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Assessing the Risk of Spreading COVID-19 in the Room Utilizing Low-Cost Monitoring System

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Abstract: High hygiene standards were established during the COVID-19 epidemic, and their adherence was closely monitored. They included the need to regularly wash one's hands and the requirement to cover person's upper airways or keep at least a two-meter space between individuals. The ITS (Information Technology Systems) community made a big contribution to this by developing methods and applications for the ongoing observation of people and the environment. Our major objective was to create a low-cost, straightforward system for tracking and assessing the danger of spreading COVID-19 in a space.The proposed system collects data from various low-cost environmental sensors such as temperature, humidity, CO_2, the number of people, the dynamics of speech, and the cleanliness of the environment with a significant connection to elements of wearable electronics and then evaluate the level of contamination and possible risks and, in the event of a high level of risk, alerts the person to take actions that can reduce or eliminate favourable conditions for the spread of the virus. The system was created at the Laboratory of industrial control systems of the University of Žilina, Slovakia. The experiment demonstrates the ability and feasibility to control the number of people in a space depending on particular symptoms like fever, coughing, and hand hygiene. On the other hand, the laboratory's temperature, humidity, and air quality should be controlled to reduce the spread of illness.

Keywords: monitoring; COVID-19; sensors; smart systems

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1. Introduction

Since the emergence of the viral disease COVID-19, this virus has killed many people, and even more, people have become infected with it. The impact of the virus changed life as we knew it, and people had to adapt to various measures to reduce the risk of infection. The main symptoms of this virus are fever, cough, and breathing problems (see Table 1).

Table 1. Basic characteristics of COVID-19 symptoms.

Signal and Symptoms	%
Fever	19–78
Fatigue	69.60
Dry cough	59.40

Because the virus is transmitted through droplet sediments, the risk of infection indoors is much higher than outdoors. Currently, many monitoring systems try to create a high level of comfort in the interior of a house or office. These systems ensure our comfort at home but cannot detect and analyse a possible virus threat because the size of the COVID-19 virus is several nanometers. It is obvious, that parameters such as temperature, humidity, and concentration of CO_2 can affect the level of risk of infection [1].

The very first studies presented an idea that a fever is usually around 98% is not necessarily true as there has been variation in reported numbers from different groups, ranging from 19% to 78% in later studies [2,3]. Therefore, measuring a fever may not be very reliable in terms of clinical diagnosis. One challenge in controlling the pandemic is that many infected patients who have no symptoms can still spread the virus, and this percentage varies, sometimes reaching 50% or more. This variability is related to factors such as the COVID-19 variant and whether or not the individual has been vaccinated. Therefore, it is necessary to design systems that observe the various symptoms of the virus and inform people in time to reduce the transmitting the virus.

Our proposed system for measuring COVID-19 in a room is very important for several reasons. It can help with monitoring the air quality in indoor spaces where people gather, such as offices, schools, or public transportation. This can provide an early warning system for potential outbreaks and help with preventing the spread of the virus. Secondly, a low-cost system for measuring COVID-19 in a room could be useful in determining the effectiveness of ventilation systems and other measures designed to reduce the transmission of the virus. This information could help to inform decisions about how to improve ventilation in indoor spaces to reduce the risk of transmission. Lastly, our system for measuring COVID-19 in a room could help to reassure people that the space is safe and that appropriate measures are being taken to reduce the risk of transmission. This could be particularly important in workplaces or public spaces where people may be hesitant to return due to concerns about the virus.

