. Bu hastalıklar tamamen engellenemese de, bazı önlemlerle etkileri azaltılabilir. Hastaların bulundukları ortamın hava kalitesini iyileştirmek ve mesleki toz ve kimyasallardan uzak durmak önemlidir. Fakat hastalar bulundukları ortamın hava kalitesi bilgisine sahip değildir. Bu yüzden atak, kurtarıcı ilaç kullanımı ve acil olarak hastaneye başvuru gibi durumlarla karşı karşıya kalabilirler. Bu çalışmada, iç ve dış mekânın toz konsantrasyonunu, hava kalitesini, nemini, sıcaklığını ve karbon monoksit (CO) değerlerini otomatik olarak ölçebilen taşınabilir mobil destekli bir hava kalitesi uyarı cihazı geliştirildi. Cihazın hava kalitesi indeksini daha iyi değerlendirebilmesi için bulanık mantık yaklaşımı kullanıldı. Ayrıca, cihaz sensörlerden gelen verileri wifi aracılığıyla bir sunucuya iletmektedir. Böylece, ölçülen değerler ile takip edilebilmektedir ve hasta potansiyel olarak tehlikeli durumlarda sesli ve görsel etkileşimlerle uyarılmaktadır.

*İlgili Yazar, email: mustafayurdakul@kku.edu.tr

1. Introduction

Chronic respiratory diseases affect millions of people worldwide, resulting in approximately 4 million deaths annually [1]. The two most prevalent chronic respiratory diseases are asthma, which affects 358 million people globally, and COPD, which affects 174 million people worldwide. Asthma is responsible for approximately 180,000 deaths worldwide each year [2]. Meanwhile, COPD deaths are eight times more frequent than asthma deaths [3] and, according to the World Health Organization, COPD is the third leading cause of death worldwide [4]. Additionally, COPD can contribute as a comorbidity to other fatal diseases such as Covid[5]. Asthma, on the other hand, is mainly caused by genetic inheritance or environmental factors such as poor air quality, dust, pollen, and animal dander [6]. Asthma and Chronic Obstructive Pulmonary Disease (COPD) are both chronic diseases that require long-term treatment. Asthma causes breathing difficulties, coughing, and shortness of breath, while COPD causes similar symptoms due to blockage of air sacs in the lungs called bronchi. Currently, there is no known cure for either disease. However, preventive medications and individual patient efforts can significantly improve quality of life and reduce morbidity and mortality. Air pollution has a direct impact on the quality of life of patients with asthma and COPD [7].

It can increase the risk of viral and bacterial infections, leading to breathing difficulties. Zhang et al. [8] reported that haze pollution and outdoor air pollutants are associated with hospitalisation rates of respiratory patients. Cai et al. [9] have reported that air pollution may contribute significantly to asthma exacerbations. Treatment of these diseases typically involves interventions to reduce symptom severity and discomfort, rather than eliminating the disease. The initial step in treatment should be to remove the patient from polluted environments. However, patients may not be able to monitor the air quality of their surroundings on a daily basis. Therefore, it is crucial for asthma and COPD patients to be aware of the air quality in their environment in order to control the disease effectively. Therefore, smart systems are needed to measure ambient air quality and provide feedback to patients. While many studies have been conducted to prevent respiratory disease triggers, this field remains an active area of research. Some relevant studies are as follow:

Abraham et al. [10] developed a low-cost air quality monitoring system using Arduino, XBee modules, and micro gas sensors. The system monitors six air quality parameters: carbon monoxide, carbon dioxide, ozone, volatile organic compounds, temperature, and humidity. The authors used the linear least squares method to calibrate the sensors and transform the measurement data.

Al-Dahoud et al. [11] employed wireless sensor networks to monitor air quality in metropolitan cities. Gas, temperature, and dust sensors were used to make measurements in the network nodes. Data transfer was achieved using Xbee modules from the module designed with the Arduino Uno microcontroller.

In a similar study, Husain et al. [12] monitored air quality in a system developed using the Arduino development board and Android technology. They measured levels of carbon dioxide, dust, and harmful gases with three sensors. The collected data is transferred to Android phones and computers via Bluetooth.

Kayyali et al. [13] designed a wearable vest to monitor physiological signals, such as weight, temperature, and blood pressure, of COPD patients.

Üçgün et al. [14] developed an IoT-based indoor air quality monitoring system using Raspberry Pi. The study measured temperature, humidity, gas, and light sensors and stored the data in a database. Furthermore, the authors developed a web interface for real-time monitoring of sensor data.

Jo et al. [15] To assess indoor air quality in real time, they developed a system where data can be transferred to the server in real time via an LTE modem. In their study, they aimed to evaluate indoor air quality by measuring aerosol concentration, VOC, CO, CO2, temperature, and humidity values. The collected data was transferred to the server via LTE modem and stored in a database. The authors also developed an interface for accessing the stored data. An alert is triggered by considering the threshold values recommended by experts.

