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Creating of a remote-presence robot based on the development board Texas Instruments to monitor the status of infected patients

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ABSTRACT

Statistics show that many infections of employees in medical institutions are associated with direct contact with patients. Furthermore, the deterioration of the patient's condition in the intervals between doctor's rounds was observed. Therefore, control and reduction of morbidity through introducing new monitoring methods without the direct involvement of human resources remains an urgent issue. This paper considers an alternative method for monitoring the state of infectious patients undergoing treatment. In this article, we have described the use of standard elements for scanning the medical state of people for the timely detection of pathologies with the implementation of instant notification of the attending physician. Based on the functionality of the Texas Instruments Robotics System Kit (TI-RLSK) developer board and additional sensors, an autonomous robot scanner was created. The considered embodiment of the model systemizes the provided recording recognition of a specific patient with the parameters of the health state in a database. In addition, the navigating system with an updated real-time map of the area enables the robot to deliver medicine to patients.

1. Introduction

Since the beginning of the COVID-19 pandemic, the number of infected people in the world in June 2021 amounted to about 173 million, and deaths reached nearly 3 million. Therefore, slowing the spread of infection is one of the priority areas of biomedical research today. The main centers under the critical influence of the spread of the disease are the infectious diseases departments of hospitals and hospitals. According to The World Health Organization, at least 115 thousand medical workers have died from the coronavirus since the beginning of the COVID-19 epidemic in the whole world. Nowadays, the issue of reducing the spread of infection by any means is critical. The use of robotic systems to reduce contact between doctors and patients and between patients themselves is now being implemented. The solution to automate interviewing and monitoring inpatients' conditions can ease the work of overloaded hospital departments and reduce the number of infections among medical workers discussed in this article (Wang et al., 2021).

It is typical for the patient's condition to be stable during the bypass but to worsen deadly literally within a few hours. In conditions of overcrowding of hospital wards, it is challenging to conduct a high-quality and timely patient examination. In this regard, it constantly records the state of patients in the ward, especially seriously ill people, and it is required to develop methods for automated questioning of the state of stable patients. The use of robotic systems cannot completely replace the examination by a doctor; however, it can allow to a greater extent, replace the monitoring of parameters that are carried out during a nursing examination while collecting information about those patients who need emergency care. Thus, this will significantly reduce the time medical personnel spends on fixing the parameters of the organism of stable patients. Utilizing robotic systems would allow medical personnel to concentrate on especially severe cases currently, reducing the time of contact with the infected, thereby reducing the risk of infection for doctors (Забегаев and Павловский, 2010).

Based on the proposed solutions described above, we have developed a robot assistant as an experimental study platform capable of recording standard body parameters to improve the equipment abilities of hospitals. To summarize, it was decided to develop an experimental study platform for an assistant robot to improve the abilities and equipment of hospital wards, capable of recording a standard number of body parameters and possibly introducing other functions if necessary.

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2. Material and methods

We choose the Texas Instruments Robotics System Kit (TI-RSLK) development board to solve this problem because of its low cost and flexible system with the ability to expand functionality properties. The advantages of this system over its counterparts are: 1) the development based on the microcontroller (model MSP432P401R), which supports low-power programs; 2) the large selection of sensors that were used to execute projects with mixed-signal microcontroller (MSP432 product); 3) open access to all Texas Instruments documentation, with the wide range of free programs for a product research company; 4) accuracy and reliability of microcontrollers when used by the consumer; and 5) low cost and the possibility of additional integration of various sensors to scan the surroundings. All of this makes it possible to jointly estimate a scalable joint state vector formed by the pose state vector in the mobile robot and the positioned vector of the observed environment (EKF SLAM method) to build a room map with identification in the environment (Choi and Lee, 2010).

As a first step, we have decided to simulate the terrain mapping algorithm and test a robot that will travel around the wards according to the presented algorithm of work while collecting data on the condition of patients and sending them to the computer of the attending physician using the Bluetooth Low Energy (BLE) module board (CC2650).

