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LOW-COST REMOTE DOSING SYSTEM FOR CARBON DIOXIDE LEVEL CONTROL IN THE UNDERCOVER CULTIVATION

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Abstract

The article presents the possibility of using a cell phone to control the level of carbon dioxide in undercover tunnels and greenhouses. Studies show that increasing the level of carbon dioxide in the air under covers results in a significant increase in the yield of the crops produced. The proposed system is autonomous. Its essential element is the multimedia Raspberry Pi platform. Under the manufacturer's assumptions, the Raspberry Pi is a microcomputer designed primarily for the operation of audio-visual equipment. It can also be used to build simple measurement systems and control systems such as the access control system. This article describes the basic features of the platform along with the extended modules. The proposed application is used to measure the CO_2 content in the air in the cultivation tunnel. The system also measures temperature and relative humidity. The measured values are compared with the threshold values and the report is sent to the mobile phone selected by the user. The developed program reports on the values recognised as threshold ones. In response to the information received, the user may decide to remotely enable the increase of CO_2 content in the air under cover. The motion sensor integrated with the system informs the user of the unauthorized entry into the controlled area. The latter element is considered a security element. While designing the system, a cost-minimisation principle of its adaptation was taken into account.

Keywords: carbon dioxide level, undercover tunnels, microcomputer type Raspberry Pi, remote control via mobile phone

INTRODUCTION

The growth of human population determines the increase in food demand. Unfortunately environmental conditions do not always favour the possibility of simple increase in its production. One of the methods of intensification is the construction of all types of shelters, which allow maintaining optimum conditions in such areas. This problem affects equally animal and plant production. In the case of plant production, besides maintaining certain temperature, humidity, length of exposure to visible spectrum with a certain wave length and the appropriate mineral composition of the soil, also the appropriate composition of the surrounding atmosphere is vital. As a result of photosynthesis, plant organisms absorb carbon dioxide (CO_2). In enclosed areas, the concentration of this compound in the atmosphere decreases over time. It must be controlled especially in the case of intensive cultivation. For further studies, it can be assumed that in natural conditions the amount of carbon dioxide remains unchanged. The loss of carbon dioxide that is absorbed by plants is compensated by CO_2 produced by organic matter decay (fermentation) processes. In the case of cultivation under cover, unfortunately, the aforementioned process does not develop in a balanced manner. In greenhouses or tunnels, the shortage of the compound must be supplemented, but above all it should be controlled.

Research conducted at various national and international centres shows that demand for carbon dioxide by different plants varies considerably (Beker 2004, Gumińska and Osmelak 1971, Mila and Murkowski 2009, Mishra et al. 1999). The mean concentration of the gas in the air outside urban areas, in the atmosphere of Central European countries (high density of CO_2 industrial sources) is over 400 ppm (molar composition expressed in parts per million). Recent studies demonstrate that the mean content of CO_2 amounts to 409.01 ppm – measured in April 2017 (Global Monitoring Division, 2017). Changes in carbon dioxide content in atmospheric air occur at a rate of about 1.2-2.0 ppm per year (the increase observed since the 1980s) (Trends in Atmospherics Carbon Dioxide, 2017).

Studies conducted in national and international centres prove the positive effect of increased content of CO_2 in air on plant weight gain (Mila and Murkowski 2009; Mishra *et al.* 1999; Beker 2004).

In general, it can be stated that the effects depicted in the increased organic matter occur when the CO_2 content in the atmosphere surrounding the plant is twice or more times higher. Studies indicate that it should be between 700-900 ppm. Among populations of plants cultivated in large quantities, tomato, which is the representative of the nightshade family (Solanaceae), was selected for the further studies.

The tomato is exceptionally sensitive to cold and frost. Its optimum growth air temperature is between 22 and 27°C during the day. At night it may be slightly lower. Air relative humidity should range between 60 and 65%. Soil temperature and humidity should also be monitored in appropriately maintained cultivation. The study focused exclusively on the atmospheric factors. Among the atmospheric factors, the increased content of carbon dioxide (CO_2) in the air has a significant effect on the growth of tomatoes. It was proven that in the case a 10-fold increase in carbon dioxide content in the air dry matter of young tomatoes increased by 73-96% as compared to the yield of plants cultivated, without the increased CO_2 content (Gumińska and Osmelak 1971).