Janeera et al. [16] used XMega and ESP8266 to measure the sound quality, dust, gas, humidity, and temperature of the environment. The data was instantly transferred to the ThingSpeak environment and monitored. Users were warned based on certain threshold values.

Hahm and Yoon [17] implemented two applications, Wireless Emergency Alert (WEA) and Air Quality Information Text (AIT), to reduce the exposure of patients with COPD, asthma, pneumonia and respiratory tract infections to harmful particulate matter. As a result, the number of patients visiting the hospital decreased.

In order to prevent asthma attacks in children, Alzoubi et al. [18] measured the temperature, humidity, dust, and carbon monoxide values of the air using sensors. They then sent this data to a smartphone application they developed using Bluetooth.

Typically, studies in the literature warn users based on certain threshold values after the sensor values are read. Alternatively, the values are saved on the server and monitored with the help of an interface. However, evaluating the suitability of the environment based solely on threshold values is insufficient. Pollutants can have negative effects even at low levels, which means that ambient values that meet the threshold may still be harmful. For instance, humidity in the air can cause particulate matter to remain suspended. To improve evaluation methods, it is important to develop an intelligent decision-making mechanism instead of relying on threshold values. Currently, there are no studies in this area. Therefore, this study aims to develop an IoT-based mobile alert system with a fuzzy logic inference mechanism to evaluate the environmental conditions of asthma and COPD patients. Sensor-measured air pollutant levels are evaluated using a fuzzy logic inference mechanism. Audio and visual alerts are then provided to individuals.

The study is divided into two parts: software and hardware. The hardware part involved measuring air pollutant levels using sensors. In the software part, a fuzzy-based controller was used to evaluate the air pollution level through a mobile application and provide patients with audible and visual warnings.

The paper's main contributions;

- A portable device has been developed that can instantly measure air pollution.
- An efficient pollution detection system was developed using the fuzzy logic method to evaluate the air pollution situation.
- An instant air pollution monitoring system was developed through a mobile application, which provides a danger warning when necessary.

The paper is organized as follows. Section 2 outlines the proposed method, while Section 3 details the experiments. The final section presents the discussion and conclusions.

2. Material and Method

2.1. Study Design

Asthma and COPD are chronic respiratory diseases that currently have no complete cure. The quality of life of patients is affected by the level of air pollution in their environment. Pollen, dust, high humidity, cigarette smoke, and various air pollutants are among the factors that negatively impact patients' quality of life. This study presents the development of a portable, mobile-supported, and fuzzy logic-based smart air quality warning device. The device can automatically measure dust concentration, air quality, humidity, temperature, and carbon monoxide (CO) values in indoor or outdoor environments. The data collected by the device's sensors are transferred to a web server. A mobile application has also been developed to enable patients to monitor the environment in real-time. The mobile application receives data evaluated by a fuzzy logic-based algorithm on the web server platform. An audible and visual warning is given if the air quality of the environment is unsuitable for the patient. Figure 1 shows the proposed system diagram.

Figure 1. Proposed System Diagram(Handshake: a reliable connection between two devices over a network)

2.2. Circuit Design

The development board used in this study uses the ESP8266 module to connect Arduino Uno to the Internet. Arduionu Uno has an ATmega328 microcontroller on it. Arduino Uno has 14 digital I/O output pins. 6 of them can be used as PWM output. There are also 6 analogue inputs, a 16MHz crystal oscillator, USB connector, power connector (2.1mm), ICSP header and reset button. The technical specifications of the Arduino Uno development board are listed in Table 1.

Table 1. Specification of Arduino Uno

Specification	Value
Microprocessor	ATmega328
Operating Voltage	+5.V DC
Dc Current Per I/O Pin	20mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1KB
Length	68.6mm
Width	53.4mm
Weight	25g

The study used the MQ-7 Carbon Monoxide, MQ-135 Air Quality, DHT-22 Humidity-Temperature and GP2Y1010AU0F Dust Sensors to measure air pollution status. The MQ-7 is a highly sensitive carbon monoxide (CO) sensor designed to measure CO concentrations in air. It is suitable for real-time observations with high sensitivity and response time. The MQ-135 gas sensor measures ammonia, benzene and hydrogen at concentrations from 10 to 10,000 ppm. The GP2Y1010AU0F is an optical sensor designed to measure dust particles in air. It uses an infrared emitting diode and a phototransistor to detect light reflected from dust in the air. It is effective in detecting very fine solid particles. The DHT22 temperature and humidity sensor is an advanced sensor unit that outputs a calibrated digital signal. In addition, 2 8x8 LED matrices have been used to warn the device when the phone is out of charge. The connection diagrams of the sensor, module and LED matrices used in the study are shown in Figure 2. The system is highly reliable and stable in long-term operation. Details of the measurement ranges of the sensors are given in Table 2.

