Chapter 16
Possibility of Creating a Low-Cost Robot Assistant for Use in General Medical Institutions During the COVID-19 Pandemic

V. Chekubasheva, O. Glukhov, O. Kravchuk, Y. Levchenko, E. Linnyk, and V. Rohovets

Abstract This article analyzes the experience and prospects of creating a robot assistant for medical institutions using in the modern conditions of Ukraine. The main directions of fundamental and applied research are proposed, taking into account budget equipment. Recently, the creation of a system for monitoring the condition of patients in difficult epidemiological conditions has become of particular relevance in the world. It involves the use of an integrated autonomous control system for robotic patients to work with patients in hospitals. For medical institutions, the task of equipping with modern pieces of equipment is also relevant. Autonomous systems carry out independent processing of medical premises and instruments, especially in infectious diseases departments and also premises with increased requirements for cleanliness. One of the possible solutions to this problem is the use of medical autonomous robotic assistants.

16.1 Introduction

Today, slowing down the spread of the infectious disease caused by the SARS-CoV-2 virus is one of the priorities of biomedical research. The main centers that have a significant impact on this are the infectious diseases departments of hospitals. Junior medical personnel is at the greatest risk due to prolonged direct contact with the infected people, whose task is to take all the main medical parameters of patients and monitor patients' conditions. At the same time, due to the huge influx of infected people, medical facilities require constant disinfection to reduce the risk of infection. Including rooms with increased requirements for cleanliness, such as surgical rooms. The performance of such work by personnel exposes them to a constant high risk of infection and requires a lot of time.

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The solution to these problems can be an autonomous robotic system that replaces part of the functions of junior medical staff and thereby reduces the time of interaction with sick patients. Such systems using frees you from daily everyday activities and allows you to focus on more seriously ill patients.

At the moment, robotic systems are being widely implemented in various fields: medicine [1], agriculture [2], logistics [3], industrial and space sectors [4], military industry [5], etc. The use of cross solutions from different areas makes it possible to improve the existing [6] robotic system and equip it with a set of devices for performing specialized tasks. In addition, the use of already known [7, 8] and available technologies can reduce the cost of a robotic system compared to existing analogs [9–11].

Thus, the purpose of this work is to create a budget autonomous robotic system with a replaceable set of blocks for various functional purposes to perform certain medical tasks. Namely: disinfection of premises, assistance in the delivery of tests and drugs, in the removal of basic medical indications of patients.

16.2 Methods and Materials

Pathophysiological mechanisms of COVID-19 involve inflammation, fever, hypoxia, 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. That is why the primary parameters that nursing staff control when bypassing patients are saturation, body temperature, pressure, pulse, diuresis, and respiratory rate [12]. The first four earlier noted parameters measurements can be carried out based on a robotic system using sensors of certain functionality [13].

Often the patient's condition remains stable during the bypass, but in just a few hours it can deteriorate sharply. In overcrowded hospitals, when patients are placed literally in corridors and other departments that are not equipped for emergency needs, it is extremely difficult to conduct a high-quality and timely examination of each patient. Because doctors have to spend a lot of time on especially seriously ill people. In addition, it is medical workers who are most at risk, not only from infection but also from professional overtime work and nervous strain. In this way, a functional diagram of the robotic platform was developed based on the above provisions (see Fig. 16.1).

This article proposes a development that combines the functions of processing rooms for various needs, as well as daily patient surveys, which improves the capabilities and equipment of hospital wards, can record a standard number of polled parameters with their sorting. Also, this device can be used as local delivery of medicines and food to patients. This system will help reduce the workload on them and compensate for the shortage of personnel.

