Istraživanja i projektovanja za privredu

ISSN 1451-4117

DOI:10.5937/jaes0-38656

www.engineeringscience.rs

publishing

Journal of Applied Engineering Science

Vol. 20, No. 4, 2022

Original Scientific Paper

Paper number: 20(2022)4, 1029, 1242-1253

DESIGN OF A COMPLEX OF MEDICAL SERVICE ROBOTS AND ANALYSIS OF TRANSMISSION CHARACTERISTICS OF DRIVES

Askar Seidakhmet[1]*, Amandyk Tuleshov[1], Nutpulla Jamalov[1], Kairat Koshekov[2], Azizbek Abduraimov[1], Aziz Kamal[1], Magzhan Kanapiya[1], Igor Gritsenko[1], Madi Kaliyev[1], Alexandr Largin[3], Algazy Zhauyt[4]

[1] Joldasbekov Institute of Mechanics and Engineering, Almaty, Kazakhstan

[2] Civil Aviation Academy, Almaty, Kazakhstan

[3] M. Kozybayev North Kazakhstan University, Petropavlovsk, Kazakhstan

[4] Almaty University of Power Engineering and Telecommunications named after G. Daukeyev, Almaty, Kazakhstan

** seydakhmet@mail.ru*

The article describes a complex of robots designed and manufactured at the Institute of Mechanics and Machine Science for a hospital environment, consisting of a transport robot and two functional robots: assistant robot and a disinfection robot. The assistant robot is designed to measure temperature and blood pressure, automate the transportation of medicines, bed linen, food, etc. using a transport robot. With the help of a scissor mechanism the assistant robot is able to adjust the height of the trays, devices for measuring temperature and blood pressure. The disinfection robot is designed to automate disinfection in enclosed spaces. UV lamps with rotating 180 degrees reflectors, allow the disinfection robot to work in two modes: direct irradiation of the room with ultraviolet light and air recycling. There is also a mode of spraying disinfectant liquid. The article describes the design of a transport robot, an assistant robot and a disinfection robot, and shows the results of experimental studies.

Keywords: transport robot, assistant robot, disinfection robot, loading and unloading operations, hospital, logistics