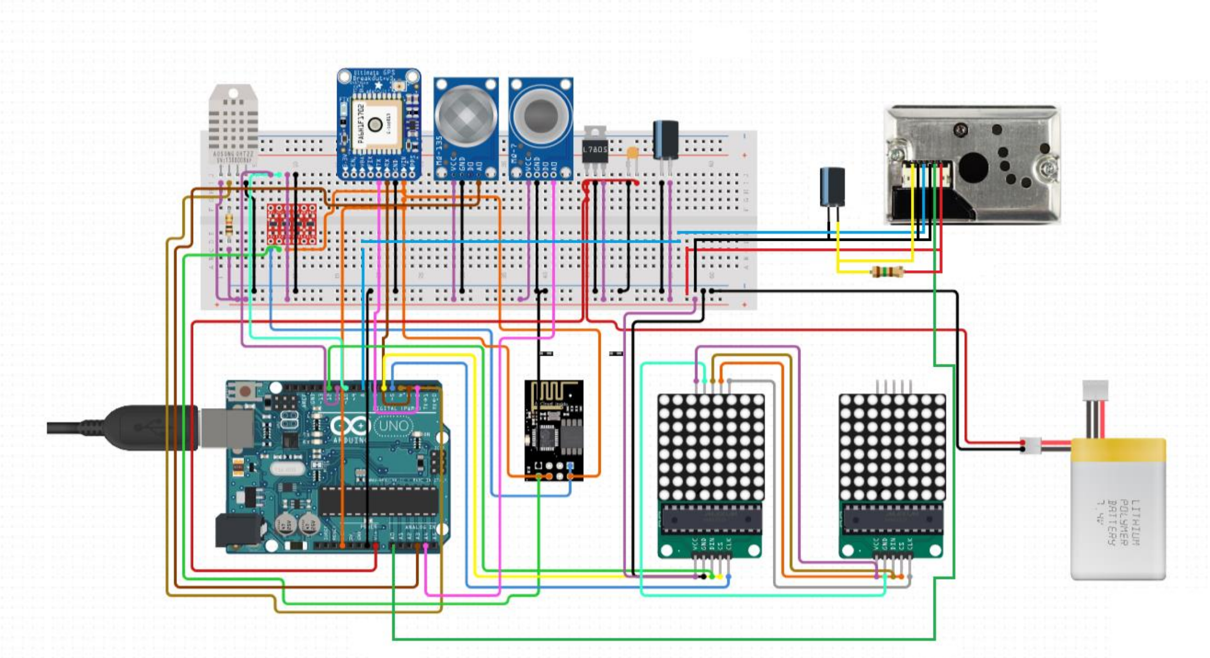

Figure 2. Connection Circuit of Components

Table 2. Technical Specification of sensors

Sensor	Specification	Value
MQ-7	Concentration	10-10.000ppm
MQ-135	Concentration	000ppm
DHT-22	Humidity Range Tempature	0-100%RH -40 – (+80) °C
GP2Y1010AU0F	Detectable particle size	0 -600 μg/m3

Figure 3. Prototype of the Alert System

The prototype system is also shown in Figure 3. Using the NodeMCU-ESP8266 module and sensors for humidity, temperature, carbon monoxide, ozone and particulate matter, the values affecting the air quality of the environment were measured. A web socket approach was used for immediate evaluation of the values obtained. A mobile application was developed to allow the user to continuously monitor the values and to provide audible and visual warnings when the air quality is inadequate. The mobile application and the developed device can exchange data instantly via a web socket. In this way, the patient can immediately monitor his environment and is automatically warned by the application in case of a possible situation.

2.3. Fuzzy Logic

A fuzzy logic algorithm, an artificial intelligence algorithm, was used to evaluate the data. The main reason for using the fuzzy logic algorithm is to detect synergistic situations. In classical methods, air quality is measured with fixed position devices. Since the developed device is portable, the patient can always have it with him/her. In addition, as the device transmits the readings to the server, more than one mobile application can use the same data. This makes it suitable for collective use as well as individual use. Fuzzy logic [19] is an artificial intelligence algorithm inspired by human behaviour and the way nature works. Its main purpose is to create decision-making processes that model human thinking mechanisms. It enables the evaluation of imprecise sentences used by humans in everyday language. For example, vague sentences such as "very close", "partially correct", "medium weight" cannot be expressed numerically, although they help to solve problems. In such cases, the fuzzy logic algorithm mimics the human mind, resulting in fuzzy solutions and numerical modelling.

Fuzzy logic consists of 3 parts: fuzzification, inference mechanism and defuzzification. Fuzzification is the stage where input values are converted into verbal expressions. The inference mechanism is the processing of inputs according to the rule base. The output value of the value is obtained in the defuzzification part. In this study, the evaluation of the data obtained from the sensors was carried out using the fuzzy logic algorithm. The main reason for using the fuzzy logic algorithm is the detection of synergistic situations. Figure 4 shows the proposed fuzzy inference mechanism.

