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A REVIEW OF REAL TIME SMART SYSTEMS DEVELOPED AT UNIVERSITY OF NIŠ

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Abstract. *This paper presents the bibliographic review of smart systems implemented so far and their application. Also this paper is dedicated to new smart mobile system developed for monitoring microclimatic parameters. This system is primarily intended for monitoring real-time microclimatic parameters, such as air quality where the presence of carbon monoxide (CO) is monitored, as well as other microclimatic parameters. The mobile system which will be described in this manuscript can be installed in public transport (to obtain information on microclimatic parameters on a known route). Also, to obtain information on microclimatic parameters from a random route, it is possible to install the system in a taxi vehicle. This system provides the ability to generate a map using the data provided by the system based on GPS coordinates. The system is based on a group of embedded sensors, GPS module, PIC microcontroller as a core and server system, and wireless internet using Global System for Mobile Telecommunications (GSM) module with General Packet Radio Service (GPRS) as a communication protocol.*

Key words: *Smart mobile system, Internet of Things, PIC microcontroller, Sensor technology*

1. INTRODUCTION

With the increase in the number of vehicles, but also with the reduction of green areas in cities, for the needs of the construction of residential buildings, as well as parking spaces, the harmful impact on microclimatic parameters has increased significantly. Today, the urban population makes up almost half of the world's population. It is estimated that a city of one million citizens produces about 25,000 tons of CO_2 and CO and about 300,000 tons of water waste every day [1]. These parameters are progressively increasing every year thanks to urbanization, which reduces the quality of life of people more and more. In order to monitor the parameters that greatly affect the air quality and other microclimatic parameters, it is necessary to have a large number of points where these parameters are monitored. Knowing

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in which parts of the city the greatest pollution is, it is possible to report certain corrective measures, such as traffic regulation, use of pollutant filters, change of heating fuel type (transition of heating plants to natural gas and renewable energy sources).

The systems used to monitor microclimatic parameters require large amounts of money (installation costs, regular maintenance and servicing needs), which on the other hand means that a small number of cities decide for this solution. To avoid this, it is necessary to implement a smart autonomous mobile system that can replace a large number of systems that are installed at measuring points. In order to have an insight into the position where the parameters were measured, it is necessary to use the GPS module, to obtain location information. Based on this, it is possible to locate where the air pollution is higher, as well as in what period of the day, month, even during the year. The advantage of such systems is reflected in the fact that a higher frequency of measuring points is possible, which makes the entire system for monitoring and measuring microclimatic parameters cheaper.

The manuscript aims is to develop a smart mobile system for real time monitoring microclimatic parameters, such as air quality where the presence of carbon monoxide (CO) is monitored, as well as other microclimatic parameters (various sensors can be added, which can change the set of microclimatic parameters which are monitored). Such a system can be part of smart cities, since it is an autonomous system for monitoring environmental parameters. The advantage of such system compared to conventional static systems is that such a system can be installed on vehicles (public transport, police, taxis, etc.), which means that the coverage of the area monitored is almost unlimited. If it is desired to monitor the established route, public transport can be used, while in case of need of a random route, taxi vehicles could be used. For example, in the city of Nis, one taxi vehicle crosses a route averaging about 400 km in 24 hours, making about 70 individual rides. In addition to monitoring microclimatic parameters, it is possible to generate a map using the data provided by the system, based on GPS coordinates.

The system has a wide application based on meteorological/microclimatics parameters that measure: temperature, humidity, atmospheric pressure, altitude, lighting, and detection and measurement of Carbon Monoxide (CO). All measurements are accompanied by information on the time and date of measurement, also with GPS coordinates, which are used so that each measurement is supported by the location where the parameter measurement was performed. GPS coordinates, time and date information are present during the storage of data on the server and are available when downloading the results. After that, the collected data on the measured parameters can be added to the map.

In connection with the previous, for the purposes of system testing various measurements were performed in Nis. Testing was performed in parts of the city where there are no measuring points (global monitoring), i.e. parts of the city that are not covered by measuring points for global monitoring. Based on the data of the site for monitoring and supervising information on air quality "*Air Pollution in Serbia: Real-time Air Quality Index Visual Map*", [2], there are 5 measuring points in Nis where air quality parameters are monitored. For a global view of the situation in terms of air quality, these points represent a sufficient number of points, but to look at the situation in specific parts of the city, it is necessary to have a significantly higher number of points. Also, the highest frequency of residential buildings, as well as people and cars are in the central parts of the cities, it is necessary to set up as many measuring points as possible in these parts of the cities. It is important to note, several other factors that additionally affect the air quality should be taken into account, and they are more often located outside the central parts of the city. Some of the factors that negatively affect are the type of building (whether it is a residential building or a building for other purposes), the type of fuel used for heating (whether it is fossil fuels, natural gas, electricity, etc.), and then which is a type of public city transport (buses, trolleybuses, metro, etc.) and perhaps the most influential factor is the existence of the heavy industry.

There are a large number of modular systems for measuring and acquiring atmospheric parameters on the market, but there are few such comprehensive systems that combine all modules for measuring/observing both microclimatic and atmospheric parameters and that such a system is also mobile. For example, it can find a system that measures only one parameter, wind speed [3]. That anemometer is a part of the meteorological station project.

It is important to note that different systems are developed at University of Niš. The smart systems such as meteorological stations, smart farms, and smart systems within smart faculty are data collection systems that can remotely collect information based on meteorological/ambient (microclimatic) parameters. In addition to storing the collected data in the Cloud or database on a web server and on the basis of the collected data, the system, depending on the purpose, takes certain actions that are expected of it [4]. Some of the mentioned systems are implemented and they are described in more detail in section 2.

It should be emphasized that in this paper there is a double goal, the first is related to the bibliographic review of smart systems implemented so far and their application, as well as the advantages they offer in relation to systems described and published in reference journals. The second goal of the paper is dedicated to a smart mobile system for monitoring microclimatic parameters, which is described in detail in section 3.