1.1. Current Situation

The team of S. Panday designed an intelligent disinfection tunnel [4]. This project aims to protect the person using an automatic system that disinfects the given person. In this paper, the authors use sensor fusion with a connection to IoT technology. Rajeesh Kumar N.V. et al. designed a concept [5] that monitors asymptotic patients using IoT-based sensors. R. Karthickraja and his team created a work [6] where they focused on the analysis of symptoms of COVID-19 using wearable sensors that belong to the IoT group. This project [7] was designed by S. Manigand, who tried to detect SARS-CoV-2 using drones. Drones used thermal cameras that detect the temperature of the human body. Drones also include disinfectant containers that can be used to disinfect a certain environment. The team led by G. Varshney designed an intelligent disinfection dispenser based on temperature measurement [8]. The device measures the temperature of the person. In the case of a favourable body temperature, the system takes disinfection on the person and lets the person into the workspace. If the temperature is higher, the system will not let the person into the workspace. The team led by I.P. Roy designed a system [9] that is used for the early detection of a person with symptoms of COVID-19. The system focuses on body temperature and blood oxygen levels. The interesting work was designed by H.K. Tripatia et al. Authors designed the Smart COVID-shield [10]. The system consists of three modules for cough detection, a temperature detection module, and a module for calculating the distance between people. The team led by J. Virbulis designed a system [11] that measures temperature, humidity, CO_2, and the concentration of people in the room. Based on these values, it evaluates the risk of infection for the person in the given room. With the onset of COVID-19, people began to isolate themselves more at home or, in most cases, worked from HomeOffice. Since they had to stay at home, they tried to increase their comfort with various new gadgets into their home. In paper [12], Maalsen S. deals with the acceleration of new technologies in the home after the outbreak of the pandemic.

1.2. Benefits of Our System

- Sensing environmental parameters to reduce the risk of viral disease transmission, where the ventilation system can be controlled based on these parameters.
- Design of a smart, reliable, and efficient room monitoring device.
- The possibility of limiting the number of people in one room.
- Identification of a potentially dangerous person with symptomatic manifestations of the disease.

The authors tried to use knowledge from various studies that were published and some of them were described in the current situation section. Unlike previous studies, the authors combined the largest possible number of relevant sensors and technologies to guarantee the highest possible level of safety in the room. The main aim of the article is the design of a new system, which was tested in the laboratory and on a selected sample of people for 1 h.

The article is divided into the following sections. The first part was the introduction and the current situation. The second part is focused on the selection of components that can be used in our system. The third part focuses on the connection of individual components and the design of data processing. The fourth part focuses on the presentation of the result and the possibilities of evaluating the measured data. The last part is focused on the possible future development of the device.

2. Components

Our project was composed of the following components:

Temperature and humidity sensors—The temperature and humidity in closed spaces (rooms) influence the speed of the spread of the viral disease COVID-19. For this reason, it is necessary to measure these parameters in every room in order to prevent the possible spread of infection. Research [13–16] shows that the viral disease spreads fastest at a temperature of 5–11 °C and absolute humidity in the range of 4–7 g/m^3.

PIR (Passive Infrared) sensor—A passive infrared detector detects objects based on radiated energy. We can measure this energy as the temperature of the human body and find out if the person has one of the symptoms of the disease (fever). The PIR detector was also used in work [17], where the authors created a robot that identified possible infected people.

CO_2 sensors—These sensors are used to indicate the freshness of the air in the room. With high values of CO_2 in the room, a person can quickly become tired and sleepy, and thus his work performance decreases. At the same time, with high values of CO_2, the virus is spread more.

VOC (Volatile Organic Compound) sensors—Viruses survive longer in a more polluted environment and become more aggressive for the human body, which is already burdened with harmful substances [18–20]. It is, therefore, necessary to measure air pollution.

Microphone—This sensor detects a coughing person in the room. Based on this information, it is possible to warn people in the room about the increased risk of developing the respiratory disease COVID-19. The microphone for detecting the frequency of breathing and coughing was also used in research such as [21,22]. Subsequently, the signal from the microphone needs to be analyzed, as they did in the research [23].

Smart ring—This sensor measures the contamination of a person's hands. At the same time, this sensor can also measure various biological signals that can be used to identify a potentially dangerous person. A person wears only one ring, so it is possible to determine the number of people in one room using our system.