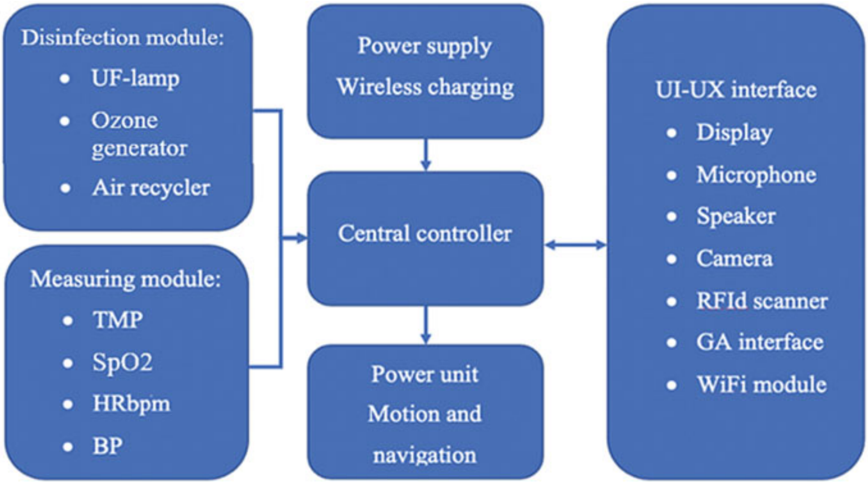

Fig. 16.1 The functional scheme

16.3 Results and Their Analysis

The system is modular and allows you to combine blocks depending on the task. The robot consists of 7 blocks (see Fig. 16.2): a mobile platform for autonomous movement; battery pack; a processing unit for a room without a person present, represented by an ozone generator; sensor unit for monitoring human parameters; a block for placing things necessary for medical personnel, patient test results, and drugs; a tablet for visualizing the attending physician and an interface for managing the system; block for processing premises with the presence of people.

16.3.1 Navigation Algorithm, the Motion Platform

TurtleBot 3 Waffle Pi [14] is used as a mobile platform as the best option to provide the necessary functions: reliability, functionality (support for ROS), optimal dimensions (281mm/306mm/141mm), high transported weight (maximum payload 30 kgs). This has the following parameters: implementation on Raspberry Pi 3, maximum translational velocity is 0.26 m/s and rotational velocity is 104.27 deg/s, presence of lidars, camera module, gyroscope, and accelerometer to implement the vSLAM method [15] to optimize the movement of the robot. The device is equipped with a camera that allows you to effectively analyze the space, remembering the location of objects on the territory and using the ceiling for orientation. This format builds a more accurate floor plan that can be viewed in a mobile application. Difference from the first type: the user can interact with the map. The application provides access to

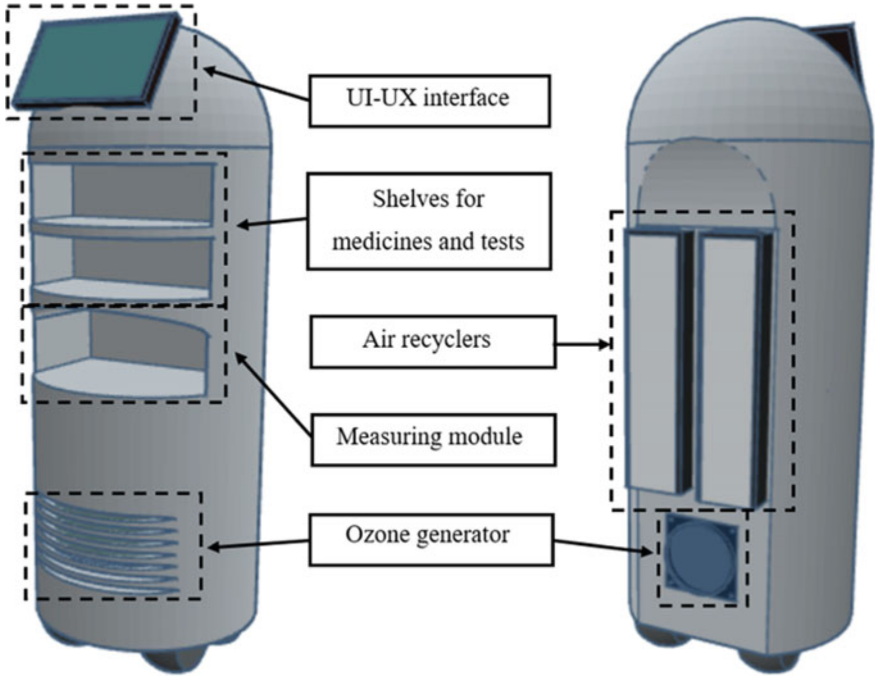

Fig. 16.2 The 3D model image of robotic assistant

building virtual walls and designating specific places for local processing [16]. It is also necessary to use methods [17] for determining the presence of people in the room.

16.3.2 Power Supply Design

The main method of charging the batteries of the assistant robot is an induction charging station, which is provided using two insulated coils. The maximum power transmitted by the charging station is 24 W, while the efficiency is 86%, the time for a full charge is 5–6 hours. The main advantage of this system is the minimal participation of a person in ensuring the process of charging the device. Power is supplied through shielded coils. Before power is applied, the transmitter sends a test signal to determine the receiver, after which a connection is established. The receiver tells the transmitter how much power to send and when (see Fig. 16.3). In addition, UV lamps are placed on the docking station to ensure the treatment of the external surfaces of the system.

To ensure maximum efficiency of charging stations it is necessary to ensure accurate positioning of the mating and receiving parts with an error of no more than 5mm.