The choice of the type of crop was determined by economic conditions. It was assessed that due to the relatively high costs of preparation and exploitation of covers, production of plants with high market potential (high demand at a relatively high unit price) was justified.

The use of artificial soil and fertilizers, which is inevitable in cultivation under cover, mostly leads (through a series of chemical reactions) to an additional decrease of carbon dioxide in air. This can be limited by the use of special fertilizer mixtures and various fertilization techniques. The solution presented in the article was based on the assumption that the delivery of carbon dioxide in the gas form directly taken up by plants would be most effective. Collection, storage and transport of carbon dioxide in a concentrated form (compressed gas) do not cause technical difficulties. A significant increase in the CO_2 content in the air under cover poses a threat, though. The most detrimental is the threat to human health. The increased concentration of this compound causes delay in human response, drowsiness and an increased feeling of breathlessness (Szargut 2005). This may result in health hazards (fall, injury when working with tools, etc.). Changing the composition of the air under cover must be strictly controlled and the access to cultivation areas should be monitored. Since carbon dioxide absorption processes occur unevenly in the daily cycle, it is absolutely vital to dose it appropriately in the selected daily cycle to ensure its optimum consumption.

The requirements (concentration control, access control, dosing time) led to the development of the control system that allows the user to control them in a mobile manner. It was assumed that the system should ensure the operator's mobility and at the same time allow for the choice of operating mode that is automatic mode and manual mode. In addition, it was assumed that the cost of such a system should not exceed the range of PLN 1000-1600. A change of cultivation will result in the change of optimal conditions.

RASPBERRY PI PLATFORM

Steering and control of technological processes related to undercover plant cultivation is not a particularly complex task mainly due to the unlikely occurrence of stochastic (random) disorders. A Raspberry Pi 3 single-board computer was used as a driver in the study.

Raspberry Pi is a series of single-board computer designed for educational and hobbies purposes. This system is equipped with a Broadcom BCM2837 SoC multimedia processor so that a large number of peripherals such as sound and communication systems as well as data processing blocks are located in one piece in the centre of the board (Figure 1). The external dimensions of this computer correspond to the packet of cigarettes. It does not have its own monitor and keyboard interface.

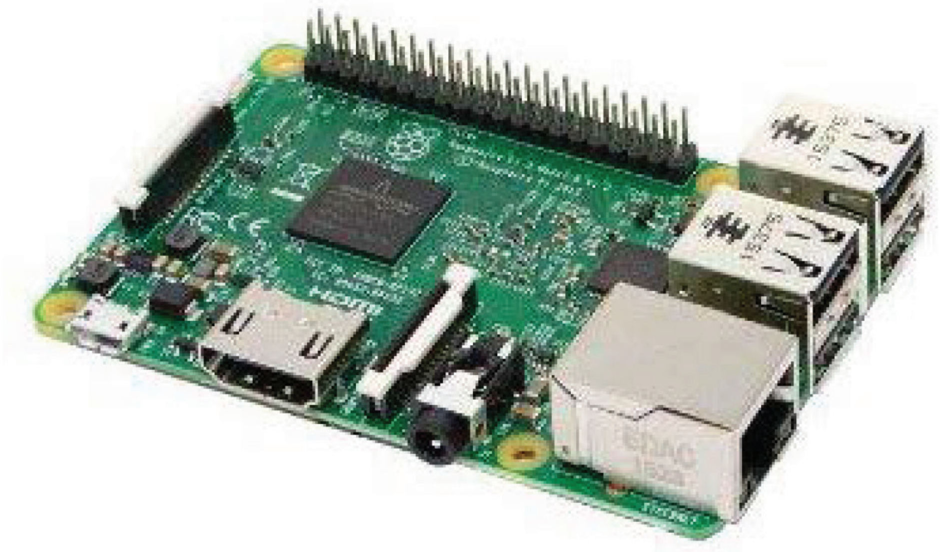

Figure 1. Raspberry Pi computer version 3

Several versions of this computer are currently available. The latest model is equipped with a 64-bit ARM-8 Cortex-A53 processor with a clock frequency of 1.2 GHz processor. This model has 1 GB of RAM. The manufacturer envisaged that the operating system would be installed on the attached SD memory card. Linux Raspbian being a variation of the Debian system is the recommended operating system. Due to the fact that Linux is available as an „open source", modification in the source code is allowed. The Raspberry platform is equipped with basic communication interfaces, the same as the standard personal computer (PC) i.e. audio and video connectors, USB, Ethernet, WiFi and Bluetooth. The number of connectors and versions depend on the Raspberry model.