Microcontroller ESP32—A simple open-source platform that we can classify as IoT. The development board uses an ESP32 chip that allows connection and communication via Wi-Fi and Bluetooth. The advantage of this board is simple programming within the freely available Arduino IDE program.

Concept of System

In Figure 1, we can see the connection between the components. All sensors, except for the smart ring, are directly connected to the main control unit, which is the ESP32 development board. The control unit collects all data from the sensors, processes them, and then sends the data to the cloud using the Wi-Fi wireless communication standard. Based on the algorithm, possible risks that could lead to the spread of the respiratory disease COVID-19 are processed and evaluated. At the same time, the data from the cloud are displayed on the website. So, it is possible to configure the system to display the rooms in which the system is located. One or more systems can be placed in one room, which ensures higher reliability and accuracy of the system.

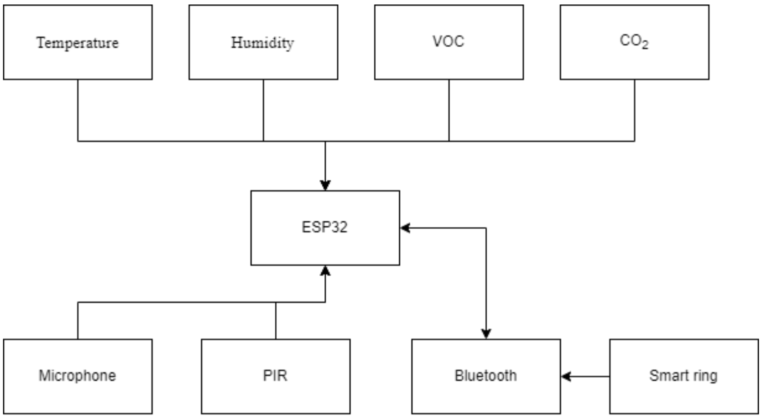

Figure 1. Connection of components.

3. Data Evaluation

The main parameter is the environment index (1). This parameter represents the evaluation of temperature, PIR detector, humidity, CO_2, and VOC index. The environmental index takes on values from 0 to 8 and more. Each environmental index has a different degree of risk (see Table 2). The values in the environmental index are determined based on the results that were based on individual risk measurements, which will be described later. The values are distributed based on the subjective opinion of the authors and these values may be changed in the future if other relevant sensors are added to the system. The result can be an ACTION, where the operator or the system itself starts the regulation of individual parameters in the room, or the system evaluates the parameters as OK and does not intervene in the regulation of the room. The environmental index R is calculated as:

$$R\,[-] = R_t + R_h + R_C + R_{PIR} + R_V \tag{1}$$

where all variables are explained in the Abbreviations section at the end of this paper.

Table 2. Environment index and level of risk.

Environment Index	Threat (Level of Risk)
0	OK
2	Low level of risk
4	Medium level of risk
6	High level of risk
8 and more	Leave the room

The second parameter is the number of people. Hygienists regularly determined the maximum number of people in one room. Based on the data on the number of smart rings in one room, the system evaluates how many people are in one room. When there are too many people, the system will warn the operator to take the necessary actions to minimise the risk of spreading the respiratory disease COVID-19. The third parameter is analysing the sound from the room. If there are people coughing and blowing their noses in the room, the system, based on the sound analysis, will evaluate the possible risk and alert the person to leave the room.

3.1. Temperature Risk

Based on knowledge from articles [12–14] was created Equation (2) and it was determined for calculating the risk of virus transmission depending on the temperature of the environment. The Equation was created for a room temperature range of 0–35 °C.

$$R_t[-] = 0.0005t^3 - 0.0234t^2 + 0.2851t \tag{2}$$

3.2. Humidity Risk

In the same way, Equation (3) was created to calculate the level of risk of viral disease transmission depending on the relative humidity in the room.

$$R_h[-] = \frac{-RH}{100[\%]} + 1 \tag{3}$$

3.3. CO_2 and VOC Risk

As the concentration of CO_2 in the room increases, the level of risk increases. It is the same with the VOC parameter. The Equation (4) for measuring the CO_2 level of risk was derived in the range of 0–5000 ppm and the equation for the VOC level of risk was in the range of 0–10,000 ppm.