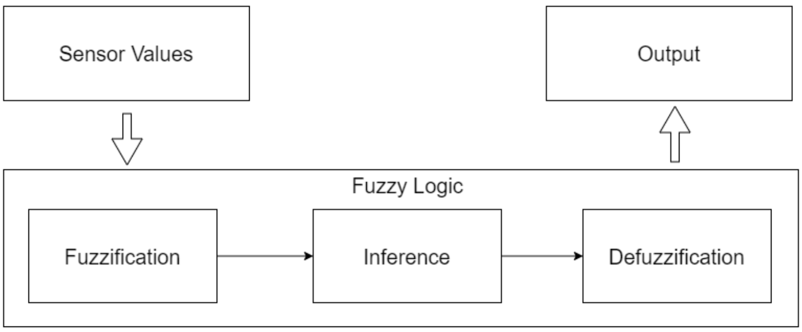

Figure 4. Fuzzy Logic Inference System

Fuzzification

Fuzzification is the conversion of numerical values given as input to the system into fuzzy values using appropriate linguistic qualifiers. With the membership function, the set to which the input information belongs and the degree of membership can be determined. Different fuzzification methods have been used in the literature. In this study, a trapezoidal fuzzifier is used. As a result of the literature review, the membership values of the verbal expressions corresponding to the numerical data obtained from the sensors were determined and shown in Table 3 [20-23].

Table 3. Membership values of sensor data used for air quality measurement

Pollutant	**Range**	**Status**
Carbonmonoxide	**Ppm**	
	0-100	Good
	100-200	Moderate
	200-250	Poor
	250-500	Very Poor
	500-1000	Unhealtthy
Air Quality	**Ppm**	
	0-100	Good
	100-200	Moderate
	200-300	Poor
	300-400	Very Poor
	400-500	Unhealthy
Dust Concentration	**µg/m3**	
	0-50	Good
	50-100	Moderate
	100-200	Unhealtthy
	200-300	Very Unhealthy
	300-600	Hazardous
Humidity	**relative(%)**	
	0-30	Dry
	30-60	Good
	50-100	Humid
Tempature	**°C**	
	-2-(18)	Cool
	18-22	Normal
	20-27	Warm
	25-35	Hot
	35-50	Very Hot
Air Quality Index	**Index**	
	0-50	Good
	50-100	Moderate
	100-300	Unhealthy

The membership functions are shown in Figure 5.