COVID-19 is a systemic multiorgan injury disease, with the lungs as the primary target organ. Its pathophysiological mechanisms involve inflammation, fever, hypoxia, water, electrolytes, acid-base balance disorder, shock, and other basic pathological processes. According to existing studies and literature reports, patients with COVID-19 have been found to often suffer from the following dysfunctions: dyspnea, fever, fatigue, poor appetite, tachycardia, and decreased oxygen-carrying capacity. Oxygen consumption is the most crucial indicator of the body's aerobic capacity and physical potential. Factors affecting oxygen uptake include the blood's ability to carry oxygen, cardiac function, redistribution of peripheral blood flows, tissue uptake, etc. The relationship between heart rate and oxygen consumption is usually non-linear when moving at low power but becomes almost linear when power gradually increases to maximum (Xia and Huang, 2021). That is why the primary parameters that are nursing staff control when bypassing patients are saturation, body temperature, pressure, pulse, diuresis, and respiratory rate. Measurements of the first four parameters can be performed using sensors of specific functionality based on a robotic system.

The robot uses three infrared range sensors (model 2Y0A21) which are located on the front of the robot, to navigate the terrain and scans the surroundings in three directions – in front and on the sides (Fig. 1). To stabilize the power line, the bypassing capacitors with a nominal value of 10 μF each at pins Vcc and GND were installed. Note that these sensors capture the basic information necessary for the robot's movement. Therefore, the accuracy of their position is essential and needs to be calibrated before each usage of robotic systems.

The following equation allows you to determine the distance from the sensor in the robot to the obstacle:

$$D_r = \frac{A_r}{n_r + B_r} + C_r,$$

$$D_c = \frac{A_c}{n_c + B_c} + C_c,$$

$$D_l = \frac{A_l}{n_l + B_l} + C_l,$$

where n_r, n_c та n_l are 14-bit samples with ADC (from 0 to 16383) at three ADC inputs, A_r, A_c, A_l, B_r, B_c, B_l, C_r, C_c and C_l are calibration factors.

Two tachometers, Romi encoders, represent the sensors. It is an angular displacement transducer with the possibility to measure the various parameters of rotation of any part with the required accuracy, like the shaft of an electric motor or gearbox with its help.

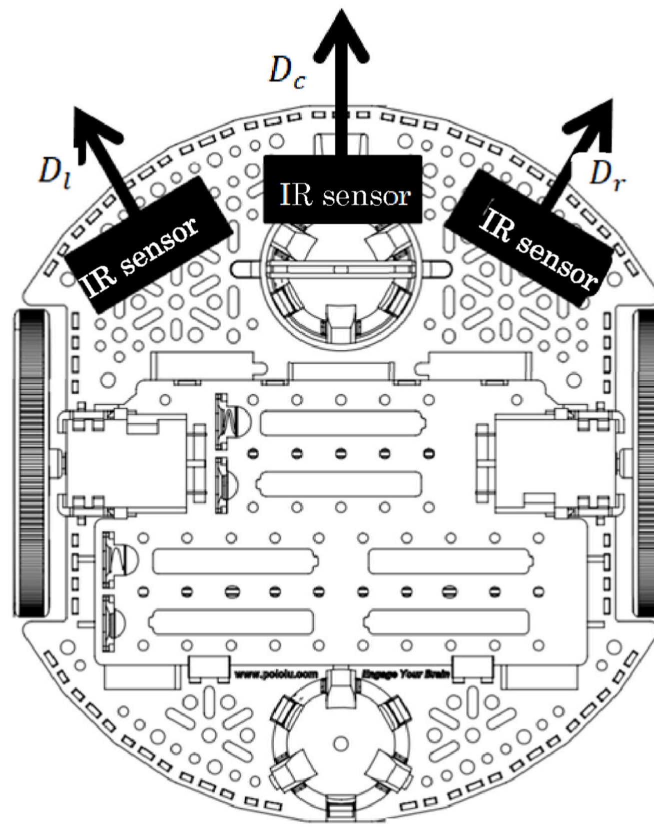

Fig. 1. Location of infrared sensors on the robot (bottom view of the robot).