$$R_C[-] = 6 \cdot 10^{-6} \cdot (CO_{val})^2 - 9 \cdot 10^{-5} \cdot CO_{val} \tag{4}$$

$$R_V[-] = 2 \cdot 10^{-8} \cdot (VO_{val})^2 - 9 \cdot 10^{-5} \cdot VO_{val} \tag{5}$$

3.4. PIR Risk

The temperature of the human body is around 36.6 °C. The PIR detector can evaluate the temperature of the human body, which makes it possible to identify a person with an increased temperature or a fever. Fever is one of the symptoms of the disease COVID-19. Based on this, Equation (6) can be created to determine the level of risk.

$$R_{PIR}[-] = \begin{cases} 0, & t_h < 37\,^{\circ}\mathrm{C} \\ 8, & t_h \geq 37\,^{\circ}\mathrm{C} \end{cases} \tag{6}$$

4. Experiment

The experiment was carried out in the laboratory on a sample of 12 people. During the experiment, all the above-mentioned parameters were measured for 50 min. Subsequently, after the end of the experiment, individual graphs were evaluated, which can be seen below (see Figures 2–4). Each parameter was measured regularly at minute intervals. The experiment started in an empty room at 11:55 when the average value of the environmental index was 1.5.

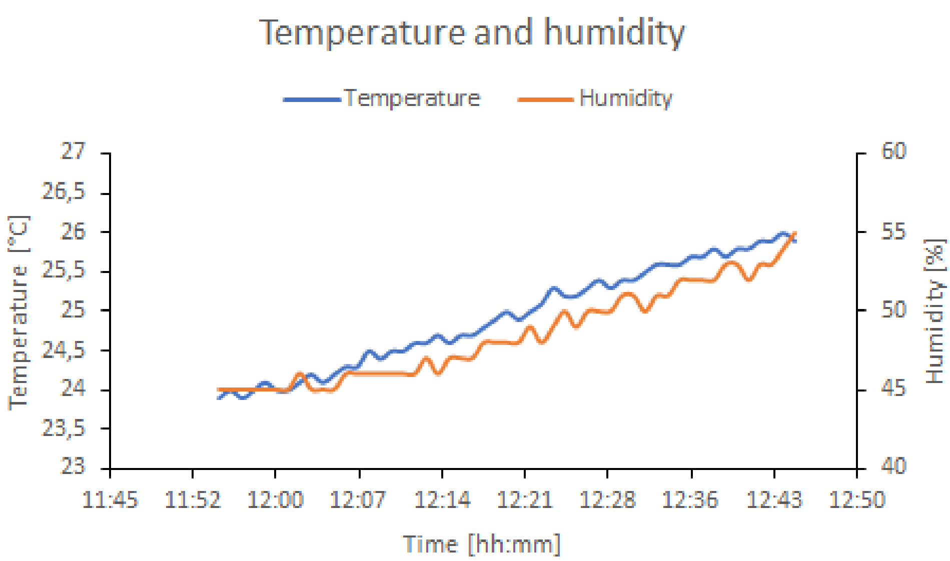

Figure 2. Temperature and humidity in the laboratory.