2. Theoretical Background with a Review of Authors' Previous Investigation

There are many different implementations of smart autonomous systems for monitoring microclimatic parameters, which can be divided according to the communication technologies they use, as well as storage media. Most implementations use wireless technologies to communicate between the sensor part and the main unit.

A smart system after monitoring and measuring parameters, stores measured data so that the end-user can easily access them, access measurement results from anywhere, and also using stored data according to his needs. Based on these needs, smart autonomous systems have been developed based on different technologies. So it could stand out four groups of smart systems based on:

1. Custom microcontroller and mobile application (Bluetooth for communication).
2. Custom microcontroller and computer (Radio Frequency (RF) for communication).
3. NodeMCU running ESP8266 Wi-Fi module and Cloud or database on the webserver (Wi-Fi Internet for communication).
4. Custom microcontroller and Cloud or database on the webserver (Global System for Mobile Telecommunications (GSM module) for communication).

It is very important to mention some implementations of smart autonomous systems for monitoring microclimatic parameters. In the manuscript [1], the authors described a mobile system that can measure Nitrogen Dioxide NO_2 and carbon monoxide CO. The system described by the authors is equipped with a GPS module, in order to obtain information on the measurement location of microclimatic parameters. As the authors stated, the system that was implemented was tested, but the measurement intervals were not the same, so that the results obtained were not measured in real time. This shortcoming affects users a lot, especially who need real-time parameter information. Therefore, our primary task was to develop the system that has the ability to monitor microclimatic parameters in real time, as well as information on the location of measurements. Also, our system enables the measurement of more microclimatic parameters than the system described in the manuscript [1]. In the following manuscript [4], the authors described a mechatronic system for measuring environmental parameters. The system is based on the Arduino Due development board with ATmega 328 microcontroller. The sensor part of this system consists of temperature and humidity sensor SHT1x, which is much more unreliable compared to the sensor used in the implementation of our system. In addition, four DS1820 temperature sensors were used, whose measuring range is smaller compared to the digital sensor used in our system. Also, four BPW 34 photodiode light sensors that are not reliable enough compared to the digital sensor we used. Finally, they used a noise sensor consisting of a capacitive microphone CZN-15E and an MCP 601 I/P. The system is static, which means that it is necessary to use more such systems to measure microclimatic parameters, which further increases the cost of the system itself. The next manuscript [5] presented a device developed by the authors for monitoring and controlling microclimatic parameters within a livestock barn. The realized system is of static type, which monitors and controls parameters such as temperature, air humidity, ammonia concentration and carbon dioxide. The sensor nodes are interconnected by RF communication using the ZigBee module, which allows a relatively short range in sending or receiving data. In this regard, such system is limited to a narrow application, that is, for monitoring microclimatic parameters in a small area. In addition, it is important to note that the authors do not specify which sensors were used for the realization of the system, based on which there is no specific information on the ranges of measurement of microclimatic parameters. In addition, it is stated in the manuscript that the system was tested within a few hours, unlike the system we implemented, where the testing period lasted at least 7 days. Finally, to our knowledge, there are no available mobile systems, comprehensive as this one described in the manuscript, which is the main motive of this manuscript. Furthermore, the systems we implemented earlier did not allow the measurement of microclimatic parameters at different locations, since they are static systems. Our implemented systems are described in more detail in our previous papers [5, 6, 7, 8] published in relevant journals, and at international conferences. The graphical illustration of realized systems is shown in Fig. 1.

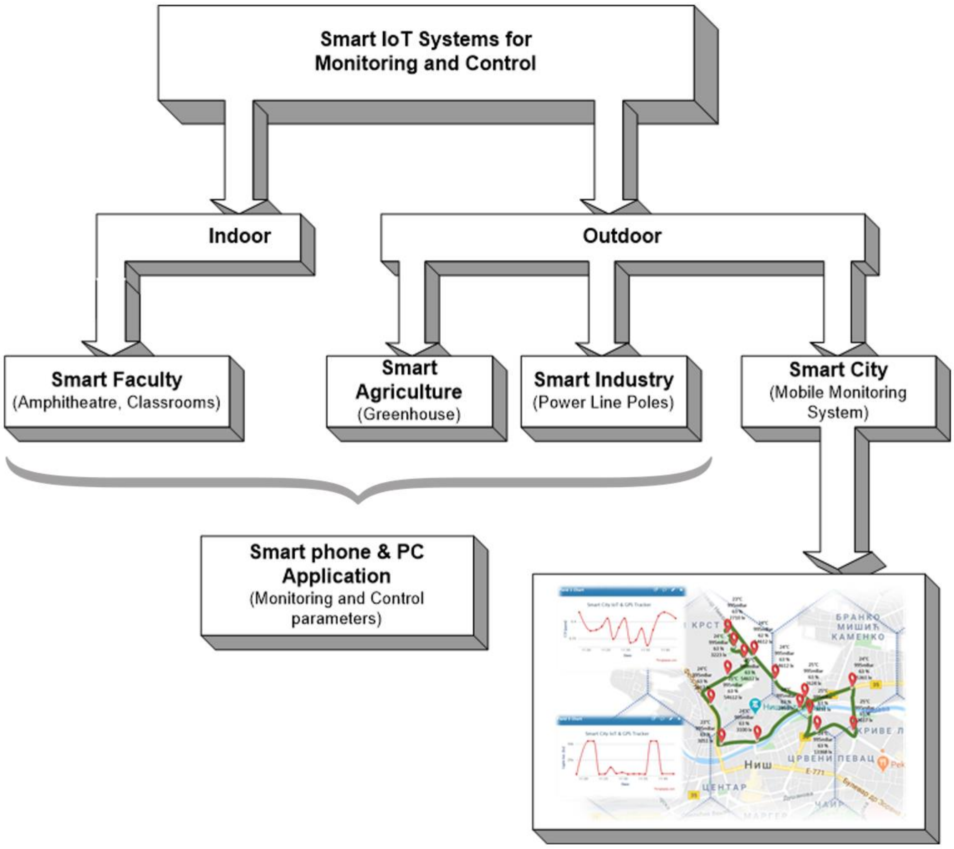

Fig. 1 Block diagram with an overview of realized smart systems and proposed smart mobile system.