SELECTION OF EXTERNAL MODULES

When selecting the external communication modules, the principle of compatibility with the platform with which the module will communicate was taken into consideration.

For the purposes of this project are utilized the modules used to measure in the air carbon dioxide content, temperature and humidity as well as a motion sensor. The Raspberry Pi platform does not support the analogue signals sent by some of the sensors mentioned. To be able to handle the above signals, an ADC converter that converts the analogue electric signal (equivalent to the measured parameter) into a proportional digital signal, must be a part of the platform.

The MQ-135 Air Quality Sensor

The study assumed that the carbon dioxide level in the test check would be determined using the MQ-135 sensor (Figure 2) (http:\\www.botland.com.pl 2017). This sensor is suitable for detecting gases such as benzene, alcohol, smoke and CO_2 in air. Results of measurements are transposed into analogue signal (analogue output). The threshold value of the concentration of the selected gas in air can be determined in this case by means of an on-board potentiometer. When the set value is exceeded, the module sends a low signal to the platform via the digital output. At the same time, the LED indicating that the threshold value has been exceeded is activated.

Figure 2. MQ-135 Carbon dioxide sensor (8)

Sensor data provided by the manufacturer indicate a measurement range of 10 to 1000 ppm which is sufficient for the application to be developed. Since the sensor output characteristics provided by the manufacturer only cover a range of up to 200 ppm, laboratory tests were performed. The tests indicated that the module meets the requirements of the application. Sensor output characteristics in the range of 20 to 1000 ppm are linearly logarithmic.

The DHT11 temperature and humidity sensor

In the test system, the air temperature and humidity measurements were carried out using the DHT11 sensor (Figure 3) (http://botland.com.pl/img/art/inne, 2017). The DHT11 sensor enables a digital readout of temperature and humidity values, so it is accessible directly for systems with Raspberry Pi platforms. This sensor measures the air temperature in the range of 0 to +50 ºC and relative humidity in the range of 20 to 90%; their measuring accuracy is 2 ºC with tolerance ± 5%. The accuracy of measurements is not too great but sufficient for this application (the temperature range in tomato cultivation is 22 – 27ºC and relative humidity 73-96%).

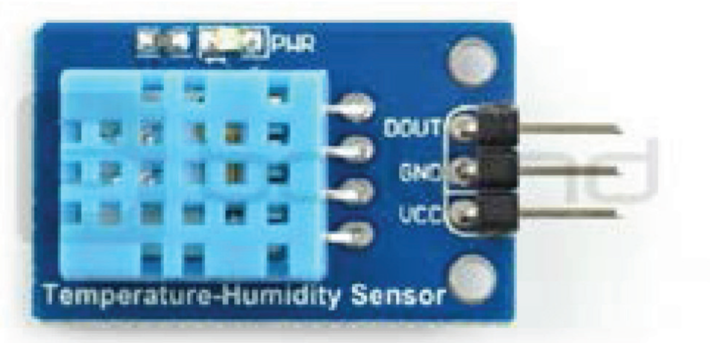

Figure 3. DHT11 temperature and humidity sensor

Relatively short time of measurement (maximum 30 sec for humidity and 15 sec for temperature) and low price of the device also influenced the choice.

The sensor sends 40-bit messages during operation. The last 8 bits of data sent by the sensor form a control value. This allows for keeping continuous track of the correctness of transmitted information.

The PIR HC-SR501 motion sensor

It was assumed that motion would be identified by the PIR HC-SR501 infrared sensor (Figure 4). Motion is detected by accurate temperature measurement, so any sudden change of its value in comparison to the previous one is treated as a warning (http://img.fasttechcdn.com, 2017).

Figure 4. PIR HC-SR501 motion detector

The converter detects an object from a distance of up to 7 m and its viewing angle is 120°. T1 and T2 potentiometers mounted on the module allow for adjusting both the duration of the high state following the detection of the disturbance (object) and the distance at which the object can be detected.

The HC-05 Bluetooth Module

The last add-on module required for the appropriate implementation of the application is the communication module that allows the collected data to be sent to and from the platform. The Raspberry Pi platform is equipped with a universal Bluetooth communication module with a range of up to 10 m. This module can work in Master or Slave modes. In the Master mode, the connection with devices in the vicinity can be initiated spontaneously by the module, and thus device „coupling" and data transmission can also take place. In the Slave mode the clock signal is only an input. Connection initiation and data transmitting in this mode do not take place impromptu (https://sklep.avt.pl/media/products, 2017).