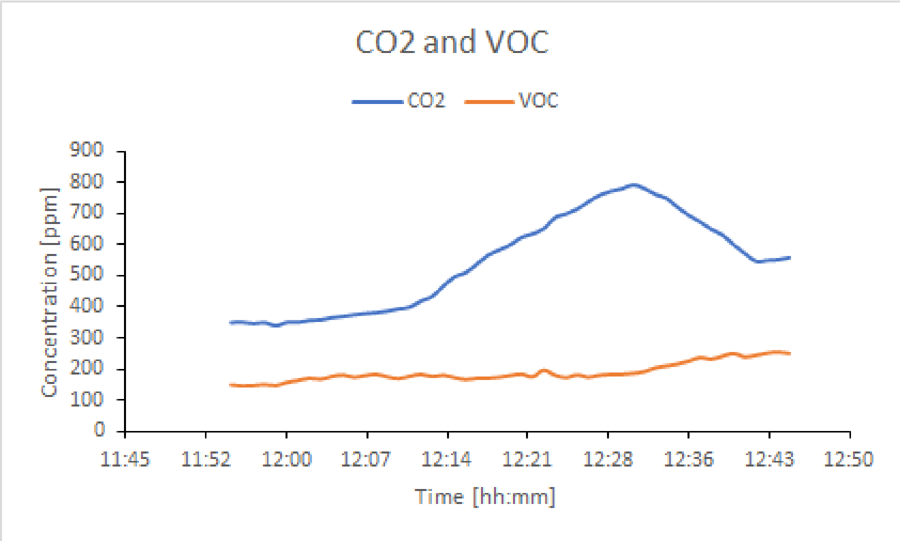

Figure 3. Concentration of CO_2 and VOX in the laboratory.

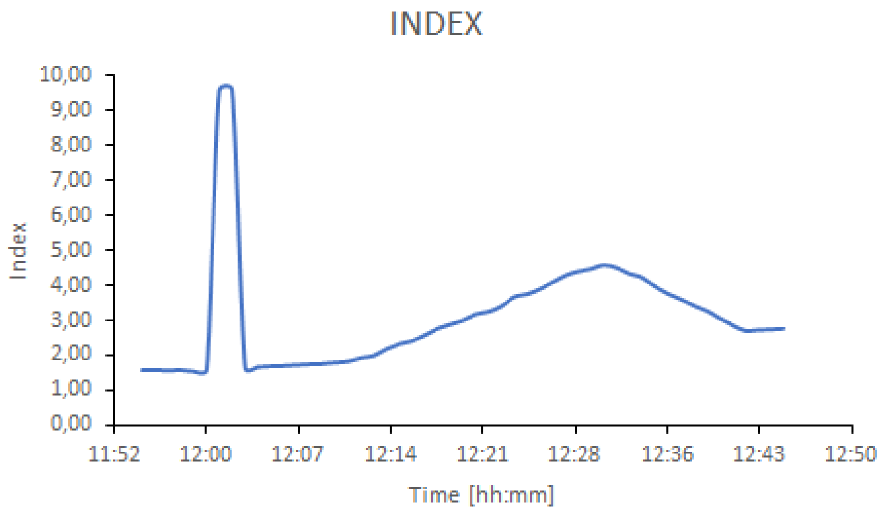

Figure 4. Calculated environment index value.

People entered the room at 12:00. Immediately after the entranced people into the room, the PIR detector recorded a person with an elevated temperature, which was seen in the graph (Figure 4) as a peak (the exposure index was 9.6). Subsequently, the person left the room, and the environment index was adjusted to a value of 1.6. In the graph (Figure 4) we can see the gradual increase of the environment index, which is affected by all the measured quantities. At 12:27 the environment index reached the value of 4, representing a middle level of risk. The operator reacted to this situation and turned on the ventilation at 12:31, thus ensuring the supply of fresh air to the room. From that moment on, it is possible to observe the decrease in the environment index on the graph (Figure 4). The sound in the room was recorded during the experiment. In Figures 5 we can see the showed sound in the room for one hour. Subsequently, a frequency analysis was performed on the given sound (see Figure 6) according to the algorithm that was described in the article. The analysis shows that there was no one in the room that had symptoms such as sneezing or sniffling.