In our previous research [6], a real-time smart meteorological station based on embedded sensors and IoT technology was analyzed (as shown in Fig. 2). The described meteorological station was based on two main parts, the first was a PIC microcontroller which represented the central part of the measuring system together with the built-in sensors. The second part was related to the ThingSpeak Internet of Things platform for storing data using GSM/GPRS communication modules. The microcontroller used to implement this system belongs to the Microchip family of PIC microcontrollers. In addition to microcontrollers, sensors were used to monitor and measure meteorological and ambient parameters such as temperature, humidity, atmospheric pressure, altitude, wind speed, light intensity, and detection and measurement of natural gas concentration (LPG). In Fig. 2, it can be seen the measured results for temperature (for more detailed information about other measured parameters in [6]). Based on a wide range of meteorological and ambient parameters, the implemented system was used not only in meteorological stations, botanical gardens, libraries, and hospitals but also in mines, since the system measured the concentration of LPG, could detect and measure the presence of Methane CH_4. In addition to the listed parameters that can be monitored and measured, there is a possibility to determine the period between two measurements, as well as how long the measurement of parameters lasts since the implemented system has an RTC module that monitors and calculates the current time. The disadvantage of this system is that it is a static system, unlike the mobile system which will be described in chapter 3 of this manuscript. Also, a less reliable sensor was used to detect and measure the concentration of natural gas (LPG), and carbon monoxide CO, in contrast to the sensor used in the implementation of the system described in chapter 3.

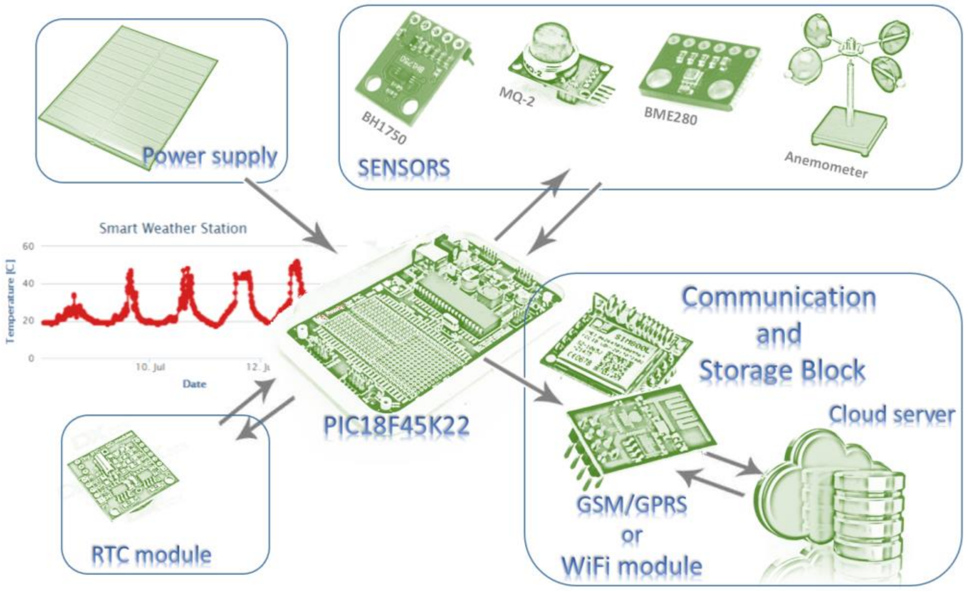

Fig. 2 Block scheme of the smart weather station. Block scheme is based on [6]. The measured results for temperature are given as an example.

Our next research [7] is related to the application of IoT technology and smart systems in the industry, more precisely to the implementation of IIoT technology (as shown in Fig. 3). The described real-time system is based on power line poles monitoring to avoid an unwanted drop of the power pole, which would cause an interruption in the power supply, fall of the power line pole on a car passing by (provided that the pole is next to the road), injury of people due to the fall of the power pole, and also not leading to an accident. To avoid this undesirable scenario, the slope of each pole was monitored using an accelerometer, to know which of the poles could cause problems. Each of the poles has its unique ID based on which it is possible to track the slope of each pole independently. In addition to the accelerometer, parameters such as temperature, humidity, and atmospheric pressure were monitored, so that the people in charge of maintaining the flagpole had an insight into the atmospheric conditions that await them in the field. The system consisted of three separate parts, which were divided hierarchically, starting with the part with the least intelligence (level 1), through level 2 which represented the connection between the flagpole and the Cloud server and the control room (level 3). In Fig. 3, it can be seen the measured results for the slope of angle (more detailed information about other measured parameters can be found in [7]). The first level consisted of a microcontroller of the PIC family that monitored and measured the parameters (angle of inclination, temperature, humidity, and atmospheric pressure) and depending on the inclination of the flagpole sent information to level 2 according to a defined measurement period. The data was sent using RF modules, to make the system as cheap as possible for implementation. Level 2 was served by a PIC microcontroller that received information about each pole based on its module based on the RF module and sent that data to the Cloud or database using the GSM/GPRS module since level 2 was located in the open. Level 3 was a database or Cloud server, along with a control room from which it was possible to access measurement data and from where messages could be sent to teams about which flag was critical.