1 INTRODUCTION

During the COVID-19 pandemic, hospitals around the world were overflowing with infected patients, doctors have worked with a heavy workload, and there were not enough support staff. There were frequent cases when medical personnel were infected with coronavirus from sick patients. This made the situation even worse. All this caused the need of reduction of the contact between medical workers, patients and potential virus carriers, also pushing scientists and engineers to create new types of robots. The first year of the pandemic, Sberbank of Russia (Sberbank Robotics Laboratory) in its annual report on the analysis of trends in the development of the global robotics market devoted an extensive section to this problem, and later published a special report "Robots against viruses" [1], also offering its own version of the disinfection robot [2]. The robot is equipped with ultraviolet radiation lamps with a power of 60 watts and can disinfect rooms with an area of more than 2.5 thousand square meters overnight. Disinfection of a room with an area of 20 square meters takes 5 minutes. The robot can function offline. To do this, firstly, the robot must be introduced to the room, as well as determine the optimal disinfection points. After that, it will be able to work either independently by command, or periodically by the schedule. When a person appears in the room, the robot automatically stops disinfection. Chanprakon et al. [3] developed a UVC robot that can move around the room and thoroughly sterilize the entire operating room with or without human intervention. The robot is equipped with three UV lamps, installed in a circle at a distance of 120 degrees from each other, and six ultrasonic sensors. The robot is installed on a mobile platform and controlled from a central command center. The Danish company UVD Robotics has introduced clinically tested and proven mobile UV robots to hospitals for effective disinfection of premises. This robot is able to detect and position itself in a hospital ward, while getting close enough to all critical objects during the disinfection process. Similar disinfection robots have been released by Geek + Robotics, Lavender and Jasmin robot, Omron, Akara Robotics at Trinity College Dublin, Milagrow Robotics has developed Indoor Disinfection RoboCop, Youibot has developed ARIS-K2 anti-virus robot, which disinfects 1000 square meters in 150 minutes. The Turkish company Milvus Robotics has developed a SEIT-UV disinfection robot, in India Anscer Robotics has developed an Anscer Robotics UV disinfection AMR robot, the Chinese company WellWit Robotics has developed a disinfection robot, the Singapore company has released a Sunburst UV Bots UV-disinfecting robot. In Barcelona, PAL Robotics has released a sanitizer robot (Figure A5) UV light disinfection AMR with a new design [4]. Robots with combined means of disinfection have also been developed: ultraviolet irradiation and spraying of chemicals. Wallexbot Tech Limited, based in Hong Kong, has developed a Puductor 2 and Puductor Standard disinfection robot to fight the negative impact of the pandemic, which provide ultrasonic and dry mist disinfection. Shanghai Technology Company TMI Robotics has developed an intelligent robot for disinfection of enclosed spaces, equipped with three disinfection technologies: with UV-C, a spray of disinfectant liquid and plasma air filtration. There is also another type of robots have been developed: robots-assistants for servicing patients or robot couriers. These robots are programmed to independently perform work of low and medium qualification, amenable to precise algorithmization: carry documents, deliver the necessary instrument to the surgeon, sort medications, interview the patient according to a certain template, measure his temperature, etc. For example, in Japan, Panasonic robots, Human Support Robot (HSR) robots from Toyota have been working in medical institutions for a long time. The Irish robot nurse RP7, developed by InTouch Health, also the Korean robot KIRO-M5. The robot from Murata Machinery Ltd is designed to dispense medicines. It also saves nurses from routine work, taking up their time with more useful things, which is especially important in conditions of shortage of medical staff in the fight against the pandemic. Panasonic has developed an autonomous robot courier Hospi-R. The robot is designed to transport samples and preparations for unloading laboratory technicians and nurses. Models of robot waiters produced by the Chinese company Pudu Robotics are also subject of interest. Guests will be able to communicate with robots in three languages — Russian, English and Chinese. Both robots are equipped with multi-level structures of trays and an interactive upper part with a display. In [5,6], the need of hospitals for automated transport systems is considered and mobile robots are proposed as a solution for automating transport tasks. The paper [7] discusses the design and application of a reconfigurable logistics robot for hospital facilities. Autonomous mobile robots have also been developed in the logistics of sterile instruments, and the evaluation of the material processing system for the strategic compliance structure has been carried out [8]. To optimize the design of automated controlled vehicles used in hospital logistics, proposals were presented in [9], also the impact of its implementation in hospitals was analyzed. The paper [1] presents a system consisting of a complex of robotic vehicles, automatic stations and intelligent containers for automating cargo transportation in hospitals, and also describes the overall architecture of the system. The analysis of the use of service robots in hospitals revealed the needs for the design of mobile robotic transport systems, as well as possible types of transport tasks that can be improved with automation. The concept of development of medical robots was developed at the Institute of Mechanics and Machine Science named after U.A. Joldasbekov. The essence of the concept is that two separate autonomous robots are being developed: a transport robot and a functional robot, which acts as a disinfection robot, an assistant robot or some other robot. The transport robot is designed to transport a functional robot, has two differential and four rotary wheels in the design and an autonomous navigation system. The functional robot also has its own wheelbase, but does not have its own drive, it is transported using a vehicle or moved with the help of personnel. For transportation with the help of a transport robot, a functional robot has an opening from below, into which a transport robot enters, hooks it and transports it. Thus, one transport robot can serve several functional robots in turn.