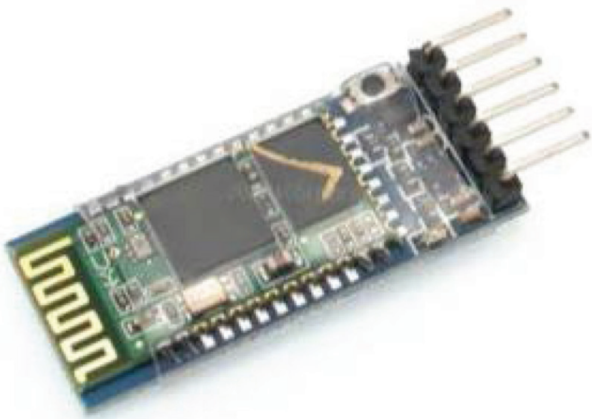

Figure 5. HC-05 Bluetooth Module

ACCESS CONTROL ALGORITHM

The application was developed to enable remote control of the condition of the carbon dioxide dosing installation and to supervise the access to cultivation under cover. The developed algorithm allows for functioning in both automatic and manual modes. Depending on user's needs, it is possible to interrupt currently active mode at any time and initiate a new one. It was assumed that the automatic supervision mode is the default one. Control of the operation of the installation takes place via a mobile application available to the user i.e. it is possible to steer and control using a mobile phone.

Operation of the program in automatic mode

After launching the program, the automatic mode is initiated by default. It was assumed that the automatic control of the sensors and granting or denying access is the main mode of the operation. Only after initiating the automatic mode, is it possible to switch, even instantly, into manual mode. The next step is to retrieve the data from the sensors that are connected to Raspberry Pi. The operating mode can be changed during the data collection process. Once the information from the given sensor is collected, it is checked whether the collected values correspond, according to the accepted criteria, to the expected relationship. Once the data has been received and processed, light signals (locally located LEDs) are triggered. The green colour of the light emitted by the LED connected to the selected GPIO port pin indicates access permission, whereas the red indicates access denial. During the above actions, the current state of the sensors is sent to the mobile application. This allows the user not only to learn about the general state of functioning of the object under investigation, but also to learn about anomalies that cause changes in its functioning. After completing all operations, the program returns to its beginning and the sensor state is re-checked. The block diagram of the program in automatic mode is shown in Figure 6.

Operation of the program in manual mode

It was assumed that initiation of manual mode would require sending a corresponding command from the mobile application. When the manual mode is enabled, the application waits for the user to select the sensor and to send a message with the choice. Then the status of the sensor is checked and the obtained data are sent. After performing the above steps, the program returns to the state in which it waits for information from the user. This enables detecting information about the sensors state. The block diagram of the program in manual mode is shown in Figure 7.

