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Creation of a Prototype of a Multi-function Remote Presence Robot for Physical Research in Electronics

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The article presents methods for constructing and implementing an automated electronic system for collecting and analyzing information about various physical parameters of the environment under conditions of long-term continuous measurements. The system is based on microprocessor devices using wireless technologies with the implementation of the EKF SLAM algorithm for localizing places with an uneven distribution of environmental parameters to minimize pollution of cleanrooms. Also, it can then transmit signals through the operator's computer to the control elements of the room. Thus, the minimization of environmental factors for physical diseases and high-precision equipment is carried out, thereby extending its service life.

Keywords: Automated system, SLAM, Kalman filter, Infrared sensor, Robot, Cleanroom, Microclimate.

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1. INTRODUCTION

A physical experiment in modern electronics is based on the use of a personal computer connected with separate mechanical, optical, power, and other parts of the experimental setup. However, the constant development of computer technology and the complication of a physical experiment require regular modernization of automated systems, taking into account modern circuitry and a change in the very concept of interaction of all parts of a physical experimental setup with a computer.

In various branches of experimental science, especially for researching micro- and nanostructures for micro and nanoelectronics, the availability of so-called cleanrooms is a key factor in the successful conduct of observations. This is the name for those zones in which the size and number of particles per cubic meter such as dust, microorganisms, aerosol particles, and chemical vapors are maintained in the air in a certain predetermined range [1]. Also, frequent requirements for sample research are the need to control parameters such as humidity, pressure, and temperature. A cleanroom can be considered a room in which the countable concentration of airborne (aerosol) particles and the number of microorganisms with sizes from 0.005 to 100 microns in the air are maintained within certain limits. Such rooms are assessed by the countable concentration of particles, that is, the number of particles per unit volume of air, the sizes of which are equal to or exceed a certain value (0.1; 0.3; 0.5 microns, etc.).

An important applied direction of today's engineering channel is the development of environmental monitoring systems for various technogenic spaces using new technologies in the fields of electronics, namely robotics, data transmission networks, and intelligent analysis. Considering, that one of the main sources of indoor pollution is the human factor (microparticles of hair and skin, fibers of tissues, and animal hair that can be on clothes, cosmetics, and sneezing), the issue of remote access to places requiring increased cleanliness control is relevant.

Complete this task, systems with implemented machine learning methods are used, which allow exploring the territory without the direct participation of the operator in this process [2]. Thus, constant monitoring is carried out for contamination of various parts of the cleanroom, and if problem areas are identified, the signal is transmitted to the operator's screen for additional measures to clean the room. Cyber-physical (electronic) systems consist of sensors, computational elements, and actuators, in which computing machines monitor and control physical processes using feedback, and what happens in physical systems affects computations. They provide close communication and coordination between computing and physical resources. This is achieved thanks to the rapid development of technologies in recent decades, such as fog and cloud computing, the Internet of Things, machine-to-machine communication, and recognition. And so, one of the important directions of optimization with the help of various sensors is their used to control the parameters of the microclimate and the unevenness of their distribution during physical experiments in laboratories.

2. DESCRIPTION OF THE OBJECT AND RESEARCH METHODS

Sensitive and intelligent sensing in robotic equipment is essential because the effective performance of ML/AI systems is highly dependent on the performance of the sensors that provide critical data to them. Both for economic reasons and for reasons of simplifying the infrastructure of the room by reducing the number of sensors, it is advisable to use one sensor on a moving system to measure each of the key parameters.

The main functional elements of the electronic system for monitoring the physical parameters of the environment at the experimental site is a microcontroller module that provides data collection. The advantages of this system over its counterparts are the development based on the MSP432P401R microcontroller, which supports low-power programs, a large selection of sensors that can be used to execute projects with MSP432 products, open access to all Texas Instruments documentation, a wide range of free programs for a product research company, the accuracy and reliability of microcontrollers when used by the consumer, low cost and the possibility of additional integration of various sensors for scanning space. All this makes it possible to implement the EKF SLAM method of building a room map with identification in space.

For monitoring rooms for physical experiments with increased environmental requirements, it is important to self-orientate the robot in the room. This is achieved by using 2Y0A21 infrared rangefinders to determine the distance to obstacles [3], as well as tachometers to determine the distance travelled. Since the directional pattern of IR sensors is 3o, it is advisable to use a system of three sensors that scan space in three directions (Fig. 1).