2 DESIGNING SERVICE ROBOTS FOR HOSPITALS AT THE JOLDASBEKOV INSTITUTE OF MECHANICS AND ENGINEERING

The analysis of the use of service robots in hospitals revealed the needs for the design of mobile robotic transport systems, as well as possible types of transport tasks that can be improved with automation. The concept of development of medical robots was developed at the Joldasbekov Institute of Mechanics and Engineering. The essence of the concept is that two separate autonomous robots are being developed: a transport robot and a functional robot, which acts as a disinfection robot, an assistant robot or some other robot. The transport robot is designed to transport a functional robot, has two differential and four rotary wheels in the design and an autonomous navigation system. The functional robot also has its own wheelbase, but does not have its own drive, so it is transported by transport robot or moved by personnel. For transportation with the help of a transport robot, a functional robot has an opening from below, into which a transport robot enters, hooks it and transports it. Thus, one transport robot can serve several functional robots in turn. Lidar, ultrasonic rangefinders and depth cameras are used in the construction of the transport robot to solve the problems of autonomous navigation and building a map of the room. We have implemented solutions for autonomous navigation and building a room map based on SLAM technology. The use of SLAM technology is based on signals from LIDAR, on the data of which the robot's position is determined and the map [hector_slam] is built. Solutions for autonomous planning of robot movement on the map – RRT [RRT] have been implemented. For RRT, the robot's own gear characteristics are used, obtained using methods for identifying characteristics based on measurement data. Cognitive functions use LIDAR data, Intel Real Sense 455 RGBD cameras. The following cognitive solutions have been implemented: human recognition, face recognition, object recognition, obstacle avoidance by RRT method. It is important to note the prospects of using the RRT method based on the identified transfer characteristics of the robot, which allows the introduction of methods of dynamic correction of movement and circumvention of moving obstacles. The robot assistant is designed to serve patients. He delivers food and medicines, allows you to have a dialogue with patients, measures the pressure with a special device and remotely measures the temperature. At the same time, for the convenience of patients, the height of the shelves of the robot assistant can vary depending on the patient's position (lying, sitting, standing position). When designing the robot assistant, strength calculations of the base were carried out, which includes a scissor mechanism, two trays and a tablet for patient communication with medical personnel and temperature measurements under the action of payloads. The design of the robot assistant uses a device for measuring blood pressure, which is a software and hardware complex developed at the Joldasbekov Institute of Mechanics and Engineering, consisting of an electronic unit for the removal, transmission of bioelectric signals and software for a personal computer that performs data processing and issuing on their basis a preliminary assessment of the level of blood pressure.

The design of a disinfection robot designed to automate disinfection in closed rooms. The disinfection robot can operate in two modes:

- spray mode of disinfecting liquid;
- the mode of irradiation with ultraviolet rays. In the irradiation mode, the disinfection robot can operate both in the direct irradiation mode of the room and in the air recirculation mode. In this case, the direct irradiation mode is used in the absence of a person in the room, and in the presence of a person, the disinfection robot

switches to the air recirculation mode to avoid burns with ultraviolet rays. A Eurasian patent was obtained for this design with rotary UV lamps [17].

During the design of the functionality and convenience of medical robots, suggestions and comments of the head of the Department of Internal Diseases of the Kazakh National Medical University named after Asfendiyarov, PhD A.B. Sugraliev were taken into account.

3 CONSTRUCTIONS OF MEDICAL ROBOTS

3.1 Construction of the transport robot

The transport robot has autonomous navigation and has the ability to overcome obstacles and plan a route. Figure 1 shows a three-dimensional model of a transport robot with 2 driving wheels and 4 swivel wheels.

a)

b)

Fig. 1. An experimental sample of a transport robot: a – a photo of a robot with an outer skin, b – a photo of a robot without an upper cover.

The transport robot shown in Figure 1 includes: 1 lidar, 8 ultrasonic rangefinders, 1 emergency button for emergency stop, 1 display, 2 depth cameras, 1 microcontroller, 1 motor driver, a block of 8 batteries, 1 charge controller, 2 step-down converters, 1 contact block for automatic charging, 2 driving wheels and 4 swivel wheels. The frame of the mobile robot platform is made of a structural aluminum profile with a size of 30x30 mm. All the rods of the frame and the devices listed above, hung on the frame, are fastened together with corners using bolts. From the outside, the frame of the mobile transport robot is lined with stainless steel sheets, which are bolted to the frame. Figure 2 shows a detailed diagram of the transport robot devices. At the top of the structure there are pins rising and falling with the help of linear actuators 8 to hook functional robots during their transportation. At the back of the mobile platform of the transport robot there are contacts designed to connect to the contacts of the battery charging device. Rplidar A1 is used as a lidar, which is used to build a two-dimensional map of the room and to detect obstacles. The mobile platform of the transport robot is driven by two motor wheels. The diameter of the driving wheels is 10 cm. Intel realsense D455 depth camera is used to build a three-dimensional map and read barcodes, labels, QR codes. Detection of obstacles in front, behind and from the sides is carried out by 8 ultrasonic rangefinders. In emergency situations, the emergency stop button is used. The movement of the transport robot and the operation of all sensors are controlled by the mars 4500u computer. The transport robot has a load capacity of up to 100 kg. The dimensions of the transport robot and functional robot are chosen so as to fit into the doorways of the hospital department. An autonomous power supply unit with 8 lithium iron-phosphate batteries provides the robot with a voltage of 24 volts. In the process of designing the design of medical robots, the following factors were taken into account: the transport robot should be able to transport other robots, be compact in order to freely pass doorways; should have high maneuverability and a small turning radius; the maximum payload should be in the range of 50 - 100 kg; the noise level should be less than 60 dB. The programming of the transport robot was carried out using the ROS system.