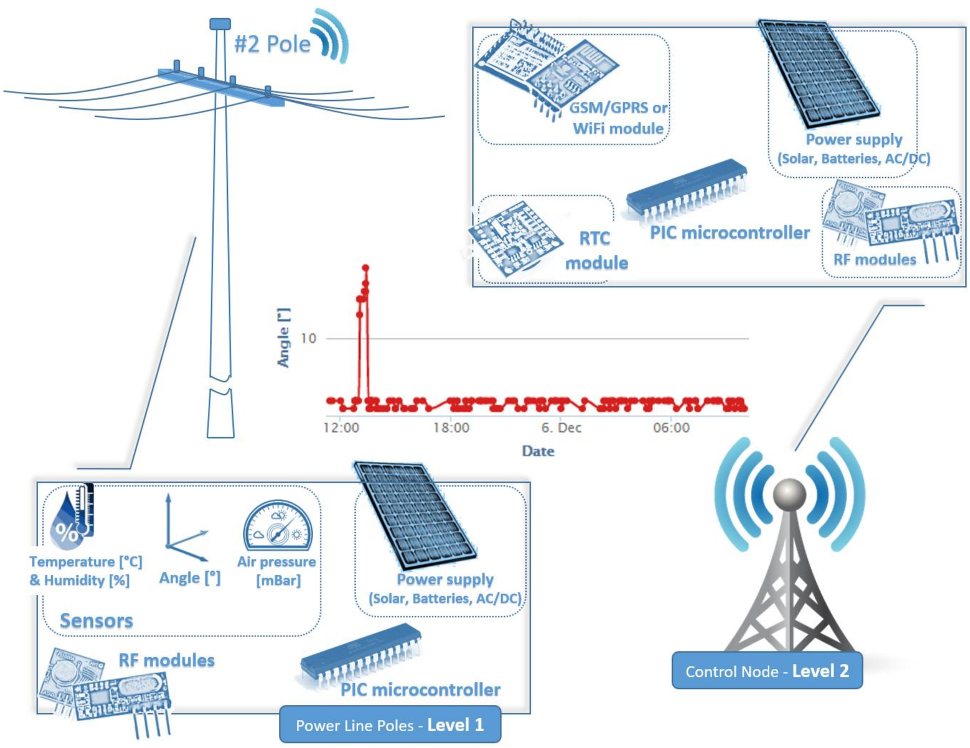

Fig. 3 Block scheme of the smart system for supervision and monitoring of the power line poles using IIoT technology. Block scheme is based on [7]. The measured results for slope of angle are given as an example.

As part of the research [8], we have implemented a system related to smart agriculture, which allows monitoring and control of the greenhouse and the most important parameters of microclimatic conditions in it (as shown in Fig. 4). Based on these parameters, it is possible to improve the quality and quantity of yield in the greenhouse. Besides, the system monitored and controlled the greenhouse irrigation system, so that the necessary fertilizer was delivered to the plants at an adequate time. The system was based on monitoring and control of greenhouses in three levels, as follows, level 1 was the control of ventilation (air conditioner and door), safety net, level 2 was the control of irrigation (water temperature, water level in the tank), and also and the amount of feed to be added to the tank. Level 3 is the most complex part of the entire system and was reflected in the fact that parameters such as greenhouse air temperature, soil temperature, air humidity, soil moisture, atmospheric pressure, soil pH, wind speed (to protect the greenhouse structure), light intensity and amount of carbon dioxide (CO_2) were monitored and controlled. In Fig. 4, it can be seen the measured results for air humidity and soil moisture (more detailed information about other measured parameters can be found in [8]). The entire system is powered by using a PIC microcontroller that sends data to a database or Cloud using a GSM/GPRS module. For the needs of the system, an application for smartphones was realized, so that the monitoring and control of the greenhouse could be done remotely.

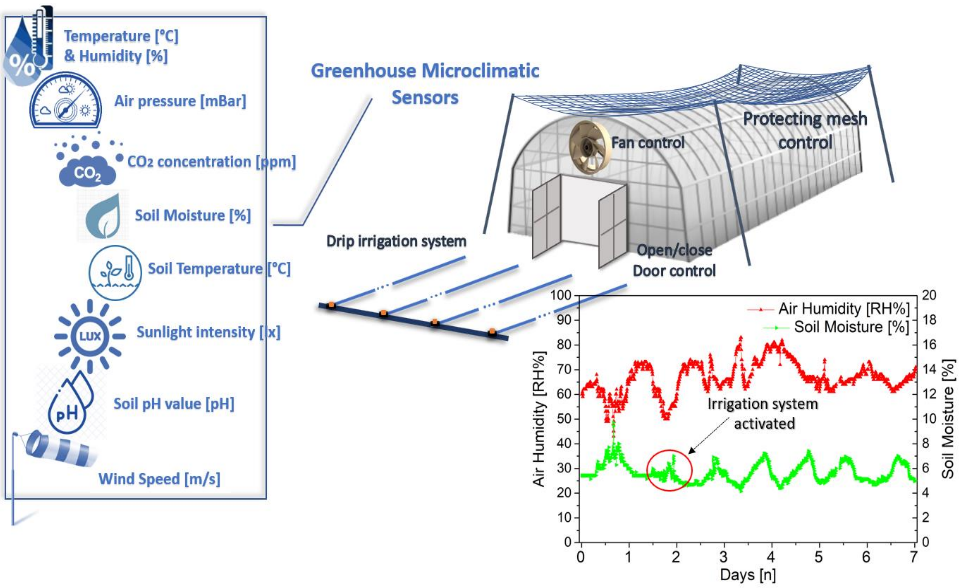

Fig. 4 Block scheme of the smart autonomous agricultural system for improving yields in greenhouse based on sensor and IoT. Block scheme is based on [8]. The measured results for air humidity and soil moisture are given as an example.