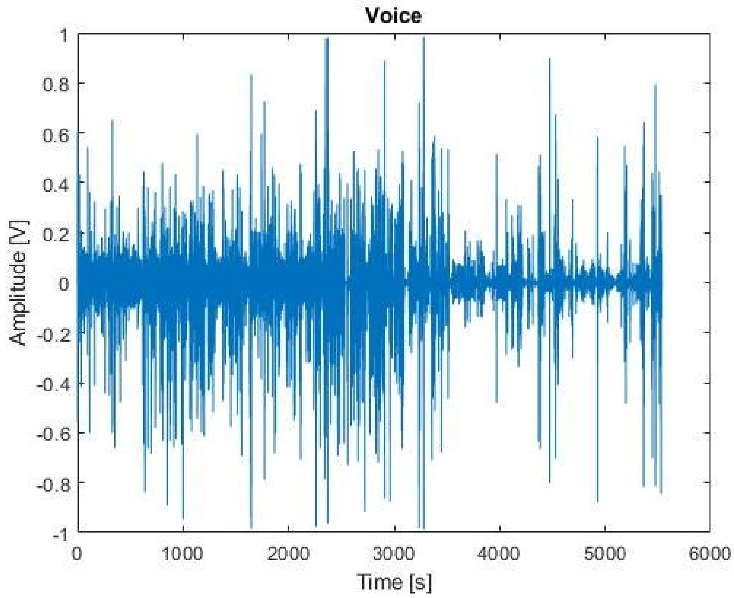

Figure 5. Recording sound from the room.

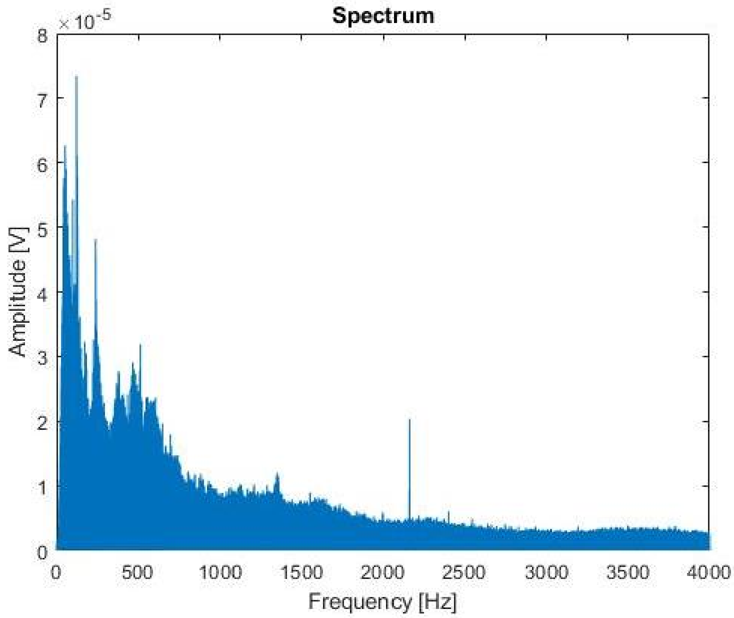

Figure 6. Frequency analysis of recording sound.

5. Advantages and Drawbacks

Our inexpensive technique for measuring COVID-19 in a room has the following potential benefits:

Accessibility: Our proposed method of measuring COVID-19 in a room would be more affordable for people and organisations with low financial resources, making it simpler to conduct broad monitoring in various settings such as workplaces, schools, and public transportation.

Real-time monitoring: The system has the ability to monitor the virus in the air in real time, allowing people and organisations to take the proper precautions to lessen the risk of transmission. These precautions might include increasing ventilation, lowering occupancy, or donning the proper personal protective equipment.

Early warning: The system could assist in providing early warning of an epidemic in a specific location by detecting airborne particles that could be carrying the virus. This would enable people and organisations to take preventive steps to lessen the spread of the virus.

Non-invasive: By using this system, the presence of the virus can be detected without the need for blood tests or swabs. By doing this, the risk of exposure to potential test subjects, including healthcare personnel, could be decreased.

Easy to use: These systems are generally easy to use and don't require specialised training, making it easier for individuals and organisations to implement them in various settings.