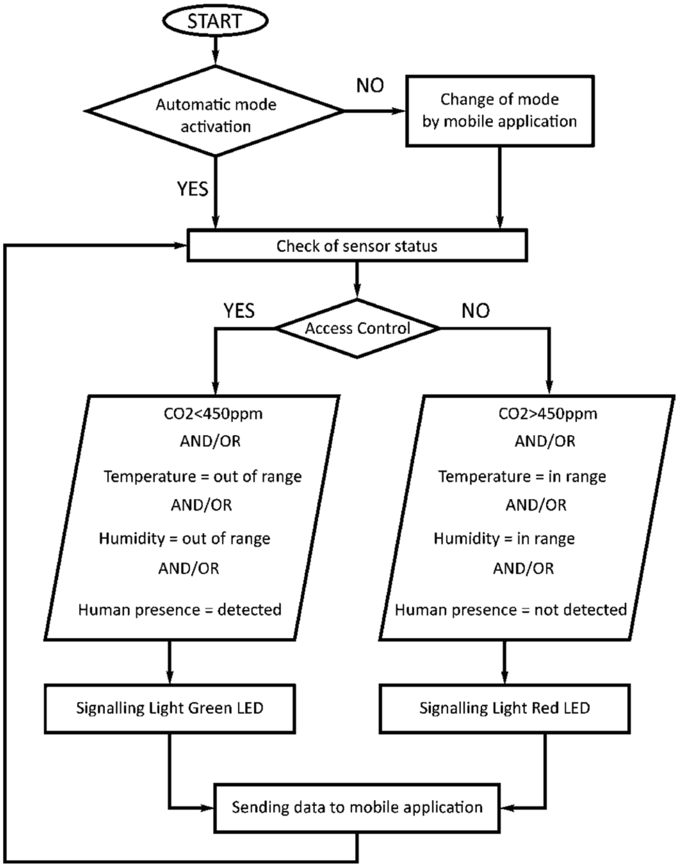

Figure 6. Operation of the program in automatic mode

After detecting a movable heat source, the PIR motion sensor presents a word MOTION on the screen. In addition to the information appearing on the screen, local signalling using LEDs remains active. This way of communication of the condition of the installation concerns primarily the indications of the CO_2 sensor. Too high concentration of gas can be harmful to human body. Therefore, the control function of this parameter is superior to access control. Detection of high CO_2 concentration is signalled by „flashing" red LEDs.

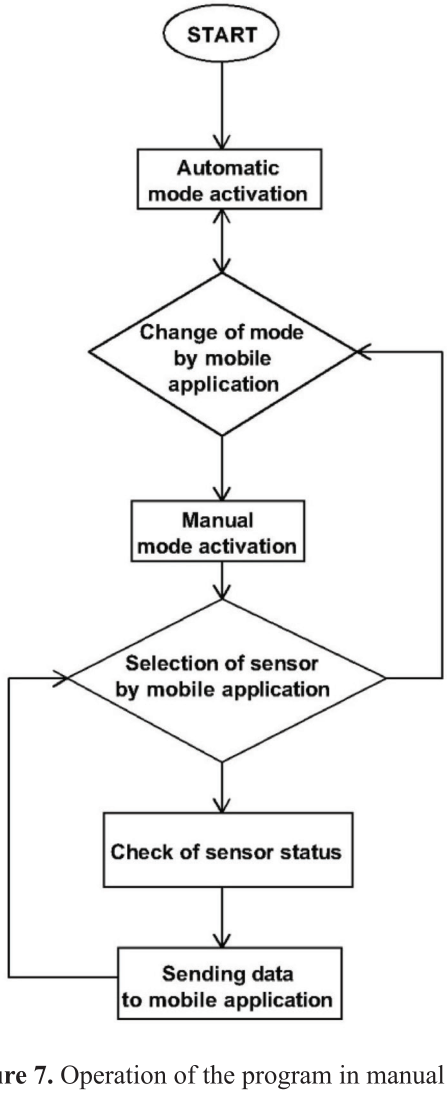

Figure 7. Operation of the program in manual mode

If the motion is detected or air temperature or humidity values exceed the established standard and if the limit value of CO_2 concentration has not been reached, the red LED (continuous light) is enabled. The state of the diode remains unchanged unless action is taken to change the parameters. Accurate identification of parameters deviating from the established standards is possible through the mobile application. Light signalling roughly checks conditions of the facility and grants or denies access. In the table below detailed information about colour and diode state in reference to sensor state is presented.

Table 1. Access to the object – information table

SIGNAL	STATE OF OBJECT
FLASHING RED	NO ACCESS (increased concentration of CO_2, other sensor parameters beyond standard)
RED	NO ACCESS (permissible content of CO_2, parameters beyond limit values)
GREEN	ACCESS GRANTED (sensor parameters below limit values)

MOBILE APPLICATION

The mobile application was designed for Android via the MIT App Inventor 2 platform, which allows for developing an application using a simple block language. It was assumed that user safety is of utmost importance and therefore the information about the state of emergency due to the CO_2 content is a priority. The developed application consists of two screens that function as a control panel and as an information receiver (Figure 8). The first screen called "Auto Mode" is activated as a start-up because the program is launched in the same way on the Raspberry Pi platform. Due to the nature of the work performed, the above mode is equipped with a text "display", which shows the messages received by the device, and the "MANUAL" button. It changes automatic mode into manual mode. Both modes also include a button called "Connect" with the use of which the Bluetooth module connection to the main control unit is activated. After successful connection, the information "Connected" is displayed on screen.

When the application is switched to manual mode, a screen with the name "Manual mode" is displayed. For functional reasons, this screen contains more elements than the automatic mode screen. Apart from the text display function, 5 buttons, which check the state of the parameters that correspond with them, were added. Checking the state of the sensors is carried out in the same way as changing the operating mode.