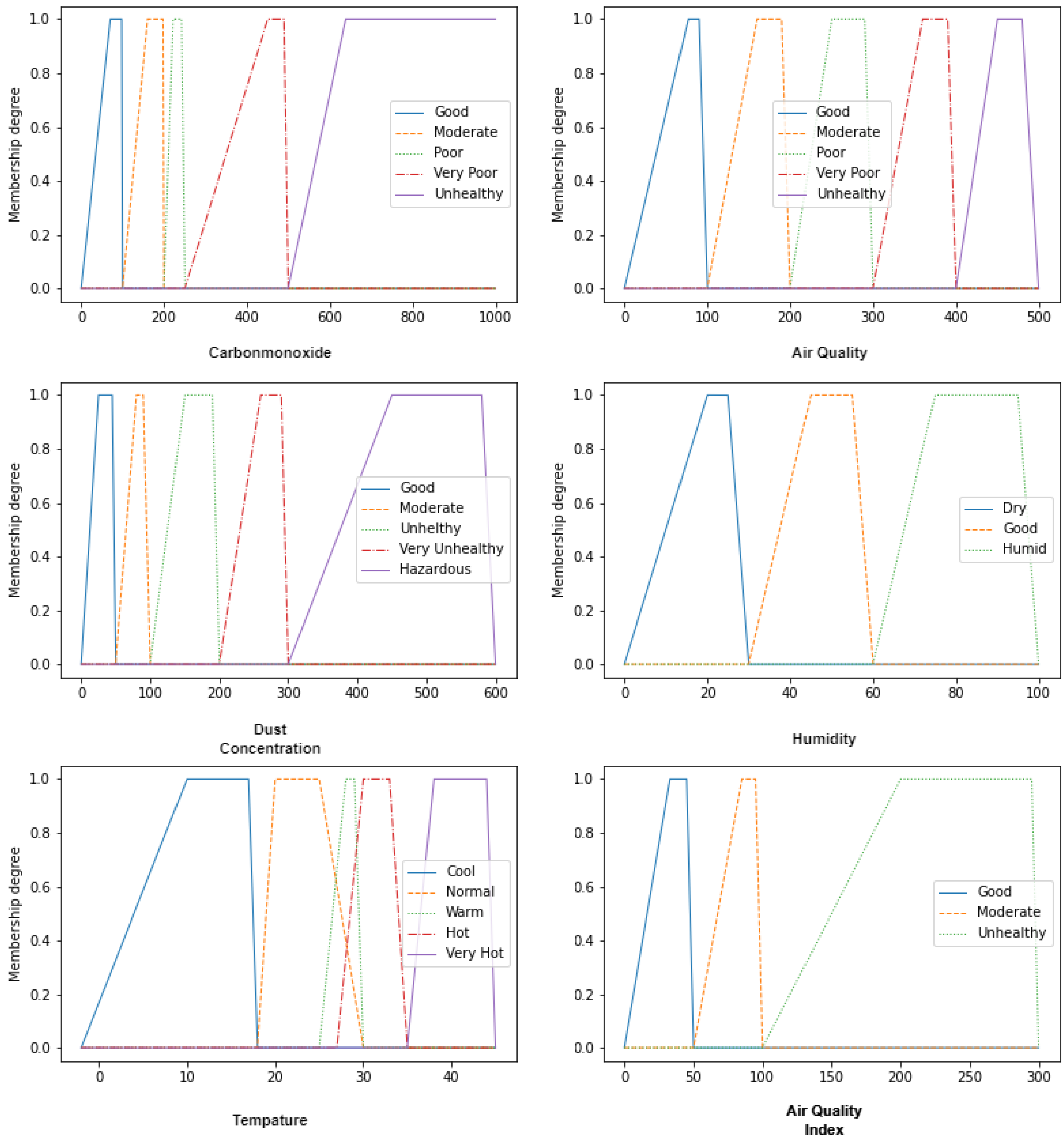

Figure 5. Membership function values for sensor data

Inference Mechanism and Rule Base

In the study, a rule base was created with the expert physician by using the lower and upper limit values of the values taken from the sensors. The rules plays a crucial role in the fuzzy inference mechanism, which is the core of the device's decision-making process for evaluating air quality. Table 4 shows some of the fuzzy rules employed within the device's rule base.

Table 4. Some rules used in fuzzy rule base

Carbonmonoxide	Op.	Air Quality	Op.	Dust Concentration	Op.	Humidity	Op.	Tempature	Air Qualiy Index
Good	And	Good	And	Good	And	Good	And	Normal	Good
Moderate	And	Good	And	Moderate	And	Dry	And	Warm	Moderate
Poor	And	Moderate	And	Unhealthy	And	Humid	And	Hot	Unhealthy

Very Poor	And	Moderate	And	Very Unhealthy	And	Good	And	Cool	Unhealthy
Unhealthy	And	Poor	And	Hazardous	And	Dry	And	Very Hot	Unhealthy
Good	And	Poor	And	Good	And	Humid	And	Normal	Moderate
Moderate	And	Very Poor	And	Moderate	And	Good	And	Warm	Moderate
Poor	Or	Very Poor	And	Unhealthy	And	Dry	And	Hot	Unhealthy
Very Poor	Or	Unhealthy	And	Very Unhealthy	And	Humid	And	Cool	Unhealthy
Unhealthy	Or	Unhealthy	And	Hazardous	And	Good	And	Very Hot	Unhealthy
Good	Or	Good	And	Good	And	Dry	And	Normal	Good
Moderate	Or	Good	And	Moderate	And	Humid	And	Warm	Good
Poor	Or	Moderate	And	Unhealthy	And	Good	And	Hot	Unhealthy
Very Poor	And	Poor	And	Very Unhealthy	And	Dry	And	Cool	Unhealthy
Unhealthy	And	Poor	And	Hazardous	And	Humid	And	Very Hot	Unhealthy

Defuzzification

Defuzzification is a method used to transform a fuzzy set (fuzzy output) into a precise output. Defuzzification is an inverse transformation compared to defuzzification because in this process the fuzzy output is converted into precise values to be applied to the system. In this study, the centroid method is used. The exact value is calculated using equation 1. In equation 1, X represents the defuzzification value, n represents the subareas, A_i represents the area of the current subarea and x_i represents the centre of gravity of the current subarea.

$$X = \frac{\sum_{i=1}^{n} A_i x_i}{\sum_{i=1}^{n} A_i} \quad (1)$$

2.4. Web Server

Web applications communicate with the server via the HTTP protocol using request/response logic. When the client requests something from the server, a connection is opened and a request is sent. The server receives the request and performs the necessary actions. The server sends a response back to the client. This traffic goes on all the time. The client has to open a connection for each request. The classic HTTP protocol is not sufficient when real-time communication is required. WebSocket is a computer communication protocol that provides a full bi-directional communication channel over a single TCP connection. Unlike the HTTP protocol, the connection remains open until terminated by either party. It is used in situations where real-time data is streaming. The Web Socket architecture used in the study was developed in the Asp.Net Core environment.