As part of the smart faculty within the research [9], we have implemented a system for monitoring and control of microclimatic parameters at the faculty, more precisely in amphitheaters and classrooms, to provide better working conditions, i.e. teaching. The system (as shown in Fig. 5) was based on monitoring and control of microclimatic parameters such as temperature, humidity, atmospheric pressure, light intensity, carbon dioxide (CO_2) concentration. The entire system is realized in the form of control nodes, where each of the ambient parameters is controlled by air conditioner and ventilation (temperature and humidity in amphitheaters/classrooms), adjustment of blinds/venetian blinds (lighting intensity in amphitheaters/classrooms). The system we have implemented is part of a smart faculty, which, based on a known number of students who have classes in one of the amphitheaters or classrooms, could set adequate conditions for the best possible student work. This system is completely designed in the Altium Designer software tool for designing printed circuit boards [10], a 3D model was made and realized as shown in [9]. As in previous systems, the central component is the microcontroller of the PIC family. In Fig. 5, it can be seen the measured results for temperature and relative humidity (more detailed information about other measured parameters can be found in [9]). A GSM/GPRS module was used to send the measured data to the database on the server. For the needs of the realization of the system, an application for smartphones was realized, to monitor and control remotely.

All research [6, 7, 8, 9] is related to smart systems that can monitor and measure meteorological, ambient and microclimatic parameters in real time, with the disadvantage of static systems, i.e. systems that are not mobile and do not have the ability to measure parameters at multiple locations.

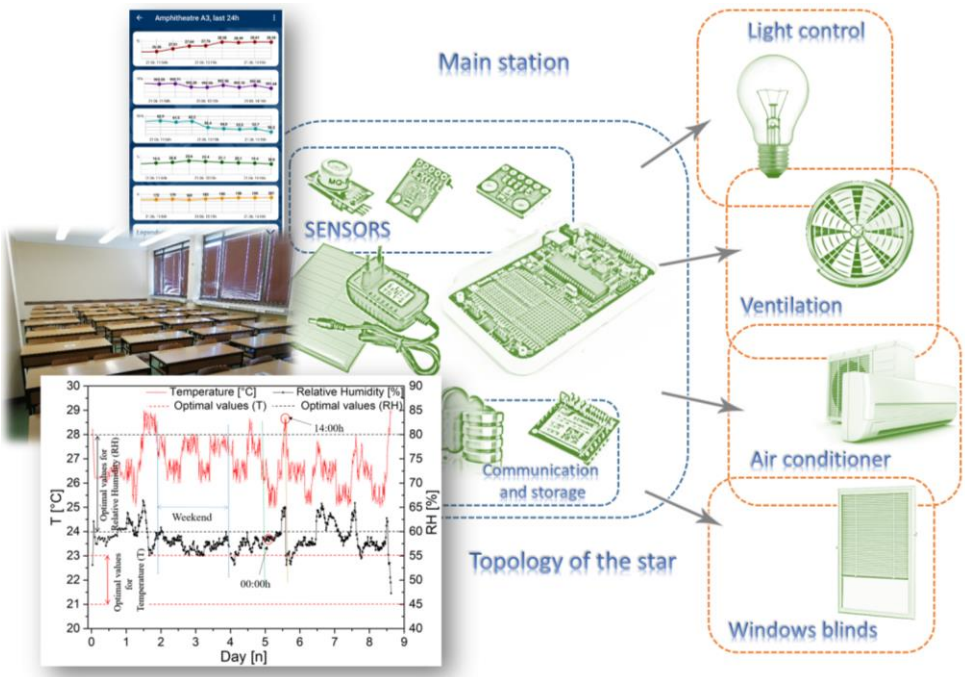

Fig. 5 Block scheme of the smart data logger system based on sensor and Internet of Things technology as part of the smart faculty. Block scheme is based on [9]. The measured results for temperature and relative humidity are given as an example.

3. DEVELOPMENT OF SMART MOBILE SYSTEM

This manuscript presents the model of smart mobile data logger for real time monitoring microclimate parameters based on PIC microcontroller and Cloud platform. The smart system is designed to be mobile, scalable and easy to setup and extend. It is based on powerful PIC microcontroller which manages the whole system. It includes embedded sensors for observing and measuring of the microclimatic parameters, GPS coordinates for information about location where the measurement were made and GPRS module which upload data to Cloud platform.

3.1. Design of solution

A smart mobile data logger system for real-time monitoring is realized so that is consists of 7 segments, shown in Fig. 6. The power supply serves all other blocks. The microcontroller PIC18F45K22 [11], which represents the core of the entire system, manages the microclimatic sensor block, which serves for microclimatic measurements and observations and GPS coordinates for location information. Also, the GSM/GPRS block, realized using the SIM800l module [12], is controlled by the above microcontroller.

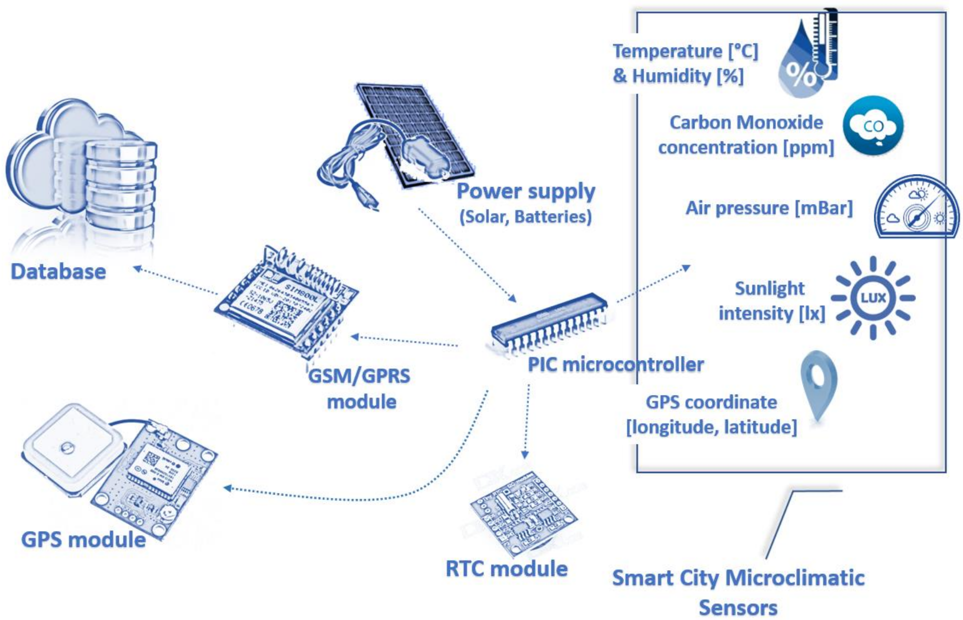

Fig. 6 Block scheme of the smart real time mobile microclimatic monitoring system based on sensor and IoT technology.