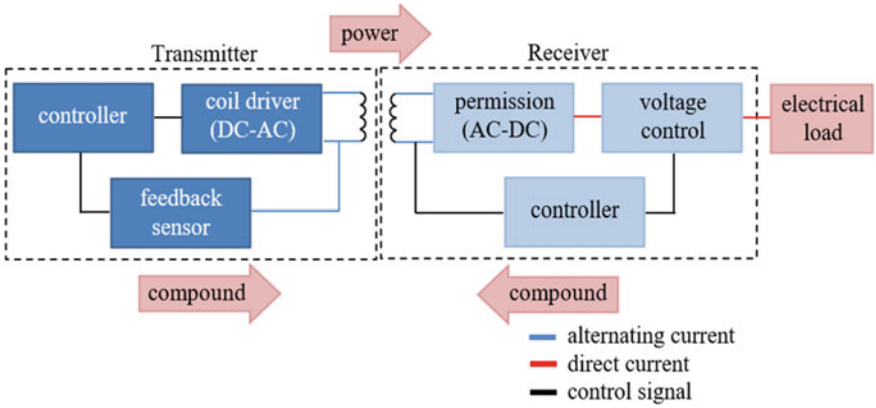

Fig. 16.3 Block diagram of an induction charging station

To accomplish this task, an induction positioning system is used based on two Hall sensors at the charging station and neodymium magnets attached to the robot body.

The system also provides for charging from a 220/110 V network. This allows you to charge the device in less than 2 h. This option is appropriate if there is a need to urgently prepare an assistant for operation. To provide a different input voltage, a dual-circuit power part of the battery charge controller is used.

16.3.3 Disinfection Equipment

The ozone generator uses allows for a higher degree of purification compared to a bactericidal recycler (90% for recirculators [18] and 99% for ozone generator [19]). First, ozone is more effective at inactivating viruses than any other treatment, while leaving no chemical waste. Daily ozone exposures increase mortality and respiratory morbidity rates. In short-term pulmonary function studies, lung inflammation, lung permeability, respiratory symptoms, increased medication usage, morbidity, and mortality [20]. Therefore, it is important to use ozonation strictly indoors without people.

The best solution for the premises treatment is to use ultraviolet bactericidal recirculators. They are safer in comparison with open-type ultraviolet and quartz emitters because they do not irradiate the entire room and people in it, but the air that is passed through the mechanism. Ultraviolet glass in recirculators transmits part of the UV spectrum radiation that is harmful to pathogenic microorganisms, but delays ozone-forming rays [21]. UV radiation destroys the DNA of bacteria and microorganisms.

16.3.4 Health Parameters Measurement Unit

The device is capable of measuring the following parameters: temperature, heart rate, saturation, and pressure. This unit is a retractable platform with a recess under the patient's arm for ease of use of the system.

The human body temperature recording is carried out by a non-contact thermometer MLX90614. It has an error measurement of 0.02 °C. It is necessary to take into account the temperature of the area where the measurement is carried out. The skin temperature on the wrist is $30.4\ ^{\circ}C$. In addition, the measurement is carried out taking into account the possible decrease in blood circulation in the limbs of patients. However, for this block, the task is not to accurately determine the temperature, but to define a sharp increase in this parameter by 3 °C.

Its connection is carried out by a serial I2C interface. The measurement of saturation is carried out by methods of measuring changes in light absorption in oxygenated and deoxygenated blood. The physical substantiation of this method lies in the difference in the processes of absorption of saturated and unsaturated blood by oxygen. Therefore, the simplest and most affordable solution would be to use a human finger. In addition, a detectable period between an increase and a decrease in blood oxygenation makes it possible to measure the pulse rate.

The blood pressure non-contact measurement provides it is necessary to use potentially alternative methods, one of which is the method of estimating blood pressure based on the time of passage of a pulse wave obtained using photoplethysmography (PPG) on the wrist and on the finger [22–24] (see Fig. 16.4).

16.3.5 UX-UI Interface

This block provides access to the functions of the robot.

A tablet is used as the main interface, which allows for remote contact with the doctor if necessary. Due to the specifics of the robot application, namely the assumption that patients will use the system from a prone position, the tablet has mechanisms for adjusting the level of inclination. This unit is equipped with a microphone, speaker, and camera to realize feedback. Also, the robot assistant is equipped with a voice recognition system as an alternative UX interface and the ability to comfortably position the tablet.