A line-following sensor, tachometers, bump switches, and distance sensors were used to implement the project. These components (quick action switches or limit switches) give the operation a "touch" feeling.

In robotics, such switches can be placed outside the robot, allowing it to respond to the environment. When a switch is pressed because the robot is in contact with something (or "runs over" it), it closes an electrical circuit and sends a signal to the control board (Павловский and Павловский, 2016).

Distance traveled, rotations and turns, and distance to obstacles are transmitted to the operator using the Bluetooth Booster Pack for the CC2650 bluetooth board module. At the same time, it uses the fingerprint sensor (model FPC1020) for patient identification, which makes it possible to identify the cell in the database intended for his data. On their basis, the EKF SLAM algorithm is further implemented to build a hospital map and determine its system (Xie et al., 2017). Previously, solving this problem was laborious and expensive because of using unique methods such as precision engineering, high-precision sensors, and calibration points (Bhatt et al., 2021). An alternative is to use multiple sensors with overlapping fields of view and combine spatial information from the sensors to obtain more accurate results.

The interaction between the patient and the assistant robot begins with identification. Then it is carried out using the FPC1020 fingerprint sensor, which allows you to identify the cell in the database intended for the data of a particular patient. The non-contact temperature sensor module (model MLX90614) performs the patient's body temperature measurement. It is the operation principle that all bodies at temperatures above 0° K emit infrared energy, which the sensor of an infrared thermometer can detect. Its designs include a lens that focuses on infrared energy emitted by an object before a detector. The detector converts energy into an electrical signal, which can then be transmitted to a microcontroller for interpretation and display in temperature units after compensating for changes in ambient temperature (Fig. 2).

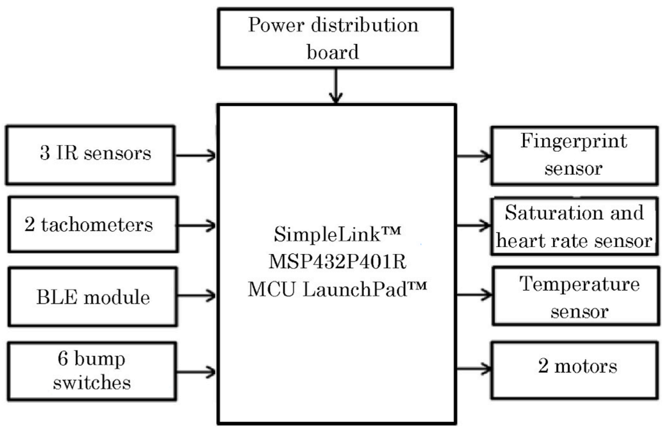

Fig. 2. Block diagram of the device for automatic interrogation of patients.

The saturation and heart rate measuring are performed by the heartbeat sensor (model KY039), which contains one infrared (950 nm) LED and one red LED (600 nm) embedded in the circuit. Since the blood light absorbs differently depending on the wavelength of the LED, blood containing more oxygen will absorb red light better. The measurement can be used to find the percentage of oxygenated hemoglobin compared to the total hemoglobin in the blood (Isupov and Zatrudina, 2018). This modified sensor can accomplish two tasks simultaneously by using two parallel leads with 330 Ohms LED protection resistors connected directly to the controller. The patient puts his finger on the sensor, placing it between the photodiode and the LEDs. The light emitted by the infrared LED is partially absorbed by the nail, skin, and the rest of the finger, but the absorption does not remain unchanged as it changes with the blood flow through the veins. When the heart contracts, it pushes blood through the veins with a change in light absorption. Finally, the controller receives data on the current generated by the light absorbed by a photodiode.