It's critical to remember that these tools do not serve as a replacement for further preventive measures like mask use, physical separation, or regular hand washing. Yet, they can be an effective tool for locating possible risk locations and taking the necessary precautions to stop the virus's spread. While there are several above mentioned advantages to using a cheap system for measuring COVID-19 in a room, there are also some potential disadvantages, including:

Reduced accuracy: More expensive laboratory-grade equipment is more accurate than less expensive devices, which could result in false positives or false negatives and possibly unneeded or insufficient actions.

Low sensitivity: If a low viral load is present in the room, these sensors may not be sensitive enough to detect very low amounts of the virus, which could give the impression that everything is fine.

Data interpretation: It may be difficult for people or organisations without a scientific background to properly interpret the data collected by these devices because it requires a certain level of technical knowledge.

False sense of security: The use of this system may induce a false sense of security and complacency, causing people and organisations to disregard other preventative measures like keeping a physical distance and donning masks.

When considering whether to utilise these devices to monitor COVID-19 in a space, it's crucial to carefully assess their limitations and potential downsides. It's also crucial to use them in conjunction with other preventive measures and to adhere to public health authorities' recommendations.

6. Results and Discussion

This system can be placed in every room within one building. In this way, we will get supervision of each room, which we can ensure the effective reduction of the risk of transmission of COVID-19. The whole concept of the system can be seen in Figure 7. A monitoring system is located in each laboratory. These devices are connected to the access point. They can be connected throw metallic wire or wireless. Individual monitoring systems send measured data to the cloud, where these data are processed and subsequently displayed on the website (see Figure 8). In Figure 8, we can see a specific application that was designed during the experiment. Actual data such as environment index, number of people in the room, and voice analysis are displayed in the application. If one of the parameters is increased, a warning will appear on the screen in the form of a yellow window (see Figure 8), and after clicking on the relevant room, all the measured data will be displayed. Based on these data, the operator can take adequate action to prevent the spread of the COVID-19 virus.

The system can be used for a more precise prediction level of the risk of COVID-19 in an indoor environment. The parameter studies show that the infection risk slightly increases for lower humidity and lower temperature. Coughing strongly increase the risk of infection in the room; therefore, distinguishing these events is very important for risk assessment. The system measures data for the indoor environment so can predict the infection risk in real-time and can be used to increase safety in an indoor environment. Based on this data, the operator can promptly react to any recorded change.

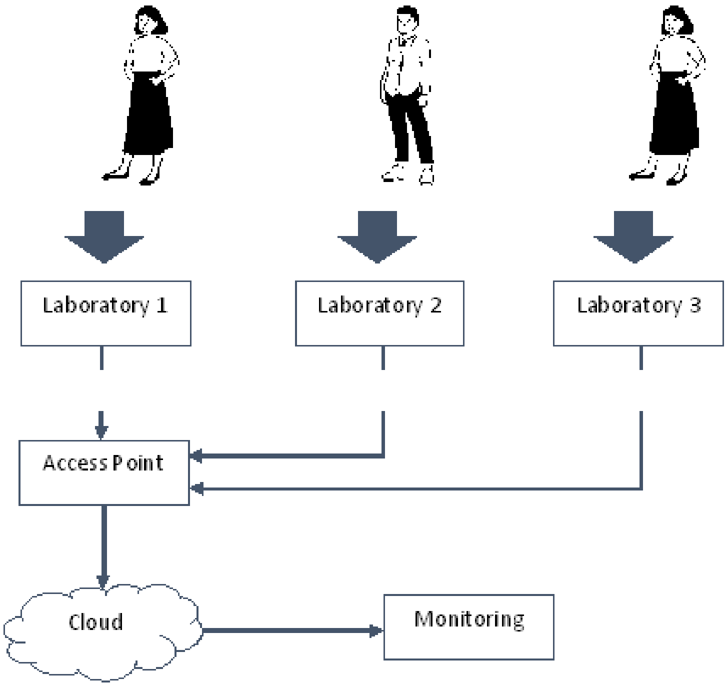

Figure 7. Concept of system.