In the process of conducting the tests, it was concluded that it would be useful to add a function, which would enable and disable the carbon dioxide dosing system. It was assumed that the gas would be "delivered" to the cultivation area through a distribution network constructed as a collector system made of polypropylene pipes equipped with suitable nozzles. The gas itself will be stored in cylinders gathered, for example, under cover. Remote opening of solenoid valves will enable to maintain the desired level of CO_2 concentration.

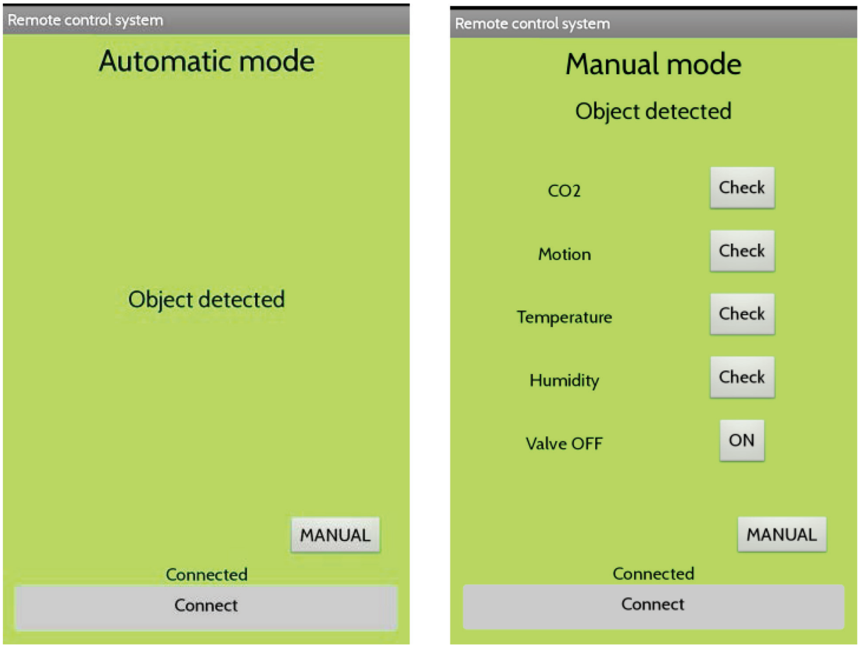

Figure 8. Automatic mode screen (left), manual mode screen (right)

Below, there are the views of the mobile phone screen in various states of operation of the monitoring installation. Presented images refer to the prototype version of the application. Figures 8 through 11 presenta the views of the mobile phone screen. Drawings were made using the android system tools (Stasiewicz 2015).