The system is also equipped with a group of bump switches to restart the movement, if it does collide with an obstacle. These elements allow the robot to make independent movements inside an enclosed space while studying the parameters of the environment.

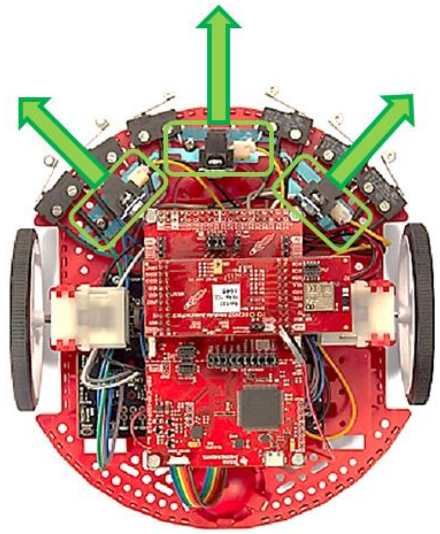


Fig. 1 – Location of infrared sensors on the robot

The main principle of ensuring cleanliness is to create excess pressure in a cleanroom concerning the adjacent rooms. The amount of supply air must exceed the exhaust by at least 20-30 %, which ensures the movement of air from rooms with high cleanliness requirements to adjacent rooms with lower requirements. Therefore, it is very important to monitor the pressure in these rooms, which ensures the use of the BMP388 sensor. It is a compact sensor designed by Bosch Sensortec specifically for robotic applications with lower energy consumption and improved accuracy. So, it provides an accuracy of measurement of absolute pressure up to 0.5 hPa and relative 0.08 hPa, supports connection via SPI and I2C buses. The absolute pressure measurement range is 300 ... 1250 hPa.

In physics experiments, ambient temperature is often the key to success. Monitoring this parameter can help eliminate both unwanted effects in materials and achieve the desired stability of the parameter throughout the study and its uniformity throughout the room. A robotic system equipped with a TMP117 sensor from Texas Instruments will be able to provide high measurement accuracy (from ± 0.3 to ± 0.1 °C) in a wide temperature range – from – 55 to +150 °C.

Using the PMS5003 optical sensor for measuring the number of fine dust particles suspended in the air, which is an indicator of the total air pollution, it is possible to determine the overall level of pollution in a room. It reacts to particles ranging in size from 0.3 to 10 micrometers, belonging to three conditional classes - PM1.0 (0.3-1 microns), PM2.5 (1-2.5 microns) and PM10 (2.5-10 microns). The key factor is that cleanrooms are characterized precisely by the countable concentration of particles, that is, the number of particles per unit volume of air, the dimensions of which are equal to or exceed a certain value (0.1; 0.3; 0.5 microns, etc.). This is how they differ from ordinary premises, in which air purity is assessed by the mass concentration of pollution in the air. Thus, using the PMS5003 counting algorithm, it is possible to estimate the degree of air pollution in the room.

The moisture indicator is also important since excessive moisture concentration can destructively affect both the test samples and the testing system itself. Therefore, it is advisable to use the AM2301 sensor, the accuracy of which is 2 % RH.

It was decided to simulate the terrain mapping algorithm and test a robot that will study the cleanroom microclimate according to the presented work algorithm, collecting data on the state of the environment and sending it to the operator's computer using the BLE CC2650 module.

The readings of the sensors and sensors enter the centralized control electronic system of the experiment process, and at this level, decisions are made to improve the indoor microclimate. Also, the robotic system can be used to deliver the test sample to the installation to prevent the ingress of biological microparticles into the cleanroom. It is known that each separate study requires its environmental parameters, some of which can have a detrimental effect on a robotic system up to its complete failure. The use in such conditions implies the replacement of not only the sensors but also most of the rest of the equipment of the system, however, this does not require significant changes in the operation algorithm itself.

A block diagram of our electronic system that correspond to the functionality described above can be seen in Fig. 2. In addition, the system will be able to easily integrate additional sensors to study other characteristics of the state of space.