2.5. Mobile Application

Using the developed device, the data received from the sensors is transferred to the server via the wes socket protocol. A mobile application was developed to monitor the data immediately and to warn the patient in case of a possible risk. The mobile application has been developed in the Android environment. In addition, the patient does not need to open the mobile application, the application continuously performs the control process with the code it runs in the background. Screenshots of the developed mobile application are shown in Figure 6.

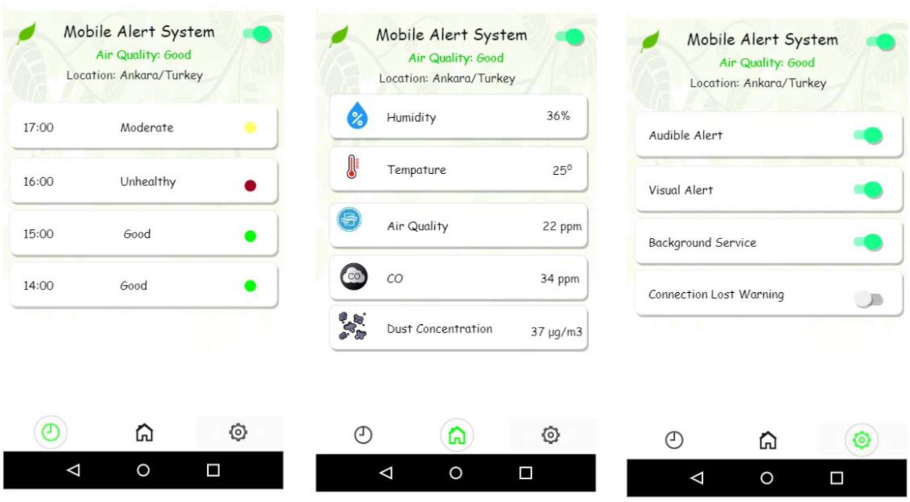

Figure 6. Mobile Application Screens

Results and Discussions

Respiratory diseases are made worse when people are exposed to air pollution. People with asthma and COPD in particular have to cope with attacks, choking coughs and rescue medication in smoggy air. Asthma and COPD are chronic (lifelong) conditions for which there is no permanent cure. However, they can be prevented if they are controlled. Quitting smoking, reducing indoor and outdoor air pollution and avoiding occupational dusts and chemicals are essential in preventing these diseases. It is therefore important for patients to be able to monitor the quality of the air in their environment. Different methods are used to measure air pollution. One of them is the measurement technique using mobile (mobile) vehicles. Air quality is determined by measuring pollution and particles in the air. This system is currently used by local authorities. As these tools are quite expensive, measurements are only taken when necessary or at specific times (about 1 or 2 times a month). Unlike stable, mobile (portable) air pollution monitors, they are only available at monitoring stations located in a specific region (province, district). These are systems that operate on 220V-380V electricity. Cihazların ölçtüğü değerler yerel yönetimin sistemine gönderilir. The limitations of these systems are that they cannot provide information on indoor air pollution and can only measure regional levels. Within the framework of this research, a portable, mobile-based warning device has been developed that can automatically measure dust concentration, air quality, humidity, temperature and carbon monoxide (CO) levels in an indoor or outdoor environment. The sensors built into this device allow measurements to be taken automatically at set intervals and sent to the server. In addition, a mobile application has been developed to monitor the sensor readings in real time. Additionally, a continuous evaluation is done in the background, and the user is warned visually and audibly in case of potential risk. The developed device only weighs 160gr. Thus, it is portable, and patients can use the mobile application to measure active values and learn about the suitability of the environment whenever and wherever they want. The developed device was tested in different conditions. The sensor values that the device warns about are shown in Table 5.

Tablo 5. Device Test Results

Humidity(%)	Temperature(°)	Air Quality(ppm)	CO(ppm)	Dust Concentration(μg/m³)	Alert
35	30	75	58	15	Unhealthy
22	20	50	12	165	Unhealthy
15	18	120	100	35	Unhealthy
45	35	20	14	25	Unhealthy
35	30	12	10	15	Healthy

The surface plots of the fuzzy logic rules used to determine the air quality index are visualised in Figure 7. By analysing these plots, it is possible to observe interactions between different environmental factors. It's not just the individual sensor readings that affect air quality, but the combined effect of these factors. The plots show a synergistic relationship between humidity and temperature. High humidity can trap dust particles and other pollutants in the air, making them more problematic, especially at higher temperatures. This can exacerbate respiratory problems in people with asthma and COPD. Similarly, the graphs indicate a synergistic effect between the air quality sensor reading (representing a combination of pollutants) and carbon monoxide levels. The presence of carbon monoxide alongside other pollutants can create a more dangerous environment for patients. The graphs also show the interaction between dust concentration and humidity. High dust concentrations can be more irritating in humid environments, leading to increased discomfort and potential respiratory complications. These findings highlight the importance of considering the complex interplay between environmental factors when assessing air quality. A single sensor reading may not be sufficient to determine air quality. By using fuzzy logic, this system can take into account these synergistic effects and provide a more comprehensive assessment of air quality risk for patients with respiratory diseases.