16.3.6 Data Storing

A database with remote access is used to store patient data. The system contains the following information-personal data (name, address, contact details of the patient

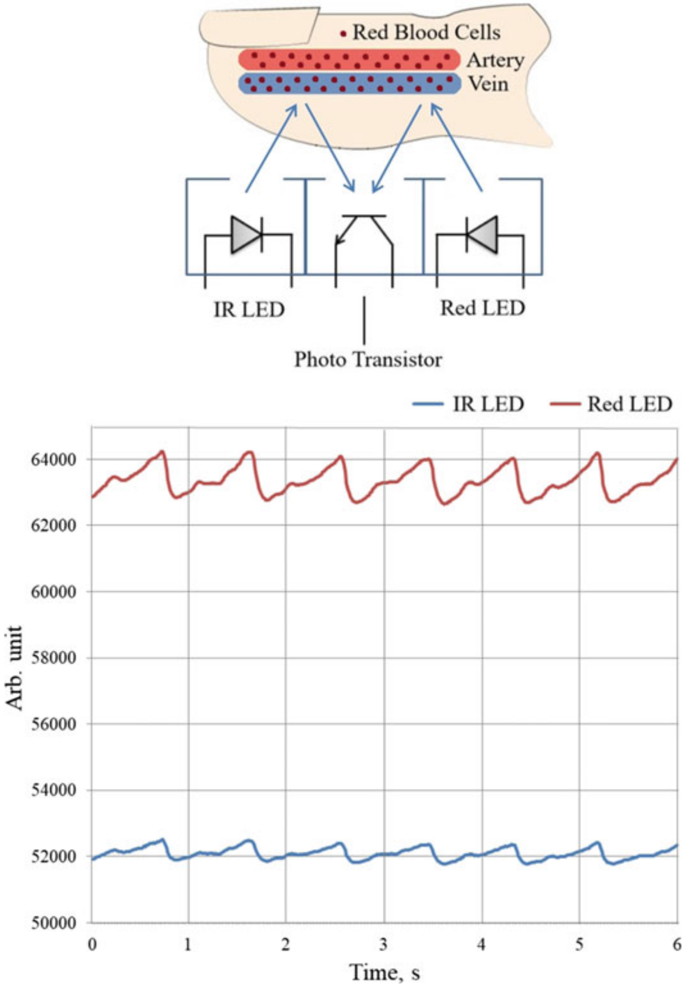

Fig. 16.4 Principle of implementation of the PPG method

and authorized representative), RFID identifier, examination results and indications of daily rounds, as well as personal complaints of the patient.

16.3.7 Control Algorithm

The microcontroller waits for a signal to be sent to the input panel, when the power is turned on. Medical staff can choose one of two work algorithms: the first is if it is necessary to complete a daily survey of the condition of patients and the processing of premises, and the second is only disinfection, for example, of a surgical room or corridors of an institution. Next, healthcare workers need to mark the key points of the movement trajectory on the hospital map. The robot will perform the specified actions when it arrives at the specified locations. During the movement, at intervals of 1 min, the robot checks whether the goal has been reached. If not, then it processes the premises all the way, depending on the presence of a person.

The process of questioning the patient begins with his identification. The robot reads the RFID tag of a person and then proceeds to interrogate the unit for measuring body parameters. An interruption of the optocoupler signal detects the presence of the patient's hand inside the unit, after which the temperature, saturation, and heart rate sensors are turned on. These data are recorded in a database and updated in real time on the attending physician's computer. When the parameter crosses the acceptable threshold of the body's vital activity, the application sends a sound signal notifying about the need for resuscitation.

After completing these steps, the robot returns to the docking station for recharging (Fig. 16.5).

16.4 Conclusion

The article market analyzes in the segment of medical robots that can combine the functions of monitoring the patients state and safe and efficient processing of disinfection. The main aspects of the development of this subject have been identified: the reduction in the cost of existing technologies and the combination of the necessary functionality in a modular system that can be adapted to the needs of a particular medical institution. Based on these observations, the concept of an assistant robot, its 3D model and functional diagram have been developed. The element base selection has been made and the device control algorithm have been developed.

A robotic IoT patient care system for medical institutions has been developed. The assistant provides the following features: daily rounds of patients, disinfection of empty rooms and in the presence of patients and staff in the room, delivery of medicines, tests, and remote survey, examination by a doctor. The robot can measure the following patient parameters: temperature, pressure, saturation, pulse. Due to the specific application of the device, non-contact optical sensors are used to measure all parameters, and all measurement methods are modified to suit operating conditions. The time of continuous battery life of the device is 5 h without recharging.

The developed device allows not only to conduct a daily survey of patients but also allows for effective bactericidal treatment of premises due to the equipping of several room disinfection systems. An ozone generator - which is great for empty rooms and kills over 90% of harmful microorganisms and a closed-type UV recycler - which is suitable for rooms where patients and staff are located.