The sensor list is shown in Table 1:

Table 1 Sensors and their measurement characteristics

Sensor	Measurement	Measurement range	Ref.
BME280	Temperature, Air humidity, Atmospheric pressure, Altitude	Temperature:-40°C to +85°C, Air humidity: 0% to 100%, Atmospheric pressure: 300 to 1100 mBar	[13]
BH1750	Light intensity	0 lx to 65535 lx	[14]
MQ-7	Carbon monoxide	20 ppm to 2000 ppm	[15]

Communication between microcontroller PIC18F45K22 and sensors BME280 and BH1750 is realized via the I2C bus. Also, there is a Global Positioning System (GPS) module NEO6MV2 [16], which are used to obtain information on the location where the observation and measurement of microclimatic parameters was performed. The information of interest for this smart mobile system is geographic longitude and latitude in the format (xx.xxxx (N), yy.yyyy (E)). This module communicates with microcontroller using UART serial communication. The Real Time Clock (RTC) module DS1307 [17], was used to set the current time and determine the measurement step. Finally, the GSM/GPRS module SIM800l serves to send measured data and location information to the Cloud (ThingSpeak [18]) realized on the MATLab webserver. This module communicates with the microcontroller via the (RX/TX) UART serial communication such as GPS module NEO6MV2, using AT commands. To interact with the user while working with the smart mobile data logger system, a 4×20 character LCD is used [19]. The LCD display serves to monitor the current measurement results and the time for the next measurement.

At the start, it is necessary for the user to set the IP address in the form of an SMS message, so that later the GSM/GPRS module has information on where to send the measured data. When the IP address is set, UART serial communication, I2C bus and A/D converter setup begins. Finally, the sensors and module are initialized, after which the measurement and sending of data to the Cloud begins.

3.2. Software design of smart system

Each thread during the work of the smart data logger system is defined as the algorithmic mode of displaying the software as shown in Fig. 7. This algorithm is based on our previous systems [6, 9]. But, the previous systems used Security Digital (SD) memory card. It was used as a backup medium for data storage in case there is no Internet access, in order not to create a "hole" in the measurement interval, ie in order not to lose information about the measured parameters. Another difference is that the GPS module is present in this algorithm, as well as part of the algorithm for its configuration.