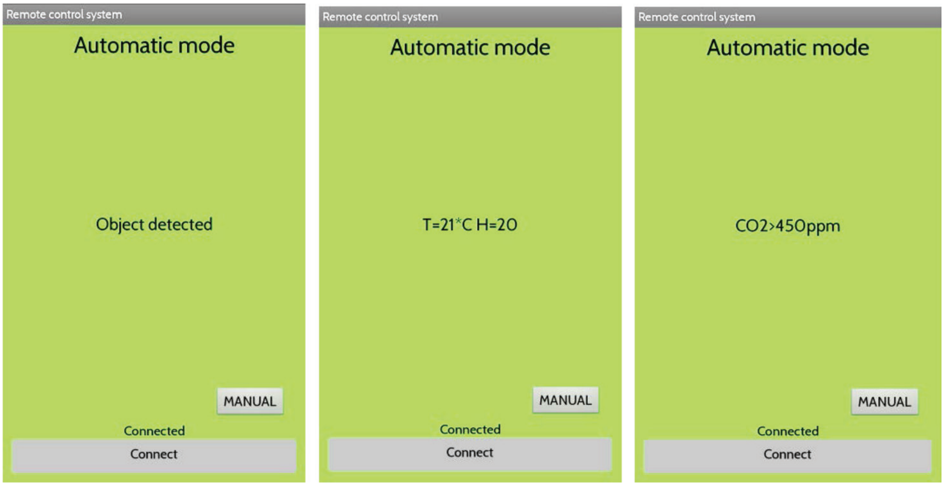

Figure 9. Data displayed by the mobile application in automatic mode

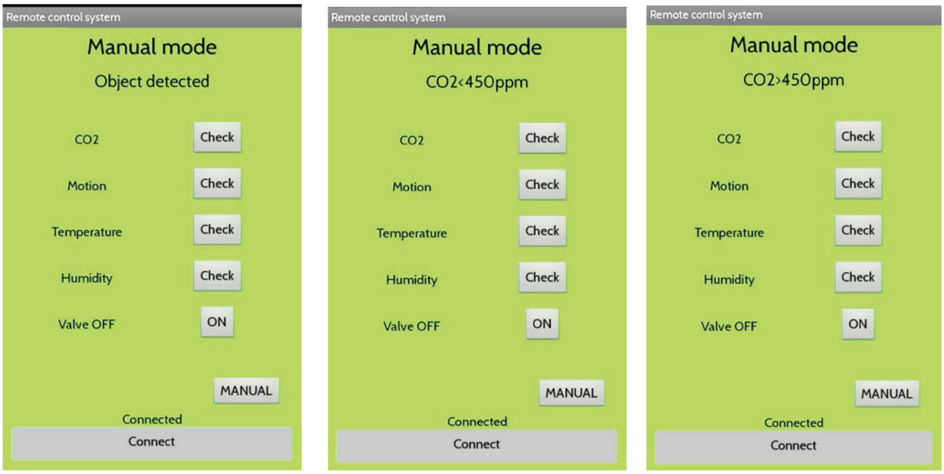

Figure 10. Data displayed by the mobile application in manual mode

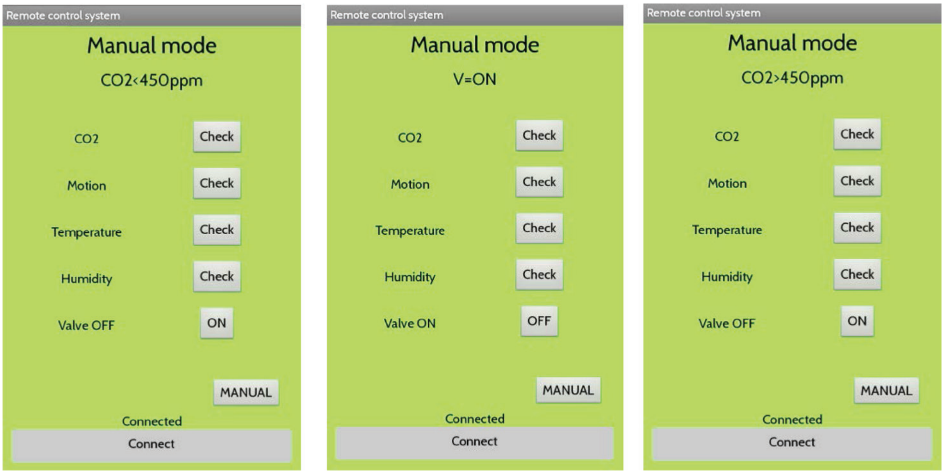

Figure 11. View of the screen of the application in manual mode; opening the gas distribution valve

SUMMARY

Verification tests carried out with the system consisting of the presented components showed that a remote monitoring system of dosing carbon dioxide into the atmosphere in tunnels can be executed and implemented for safe operation even if the budget is tight. The cost of the installation did not exceed the projected budget of PLN 1000. The most expensive element is the platform itself. In Raspberry Pi 3 ver. B + version the cost falls into the range of PLN 190 to 280. MQ-135, HC-05, PIR HC-SR501 and DHT 11 modules cost PLN 20, PLN 30, PLN 10 and PLN 33 respectively. The total cost is just over PLN 370. The most important measurement element is the carbon dioxide sensor. A module with an extended measuring range, e.g. up to 10,000 ppm would be recommended in professional applications The price of such a module exceeds PLN 220. The problem of communication and data transfer should be dealt in the same way. For this reason, the described measuring system should be supplemented with a GSM transmission module, e.g. GSM Shield version v 2.064 (approx. cost PLN 210). The presented data show that the cost of subassemblies for professional installation is about PLN 800. The presented prices are net prices.

The authors estimate that the solenoid valve with the power module costs approximately PLN 500, and that the cost of materials needed to construct the CO_2 distribution collector should not be higher than PLN 250.

The presented calculation does not take into account the purchase cost of a telephone and the cost of the setup. The presented solution is the basic (base) solution. Increasing the number of gas measurement and distribution points as well as temperature measurement points will result in a proportional increase in the running of the installation.

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