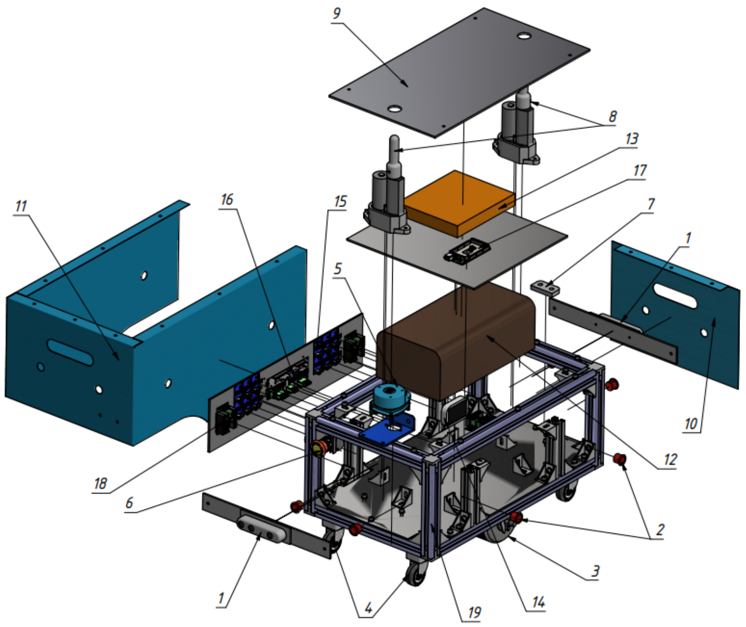


Fig. 2. Detailed diagram of the transport robot devices: 1- depth camera; 2- ultrasonic rangefinders; 3- driving wheels; 4- rotary wheels; 5- lidar; 6- emergency button; 7 – battery pack charging contacts; 8- linear actuator with pin; 9- top cover; 10- rear cover; 11- front cover; 12- battery pack; 13- computer; 14- power supply charge display; 15- ultrasonic rangefinder board; 16- motor driver; 17- debugging board; 18- step-down converter; 19- structural aluminum profile.

To hook other functional robots by the transport robot, a pin rising and falling with the help of a linear actuator is used. Figure 3a shows the design of a pin with a linear actuator located on a transport robot. Figure 3b shows the design of a part with a hole located on the assistant robot and the disinfection robot. The manufactured autonomous transport robot is capable of transporting the assistant robot and the disinfection robot to the required hospital premises.

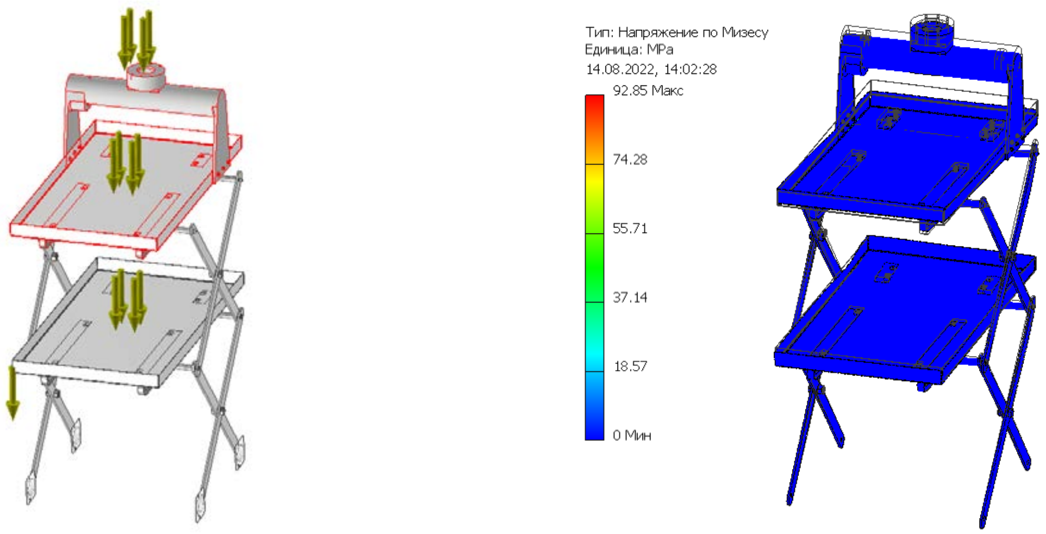
a)

b)

Fig. 3. a – design of a pin with a linear actuator, b - design of a part with a hole.