The EKF SLAM was introduced on the robot for better orienting surroundings (Emharraf et al., 2016) and for building a map of optimal fast movement from ward to ward without disturbing the hospital staff. The work of the device is based on two constantly repeating phases (Fig. 3). In the first stage, the state's forecast is calculated at the next moment in time (note the inaccuracy of their measurement). In other words, the extrapolation method is mathematically implemented to predict the values of the system. The sensors capture some inputs. They are used to predict the state of the system one step ahead. Then the covariance error of the system is determined, and the obtained theoretical data needs to be corrected with new values constantly arriving at the system's input. It stores two different quantities in memory that represent the state of one dynamic process: the extrapolated value of the dynamic system and the measured value. It is necessary to determine to what degree each is valid and what happens in the second stage. First, the deviation of the actual state of the system from the extrapolated value is determined based on the available data. Then a covariance matrix is generated for the error vector. It is also necessary to determine the optimal value of the gains, which reflects the degree of confidence in the calculated and empirical values. The value of the system state and the covariance matrix of the state vector estimate are corrected based on these data. Next, the corrected covariance matrix of the state vector of the dynamic system is calculated, and after that, the system again goes to the first phase. This is a constantly repeated cycle of updating data with new ones, recording those values that the robot has not yet registered.

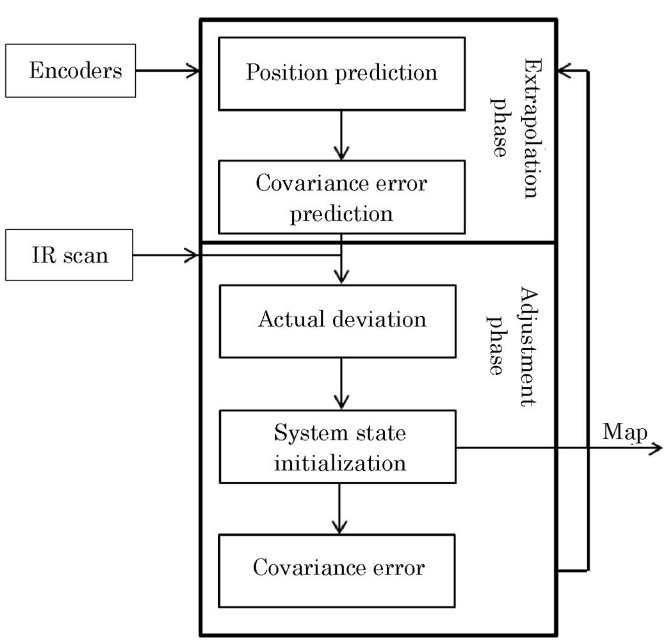

Fig. 3. The scheme of the algorithm for constructing maps.

3. Results and discussion

In particular, the test was carried out for the system's efficiency in a residential environment. When the robot was launched at the location, observations were obtained, demonstrating that the system is performing the assigned task of avoiding obstacles.

The simulation and the mapping shown in Fig. 4 of the EKF SLAM were performed using the Matlab software. Over time accumulated errors analysis graphs according to the performed area research are given below. The study has shown how the errors affect the general uncertainty of the mapping results and the object's simultaneous localization. The error minimization task accomplishment is visible from the received data.

A graph of the robot's position prediction over time (Fig. 5, a) is obtained. This graph shows the process of the first phase of the Kalman filter. The algorithm gives an error of no more than 0.3 m on average, and a significant error appears during the turn, but not earlier than 600-800 s. It is caused by the prediction made after the sensors fix the landmarks. In contrast, prediction after rotation is improved because the system has already studied the landmarks used, which are pre-stored in the matrix.