Due to the modularity of the developed system, the user can configure it at his discretion, depending on the needs of a particular medical institution, which will significantly affect the final cost of the device. Modularity is achieved through the

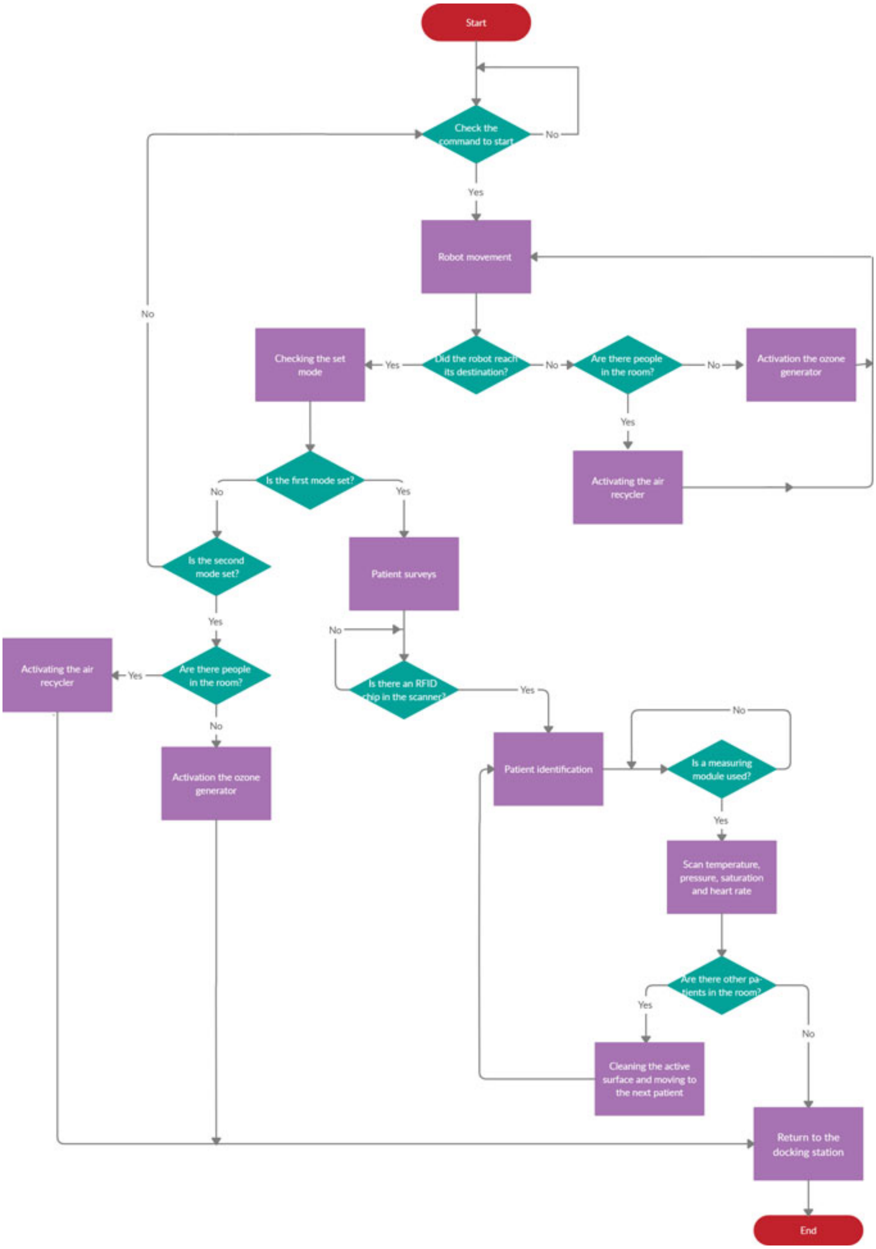

Fig. 16.5 Device operation algorithm

use of a programmable data bus. This will make it possible to use the developed device not only in epidemiological conditions but also as an auxiliary system in non-infectious departments of hospitals to prevent staff overtime.

Among the features of the system, one can also note the ability to build a doctor's round of patients, choosing the optimal trajectory of movement, the ability to independently fix the need for recharging and finding a wireless docking station, UI-UX interface for communication between a doctor and a patient with support for video communication and voice control, real-time transmission data on the state of health of people for comfortable and quick information of the medical database.

This set of functions favorably distinguishes the developed device from competitors both in the range of options provided and in the availability for purchase or manufacture and is an effective means of combating the spread of various infectious diseases.

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