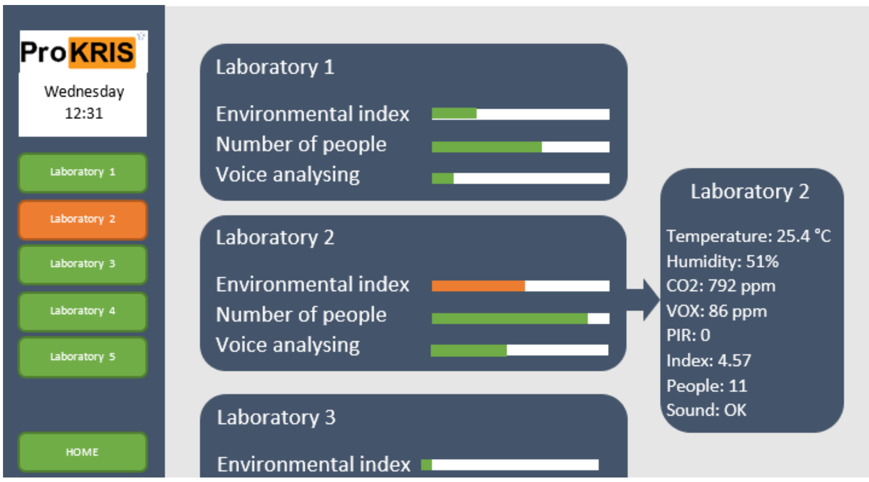

Figure 8. Webpage.

Additionally, households became quarantine objects overnight, which were not at all adapted to medical standards, which contributed to the infection of the entire household. Our designed system can, in principle, replace or improve dwellings and thus prevent the infection of other household members. Even though temperature measurement may not be explicitly authoritative for the infection-person relationship, with such a home quarantine, a high percentage of infection of other household members can be assumed, even if they are asymptomatic. The manifestation of a high temperature even in one person is an authoritative fact for the entire enclosed group. This system can ultimately detect a high level of contagiousness in a given facility even if different members have different symptoms, especially in the initial incubation phase.

7. Conclusions

In conclusion, the development of COVID-19 detection systems has been a critical component of the global response to the pandemic. Due to the virus's rapid transmission, quick and precise testing is essential for identifying affected people, putting into place efficient treatment and prevention strategies, and eventually limiting the disease's progression. Healthcare professionals may now diagnose COVID-19 infections rapidly and precisely thanks to the development of numerous detection technologies, including RT-PCR, fast antigen testing, and antibody tests.

The significance of ongoing research and improvement in COVID-19 detection technologies cannot be emphasised as the pandemic continues to change. Controlling the spread of the virus and finally putting an end to the pandemic will depend on ongoing efforts to speed up, increase accuracy and make COVID-19 testing more accessible. In order to increase testing capacity and enhance public health results, innovative technologies and methods must be developed. Therefore, our COVID-19 detection systems might play a vital role in the global response to the pandemic, and ongoing efforts will be critical in mitigating the impact of COVID-19 on global health and society.

We can consider this article as an example of a monitoring system that can be further modified with different sensors. Alternatively, improve the algorithms for the detection of individual measured values, which will improve the environmental index and the system can react to them much faster. Our effort was to design a cheap and simple system that has some loopholes and it is possible to make a lot of improvements and modifications to it. Experimental results show the feasibility of this system.

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Abbreviations

The following abbreviations are used in this manuscript:

CO_2	Carbon dioxide
R	Environmental index of risk
R_t	Level of risk from temperature sensors
R_h	Level of risk from humidity sensors
R_C	Level of risk from CO_2 sensors
R_PIR	Level of risk from PIR sensors
R_V	Level of risk from VOC sensors
ppm	Parts per million
t	Temperature [°C]
RH	Humidity [%]
CO_val	Value of CO_2 [ppm]
VO_val	Value of VO_x [ppm]
t_h	Temperature of the human body [°C]

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