3.2 Construction of the robot assistant

The robot assistant is designed to automate the transportation of medicines, bed linen, food, etc. with the help of a transport robot in hospital departments. The design of the robot assistant consists of two independent components: a mobile mobile platform (lower part) and an upper part with two shelves with trays, a device for measuring the patient's blood pressure (BP), devices for remote temperature measurement and conducting an online dialogue between the patient and the staff. The lower part can move on 4 wheels and has an opening at the bottom for the entry of the transport robot and further transportation. If necessary, the robot assistant can move with the help of maintenance personnel. Shelves with trays can be raised or lowered to a height convenient for the patient using a scissor mechanism and a linear actuator. The upper tray in Figure 4 is used to deliver food, the lower tray is used to deliver medicines to patients. When designing the robot assistant, strength calculations of the base were carried out, which includes a scissor mechanism, two trays and a tablet for patient communication with medical personnel and temperature measurements under the action of payloads. To check the reliability of the design in the form of a scissor mechanism, two trays, a base mounted on the upper tray, and which can withstand the applied load of the tablet, a finite element calculation (FEA) was carried out according to the model in the Autodesk Inventor system. A 3D model of the design described above was separately considered, the effect on the model of a 0.9 kg tablet located at the top of the base, a load with a maximum weight of 3 kg on the upper tray and a load with a maximum weight of 2 kg on the lower tray were modeled as a load distributed over an area. The links of the scissor mechanism and the trays are made of stainless steel. Figure 4 shows a picture of the Mises stress distribution in the structure when the mechanism is in the upper position. The maximum tension at the mounting angle under the lower tray and is equal to 92.5 MPa, the tension at the bend of the larger side of the upper tray is 69.3 MPa, the tension at the bottom of the upper tray in the middle of the far width is 1.6 MPa, the tension at the bottom of the lower tray in the middle of the far width is 3.4 MPa, the maximum tension in the links of the mechanism is about 2.2 MPa. Similarly, the same finite element calculation was carried out for the mechanism in the lower position. As the analysis of the obtained data showed, the tension for the lower position is less than for the upper position. In general, the developed design for the use of a scissor mechanism for lifting trays and a tablet for patient communication with medical personnel and temperature measurement has sufficient strength.



a) b)

Fig. 4. Finite element calculation for a mechanism in the upper position: a) a diagram indicating the applied forces and supports, b) calculated maximum stresses according to Mises.

An analysis of the moving points of the scissor mechanism was also carried out. Figure 5 shows a picture of the vertical movements of the points of the mechanism and the trays located on it. As calculations have shown, the points of the upper tray on the back wall have the greatest displacement equal to 0.33 mm. As you can see, the maximum displacement is very small, sufficient when operating a scissor mechanism with trays and a base for a tablet.

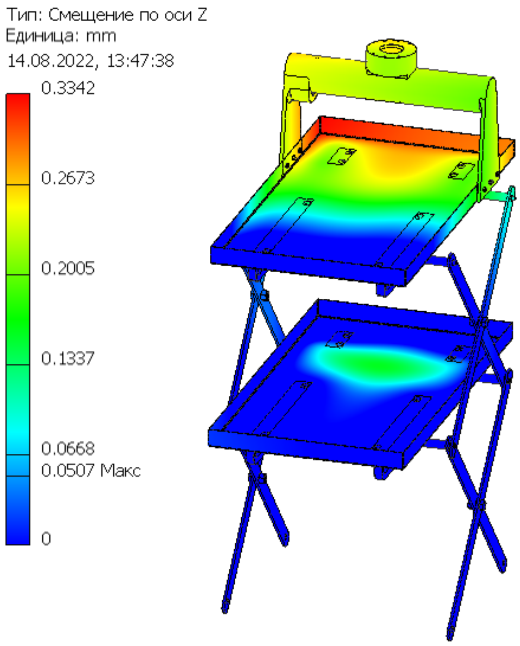


Fig. 5. A picture of vertical displacements of points obtained by finite element calculation for a mechanism in the upper position

In the initial position, the upper part of the assistant robot is in the folded transport position. The transport robot drives up to the assistant robot from the right angle and hooks the assistant robot to itself, then it begins to move along the planned route. The robot assistant has its own independent intelligent system, separate from the transport robot. The robot assistant is able to adjust the height of the devices for measuring temperature and measuring blood pressure using a scissor mechanism. Figure 6 shows a photo of an experimental sample of an assistant robot.

Fig. 6. An experimental sample of an assistant robot.