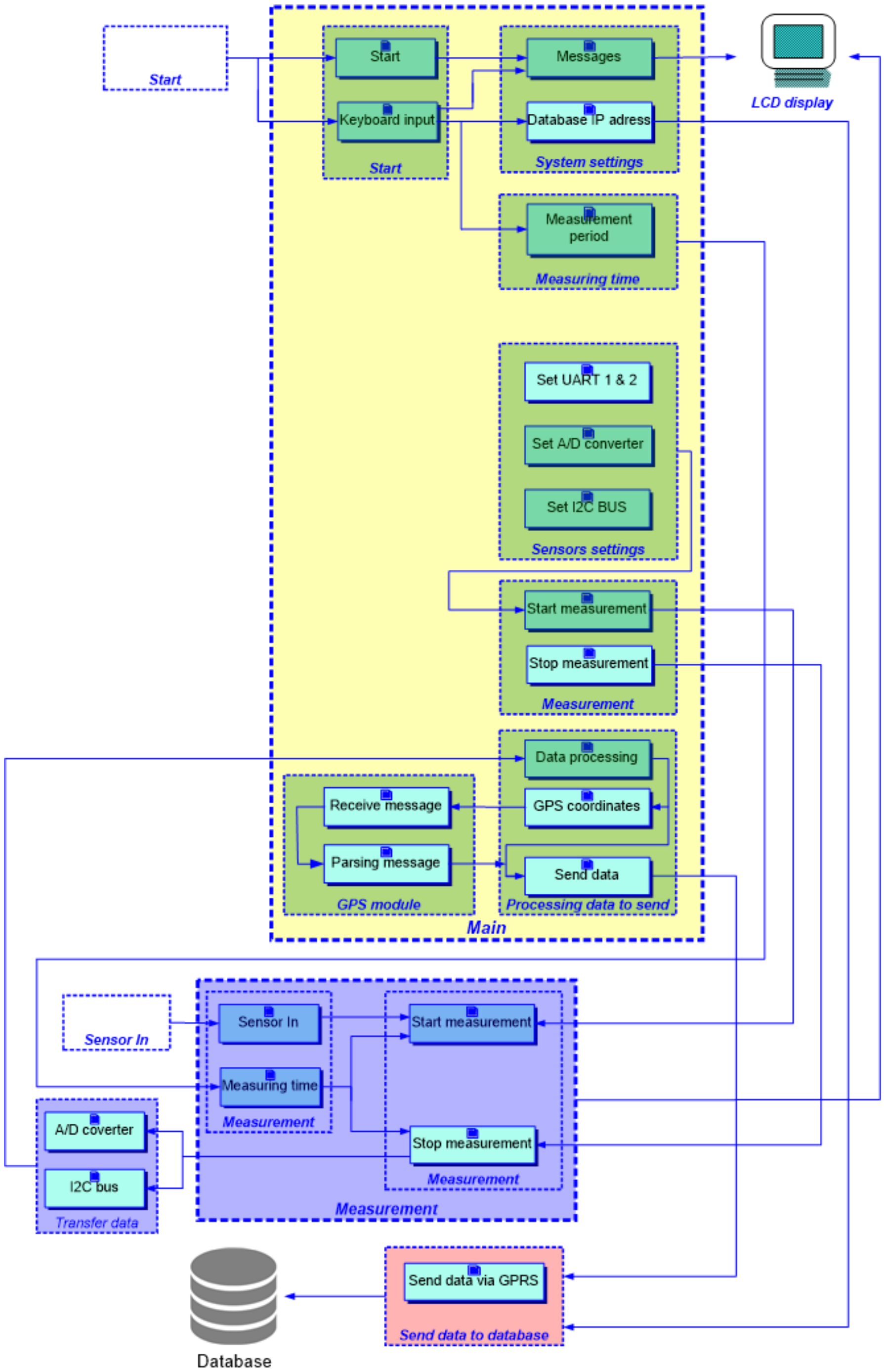

Fig. 7 Basic algorithm of the embedded software of smart mobile monitoring system

4. EXPERIMENTAL RESULTS

The microclimatic parameters were measured with a prototype of a smart mobile data logger system in the City of Niš, in order to confirm its validity. All the measured results are shown in Fig. 8. However, by driving a vehicle it is provided a large amount of data for a certain area, so it is not that obvious to analyze data. For these reasons, we can divide the city into cells (larger or smaller, depending on the need) and assign only the most recent data we have measured in each cell.

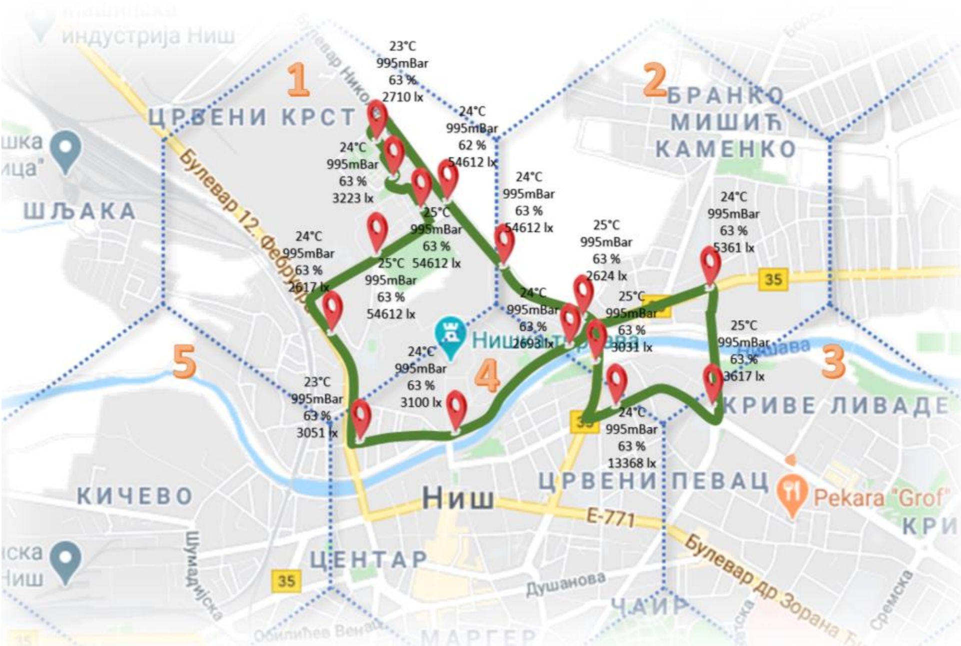

Fig. 8 Generated map based on the obtained results measured by the realized system

On the example of temperature measurement, we can see that the vehicle is transferred from cell to cell (marked with numbers 1 to 5), as illustrated in Fig. 9. It may happen that in the same cell in one pass we have a larger number of measurements, but for better visibility, only the results of the last measurement are shown, as illustrated in Fig. 10.

The points T_1, T_2, T_3, and T_4 (the last measured points in each of the specific cells), in Fig. 10, coincide with the measured points shown in Fig. 9. The vertical lines on the chart shown in Fig. 9 show the moments when the vehicle left a certain cell, i.e. entered the next one. Therefore, all points measured in one cell can be seen. When multiple systems are installed on different vehicles, the last measured data from all vehicles in that cell will be recorded in the cell. The route taken by the vehicle will not be shown, it is shown here only for the purpose of a detailed description of the operation of the system.

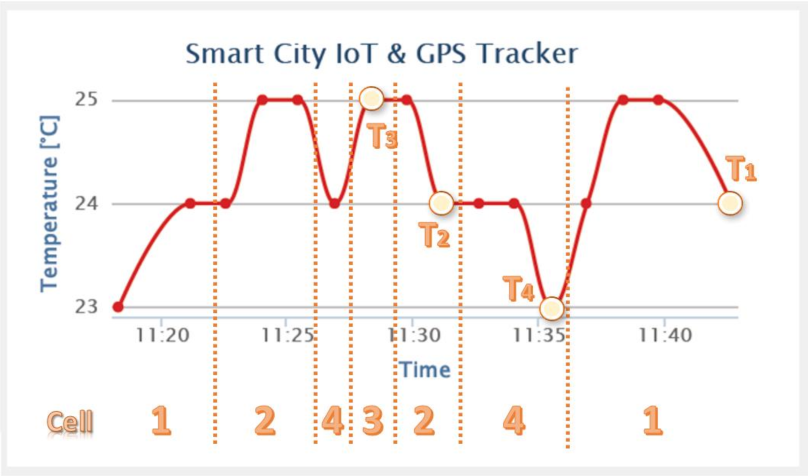

Fig. 9 Measured temperature data with marked points that were last measured in specific cells