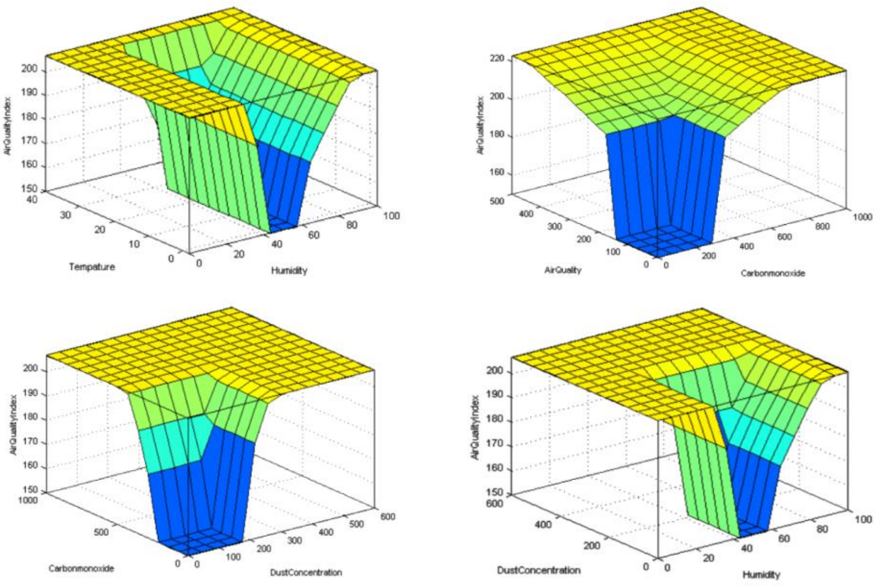

Figure 7. Surface plots of input and output values

In conclusion, in this study a portable, mobile and fuzzy logic based intelligent air quality warning device for patients with asthma and COPD was presented. The device can measure dust concentration, air quality, humidity, temperature and carbon monoxide (CO) levels. Sensor data is transmitted to a web server and a mobile application allows patients to monitor their environment in real time. A fuzzy logic algorithm evaluates the sensor data to provide audible and visual alerts when air quality poses a health risk. This system has several advantages over traditional methods. Unlike stationary air pollution monitors, the proposed device is portable and can be used indoors or outdoors. In addition, the fuzzy logic algorithm provides a more nuanced assessment of air quality than simple threshold-based methods. The lightweight design and real-time monitoring capabilities make this system a valuable tool for asthma and COPD patients to manage their condition.

Acknowledgements

We want to special thanks to Aysun Yurdakul who is medical doctor in Selçuk University for her assistance in prepearing fuzzy data set.

References

[1] T. Ferkol and D. Schraufnagel, "The global burden of respiratory disease," Ann Am Thorac Soc, vol. 11, no. 3, pp. 404–406, Mar. 2014, doi: 10.1513/AnnalsATS.201311-405PS.
[2] P. Burney, D. Jarvis, and R. Perez-Padilla, "The global burden of chronic respiratory disease in adults," Int J Tuberc Lung Dis, vol. 19, no. 1, pp. 10–20, Jan. 2015, doi: 10.5588/ijtld.14.0446.
[3] GBD 2015 Chronic Respiratory Disease Collaborators, "Global, regional, and national deaths, prevalence, disability-adjusted life years, and years lived with disability for chronic obstructive pulmonary disease and asthma, 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015," Lancet Respir Med, vol. 5, no. 9, pp. 691–706, Sep. 2017, doi: 10.1016/S2213-2600(17)30293-X.
[4] "The top 10 causes of death." Accessed: Jan. 29, 2024. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death
[5] F. V. Gerayeli et al., "COPD and the risk of poor outcomes in COVID-19: A systematic review and meta-analysis," EClinicalMedicine, vol. 33, p. 100789, Mar. 2021, doi: 10.1016/j.eclinm.2021.100789.
[6] S. Musafiri et al., "Prevalence of atopy, asthma and COPD in an urban and a rural area of an African country," Respiratory Medicine, vol. 105, no. 11, pp. 1596–1605, Nov. 2011, doi: 10.1016/j.rmed.2011.06.013.
[7] M. Darçın, "Association between air quality and quality of life," Environ Sci Pollut Res, vol. 21, no. 3, pp. 1954–1959, Feb. 2014, doi: 10.1007/s11356-013-2101-3.
[8] Z. Zhang et al., "Impact of haze and air pollution-related hazards on hospital admissions in Guangzhou, China," Environ Sci Pollut Res, vol. 21, no. 6, pp. 4236–4244, Mar. 2014, doi: 10.1007/s11356-013-2374-6.
[9] J. Cai et al., "Acute effects of air pollution on asthma hospitalization in Shanghai, China," Environ Pollut, vol. 191, pp. 139–144, Aug. 2014, doi: 10.1016/j.envpol.2014.04.028.
[10] S. Abraham and X. Li, "A Cost-effective Wireless Sensor Network System for Indoor Air Quality Monitoring Applications," Procedia Computer Science, vol. 34, pp. 165–171, Jan. 2014, doi: 10.1016/j.procs.2014.07.090.