The graph of errors of the position determining of the robot during the simulation time (Fig. 5, b) is obtained. A significant error can be seen at the corners: the steeper the turn, the bigger the error. It demonstrates how many meters every second the robot accumulates a mistake because the position of the robot directly affects the determination of the location of obstacles. The figure shows that errors of up to 4 m appear over time. The robot rotates for 600-800 s to re-scan space, and then the system makes mistakes. It is because the system re-initializes the space and takes some time. It is worth noting that the error of position determination after turning is significant, and position prediction errors decrease over time. It indicates that the robot remembers and compares the data. The prediction indicates that the error in determining the robot's position in the future will also go to zero. A high rate of position determination is not required due to the elements mentioned above of robot protection. The SLAM EKF is needed here to plan a re-trajectory for faster scanning of the patient for the most part. The methods for analyzing the environment considered using inexpensive infrared rangefinders and a method for stabilizing their power line. The principle of operation and possible application of EKF SLAM to optimize the distance traveled are presented. The main problems of organizing medical care in an epidemic were studied, as well as the primary diagnostic, signs of COVID-19 damage to the body, and ways to control the necessary parameters of the human body using cheap electronic components.

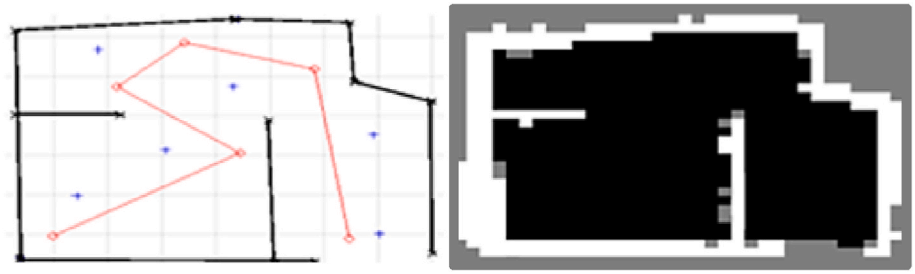

Fig. 4. The studied area drawing and the resulting map.

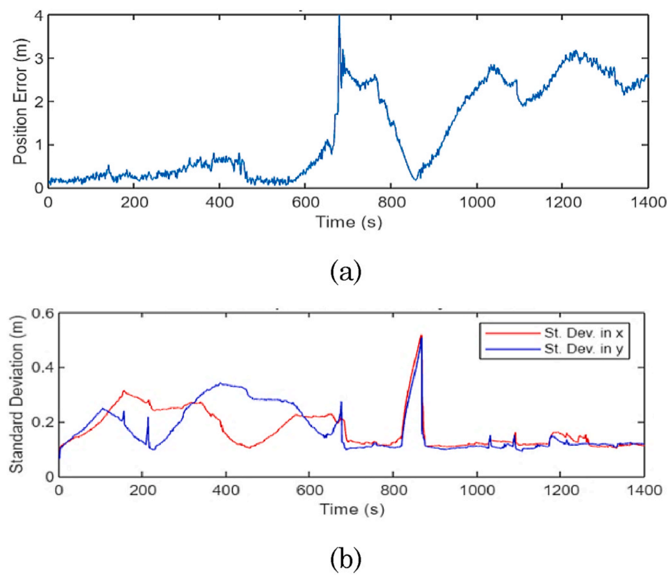

Fig. 5. Graphs of position error over time (a) and position uncertainty over time (b).

4. Conclusions

This article embodies a model of a robotic system based on the developer's TI-RSLK, which can navigate in an unknown environment and analyze and transmit patient status data through the BLE module to the operator's device without direct involvement of the doctor.

Since this robotic system is based on an autonomous movement algorithm, it is implemented without an operator's participation. This significantly reduces the total cost of equipment in hospital wards. Moreover, the sensors can move from room to room, and there is no need to provide them separately to each patient with a stable state of health.

This system will improve the equipment of hospitals in conditions of an increased frequency of infectious diseases by reducing the number of frequent contacts between people, doctors, and patients. It will decrease the likelihood of disease transmission and death itself in the future. Also, this device will help to facilitate reporting and compilation of databases on the patient's condition, thereby providing specialists with more opportunities to provide direct medical help and conduct high-quality diagnostics in further investigations.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Hanna Hlukhova, Ph.D., and Oleg Glukhov, Ph.D. are family members, but they work in different Research centers and live in different countries for more than 5 years.

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