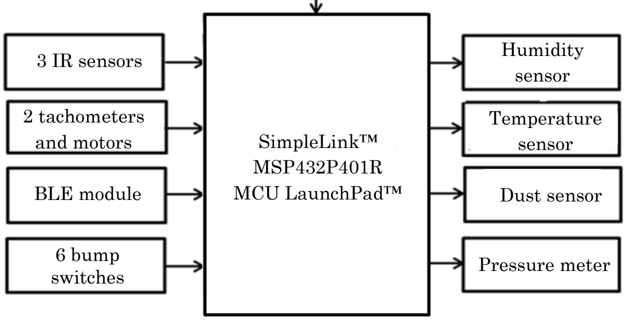


Fig. 2 – Block diagram of the device

When controlling the movement of an autonomous mobile robot or a group of robots [4] to explore the space, the premises must be used to accurately assess the position of the robot in space [5]. To solve the problem of planning the trajectory when making a detour of the room, it is necessary first to determine the location of the robot and establish the situation to solve the so-called problem of simultaneous localization and cartography. It implies that the apparatus is placed in an environment that contains no a priori information. Using only onboard sensors, the robot must pass in this environment from the initial position to the given one, while building a map of the area. In this task, it is required to exclude unplanned changes that affect the course of the experiment, performing an accurate assessment of the environmental parameters in the room [6].

The principle of the algorithm is to perform two cycles. At the first stage, the state is predicted at the next moment in time (considering the inaccuracy of their measurement), that is, the extrapolation method is mathematically implemented to predict the values of the system. The inputs captured by the sensors are used to predict the state of the system one step ahead. Then this theoretical data must be corrected with new values, which are constantly changing at the input of the system. The memory stores two different quantities that are stored in the state of one dynamic process: the extrapolated value of the dynamic system and the measured value. It is necessary to determine to what extent they are valid. Based on the data values, the deviation of the actual state of the system from the extrapolated one is determined [7]. It is also necessary to determine the optimal value of the payoff, the degree of confidence in the calculated and empirical values [8]. The system value and the state event covariance matrix are adjusted based on this data. Next, the corrected covariance matrix of the state of the dynamic system is calculated. This is a constantly repeating cycle of data updating, recording those values that have not yet been registered by the robot (Fig. 3).

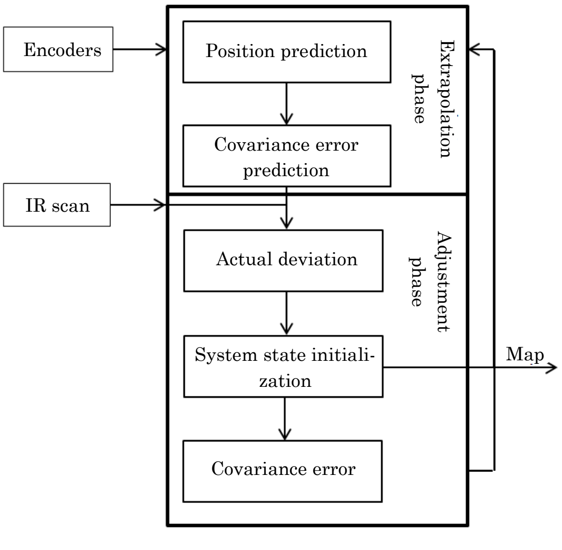


Fig. 3 – The scheme of the SLAM

3. RESULTS AND DISCUSSION

A test was carried out for the effectiveness of the system in residential areas. When the robot was launched on-site, observations were obtained that demonstrate that the system is performing it assigned task of avoiding obstacles and transmitting it position data in real-time to the operator's screen.

Simulation and display (Fig. 4) of EKF SLAM were performed using Matlab software. The graphs of the analysis of accumulated errors based on the results of the study are below. It examines how errors influent on the overall uncertainty of the mapping results and the simultaneous localization of the object. The execution of the task of minimizing errors can be seen from the data obtained. Unknown areas, that is the space behind the walls and tables are marked in gray, and the borders fixed by the robot are white.