[11] A. Al-Dahoud, M. Fezari, I. Jannoud, and T. A. Al-Rawashdeh, “Monitoring Metropolitan City Air-quality Using Wireless Sensor Nodes based on ARDUINO and XBEE,” Accessed: Jan. 29, 2024. [Online]. Available: https://www.semanticscholar.org/paper/Monitoring-Metropolitan-City-Air-quality-Using-on-Al-Dahoud-Fezari/e0400014e15b672bbf2342833cd35a511fcb6869
[12] A. M. Husain, T. Rini, M. Haque, and M. R. Alam, “Air Quality Monitoring : The Use of Arduino and Android,” 2016. Accessed: Jan. 29, 2024. [Online]. Available: https://www.semanticscholar.org/paper/Air-Quality-Monitoring-%3A-The-Use-of-Arduino-and-Husain-Rini/45915b48d382a6619683bc69218eccd5148115f9
[13] R. Kayyali et al., “Qualitative investigation into a wearable system for chronic obstructive pulmonary disease: the stakeholders’ perspective,” BMJ Open, vol. 6, no. 8, p. e011657, Aug. 2016, doi: 10.1136/bmjopen-2016-011657.
[14] H. Üçgün, F. Gömbeci̇, U. Yüzgeç, and N. Yalçin, “IoT Tabanlı Platform ile Gerçek Zamanlı İç Ortam Hava Kalitesi İzleme Sistemi,” Bilecik Şeyh Edebali Üniversitesi Fen Bilimleri Dergisi, vol. 7, no. 1, Art. no. 1, Jun. 2020, doi: 10.35193/bseufbd.730919.
[15] J. Jo, B. Jo, J. Kim, S. Kim, and W. Han, “Development of an IoT-Based Indoor Air Quality Monitoring Platform,” Journal of Sensors, vol. 2020, p. e8749764, Jan. 2020, doi: 10.1155/2020/8749764.
[16] D. A. Janeera., H. Poovizhi., S. S. Sheik Haseena., and S. Nivetha., “Smart Embedded Framework using Arduino and IoT for Real-Time Noise and Air Pollution Monitoring and Alert system,” in 2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS), Mar. 2021, pp. 1416–1420. doi: 10.1109/ICAIS50930.2021.9396041.
[17] Y. Hahm and H. Yoon, “The impact of air pollution alert services on respiratory diseases: generalized additive modeling study in South Korea,” Environ. Res. Lett., vol. 16, no. 6, p. 064048, May 2021, doi: 10.1088/1748-9326/ac002f.
[18] K. Alzoubi, M. Al-bzoor, O. Aljalahma, and M. Ali, “Air Quality Monitoring and Alerting System to Help in Reducing Asthma Attack in Asthmatic Children,” presented at the International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC), SCITEPRESS, Feb. 2021, pp. 91–98. doi: 10.5220/0009971200002865.
[19] L. A. Zadeh, “Fuzzy Logic, Neural Networks, and Soft Computing,” in Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems, vol. Volume 6, in Advances in Fuzzy Systems ? Applications and Theory, no. Volume 6, vol. Volume 6. , WORLD SCIENTIFIC, 1996, pp. 775–782. doi: 10.1142/9789814261302_0040.
[20] J. Ahn, D. Shin, K. Kim, and J. Yang, “Indoor Air Quality Analysis Using Deep Learning with Sensor Data,” Sensors, vol. 17, no. 11, Art. no. 11, Nov. 2017, doi: 10.3390/s17112476.
[21] C. Johnes, R. A. Sharpe, T. Menneer, T. Taylor, and P. Nestel, “Using Sensor Data to Identify Factors Affecting Internal Air Quality within 279 Lower Income Households in Cornwall, South West of England,” Int J Environ Res Public Health, vol. 20, no. 2, p. 1075, Jan. 2023, doi: 10.3390/ijerph20021075.
[22] J. Buelvas, D. Múnera, D. P. Tobón V., J. Aguirre, and N. Gaviria, “Data Quality in IoT-Based Air Quality Monitoring Systems: a Systematic Mapping Study,” Water Air Soil Pollut, vol. 234, no. 4, p. 248, Apr. 2023, doi: 10.1007/s11270-023-06127-9.
[23] A. Gressent, L. Malherbe, A. Colette, H. Rollin, and R. Scimia, “Data fusion for air quality mapping using low-cost sensor observations: Feasibility and added-value,” Environment International, vol. 143, p. 105965, Oct. 2020, doi: 10.1016/j.envint.2020.105965.