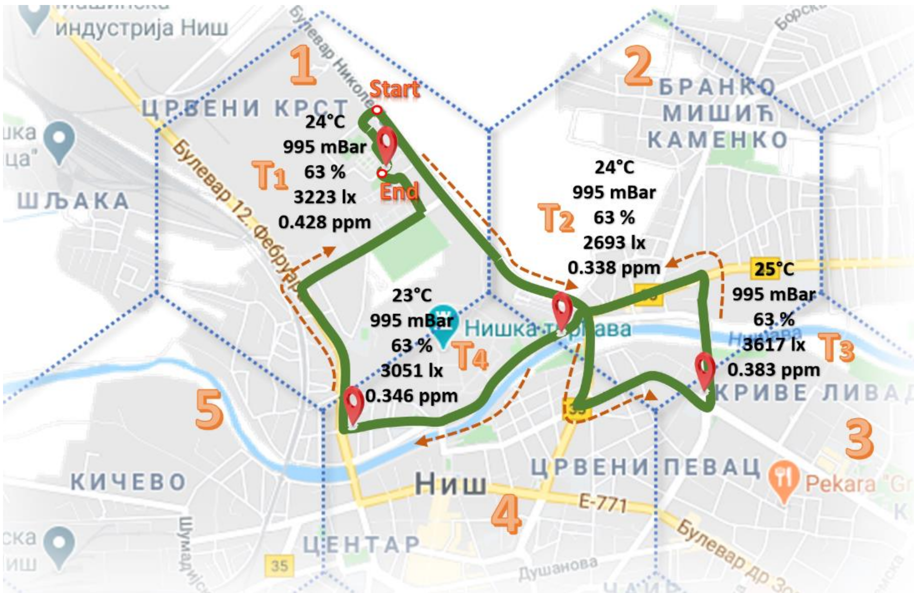

Fig. 10 Generated map based on the latest results measured by the realized system in specific cells (vehicle direction is also shown)

The functionality of this system is shown on the example of temperature measurement. However, other parameters were also measured as shown in Fig. 11. Microclimatic parameters were measured on June, 26th (Friday), 2020 in Niš. Measurements were performed during the working day when the frequency of vehicles is significantly pronounced.

Fig. 11 Measured parameters using the realized system (Temperature and CO concentration (Field 1 and Field 2) – first two charts, Air pressure and Air humidity (Field 3 and Field 4) – second two charts, Light intensity and GPS coordinates (Field 5 and Field 6) – third two charts)

The results we recorded during the testing can be used by experts from various fields such as tourism and catering, traffic, meteorological stations, as well as experts dealing with air and environmental pollution. Based on the provided results, people from the above areas can have an insight into more detailed information that is extremely important to them for their activities, as well as for taking certain actions in accordance with the obtained results. As our system also provides information on the location (GPS coordinates) where the measurements were performed (coordinates are shown in Field 6 for each measurement separately), it is possible to monitor the microclimatic parameters in each area in much more detail, even where there are no measuring points that monitor the level of air pollution globally (Fig. 12).

Fig. 12 Real time Air Quality measurement places [2]

Based on the site with monitoring of the air pollution index [2] in Nis, it can be seen that a small part of the city has the possibility of monitoring. There is a problem with updating the data on this site, as the data is updated in a few hours (usually 2 to 3 hours). Most of the city with significant traffic is not covered by systems for monitoring microclimatic parameters. Our smart mobile system for real-time monitoring enables the coverage of a large percentage of the city area, and along the way, it is possible for the system to be used within the city transport, taxi vehicles, which reduces the cost of installing a large number of systems since one system is enough to cover the entire city.

As stated in the manuscript, the realized system, considering that it is modular, offers the possibility of using other sensors, ie monitoring and other microclimatic parameters, depending on the needs of the user.

5. Discussion and Future work

The systems we have implemented so far find application within large smart systems such as smart colleges, where they represent one segment within the whole complex system. In addition, the system has found application in agriculture, and also a smart meteorological station is used not only within meteorological stations, but also in mines (since it has sensors that monitor microclimatic parameters that are vital not only for the mine, but also for the miners in it).

This manuscript describes the smart mobile system for monitoring microclimatic parameters, which can replace a large number of static systems. The static systems that we realized were divided according to the spheres in which they found the primary application (represented by the block diagram in Fig. 1). Each system presented within the block diagram is realized completely, in other words, from idea to realization. First, the functionality of each system was confirmed separately within the laboratory, and after that in real working conditions (by realizing a prototype on the protoboard). When the testing of the prototype proved its functionality, a printed circuit board was designed using the Altium Designer software tool. After that, when the systems are completely physically realized, they are tested in real conditions within the prescribed 7 days needed to confirm the functionality of the systems themselves. The systems we have implemented are suitable for Outdoor and Indoor application, with the proviso that the systems suitable for Outdoor application are implemented for different needs and spheres.

The idea is to test the implemented systems in the future in laboratory and real conditions, but so that these systems do not require additional maintenance and servicing. This would significantly reduce the financial resources required to implement such systems. To make this as easy as possible, it is not enough to test the reliability of one component within the system, but we want to test the reliability of our entire system as a whole. In manuscript [20], the authors state that there are a small number of manuscripts that deal with this problem. Specifically, they state that "System-level condition monitoring has not been explored sufficiently compared with component-level counterpart".

6. Conclusion

The manuscript describes the implemented smart mobile system for real-time monitoring and measuring microclimatic parameters. The system was successfully tested in real conditions in the city of Nis and the results obtained by applying the system are presented in the paper. The realized system is suitable because it can replace a large number of static systems. In addition, the proposed system has the ability to collect information about the location where measurements were made based on GPS coordinates. Finally, the realized system is modular, therefore it is possible to expand it if it is necessary.

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