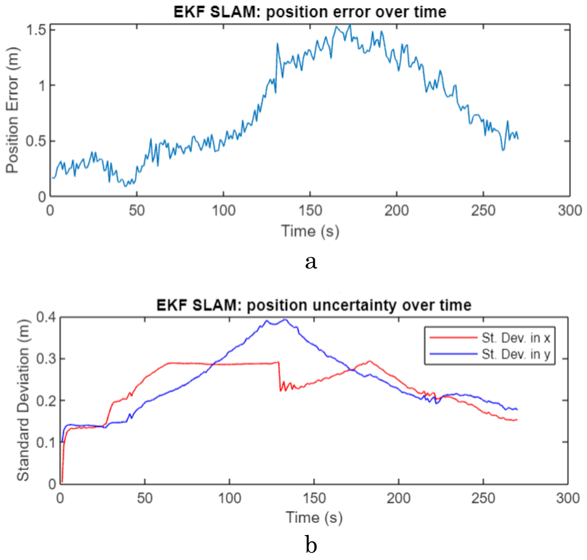
The graph of the forecast of the position of the robot in time is obtained (Fig. 5a). The graph shows the error in determining the position of the robotic electronic system over time. The algorithm used an average error of no more than 1.5 m, and a large error appears when turning.

A graph of errors in determining the position of the robot during the simulation was obtained (Fig. 5b). A significant error is noticeable at the corners: the steeper the turn, the greater the error. It shows how many meters each second the robot accumulates error because the position of the robot directly affects the location of obstacles. The figure shows that over time errors of up to 0.4 m appear. The robot rotates 100-150 s to scan the area around the table with laboratory equipment, and then the system accumulates the error. This is because it takes some time to define oneself in space when turning on new landmarks. It is worth noting that position prediction errors decrease over time, which suggests that the robot remembers and compares the data. A high speed of positioning is not required due to the presence of the above elements of the protection of the robot. For the most part, the SLAM EKF is needed here to plan trajectory changes for faster cleanroom scans.

This electronic system simultaneously scans the environmental data and, in the event of a discrepancy in the microclimate parameters, transmits data to activate air conditioning systems, and so on.

The received data is transmitted to the consumer in portions, which allows ensuring the safety of information during its local storage, which allows it to be saved in the event of a failure of the system itself.

Fig. 4 – The resulting map



a

b

Fig. 5 – Graphs of position error over time (a) and position uncertainty over time (b)

4. CONCLUSIONS

This article implements a model of the electronic robotic system based on the TI-RSLK platform which can move in an unknown space, analyze, and transmit data about the state of the environment through the BLE module to the operator's device without direct operator participation. With the help of IoT, it transmits data to devices that control the climate, which makes it possible to provide the necessary conditions for the experiment.

Since based on this robotic system, an autonomous movement algorithm is implemented without the participation of an operator, this significantly reduces the cost of the total cost of equipment in cleanrooms, since the sensors move around the cleanroom (any room) and can determine the uneven distribution of microclimate parameters, especially in case of physical experiment with small size samples. The invariability of the experimental conditions determines the stability of the parameters of the studied (created) sample, which is one of the most important requirements in micro- and nanoelectronics.

Methods for analyzing the environment using inexpensive infrared rangefinders are considered. The principle of operation and possible application of EKF SLAM to optimize the distance traveled and identify the zone of unfavorable microclimate are presented.

This electronic system can improve laboratory equipment. The advantage of this system lies in the flexibility of the platform, into which it is easy to integrate equipment that could record other parameters required specifically for certain physical experiments. Thus, the developed robotic system is a versatile and low-cost system capable of analyzing any environment and delivering samples that require a remote presence to prevent a decrease in the required level of cleanliness of the room.

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Створення прототипу багатофункціонального віддаленого робота присутності для фізичних досліджень у електроніці

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У статті представлені методи побудови та впровадження автоматизованої електронної системи збору та аналізу інформації про різні фізичні параметри навколишнього середовища в умовах тривалих безперервних вимірювань. Система розроблена на базі мікропроцесорних пристроїв з використанням бездротових технологій з реалізацією алгоритму EKF SLAM для локалізації місць з нерівномірним розподілом параметрів навколишнього середовища для мінімізації забруднення чистих приміщень. Крім того, вона може передавати сигнали через комп'ютер оператора до елементів управління приміщенням. Таким чином, здійснюється мінімізація факторів зовнішнього середовища для фізичних зразків та високоточного обладнання, тим самим продовжуючи термін її служби.

Ключові слова: Автоматизована система, SLAM, Фільтр Калмана, Інфрачервоний датчик, Робот, Чисте приміщення, Мікроклімат.