The device for measuring blood pressure (BP) is a software and hardware complex developed at the Institute of Mechanics and Machine Science named after U.A. Joldasbekov, consisting of an electronic unit for recieving and transmission of bioelectric signals, software for a personal computer (PC) that performs data processing and issuing on their basis a preliminary assessment of BP level. The electronic unit is a microcontroller device based on an ESP32 system on a chip (SoC) with integrated Wi-Fi 802.11 b/g/n and Bluetooth v4.2 BR/EDR and BLE controllers. The system is equipped with a dual-core 32-bit Tensilica Xtensa LX6 processor and developed by Espressif Systems [10]. ESP32 as part of the device solves the problem of collecting information from the MAX86150 biosensor from Maxim Integrated [11]. This biosensor is an integrated circuit that allows recording such bioelectric signals of the human body as an electrocardiogram (ECG) and a photoplethysmogram (PPG). Due to the use of a high-bit ΣΔ analog-to-digital converter (19-bit ΣΔ ADC) and a special instrumental amplifier in the sensor, it is possible to register an ECG signal in one lead using dry electrodes. In addition, the shape of the PPG signal is recorded using the built-in red and infrared LEDs with a wavelength of 660 and 880 nm, respectively, built into the sensor.The MAX86150 sensor has a miniature size of 3.3x5.6x1.3 mm and low power consumption at a supply voltage of 1.8 V, which is used in wearable electronics. Communication with the microcontroller (MC) is carried out via the I2C bus. The MC reads ECG and PPG signal samples from the sensor's ring buffer, recorded with a sampling frequency of 200 Hz and a bit depth of 18 and 19 bits, respectively. The location of the ECG electrodes on the device implies the reception of an electrocardiographic signal according to the right hand – left hand scheme, i.e. the first standard lead I. The PPG is registered according to the reflected pattern on the finger of the right or left hand for the emission of an infrared LED. The MC lowers the bit rate of data from the sensor and transmits it wirelessly to the PC. Optionally, wireless transmission can be carried out either via Bluetooth v4 protocol [12] or ESP-NOW technology [13]. If Bluetooth technology is selected, the PC must be equipped with an appropriate wireless transceiver. The standard provides a data transfer rate of up to 1 Mbit/s at a distance of up to 100 m in an open area. In indoor conditions, the distance can be reduced to 10 m. ESP-NOW is a WiFi communication protocol developed by Espressif for its MCs. This protocol transmits short packets between pairs of paired devices. At the same time, additional procedures related to the support of the WiFi protocol are not used, which speeds up the process of packet exchange. The transfer rate for this protocol is no more than 1 Mbit/s at a frequency of 2.4 GHz. Using the ESP-NOW protocol provides a wider coverage area (equivalent to the range of a Wi-Fi network) compared to the Bluetooth standard. At the same time, in order to receive data via the ESP-NOW protocol, a receiving device in the “Slave” mode is connected to the PC, which implements data input to the PC via a virtual serial port. In the developed device, the reception of signals to a PC via a wireless channel is also provided by SoC ESP32, and data from the serial port of the MC is transmitted to the USB port of the computer via a USB-to-UART bridge on the integrated chip CH9102 [14]. The electronic unit is powered by a lithium battery with an 18650 form factor. A scheme for monitoring the discharge and overcharging of the battery is provided. The BP measurement device software is an application with a graphical user interface. This application allows you to start the process of recording signals to a PC disk with their form displayed in real time. For this purpose, a bank of digital filters with finite and infinite pulse characteristics operating in real time is used. Demonstration of the recorded ECG and PPG signals allows you to establish the correctness of the received data for subsequent analysis. Bioelectric signals are stored on a PC disk in CSV format for further analysis and storage. After receiving the ECG and PPG signals with the help of the developed software, it is possible to analyze them to obtain information about the human BP. A pre-trained machine learning model is used for this purpose. ECG and PPG signals are filtered using a wavelet filter to remove the low–frequency component in the range of 0 - 0.7 Hz, as well as using a low-frequency Butterworth filter with a cutoff frequency of 30 Hz to eliminate high-frequency artifacts and network interference. For the Butterworth filter, block processing is used to eliminate phase-frequency distortion. Various time, amplitude, and other characteristics are extracted from bioelectric signals, both individual for ECG or PPG, and mutual. The obtained characteristics are informative features for the machine learning model.

The model classifies data according to the following criteria.

1. Low pressure: systolic pressure (SP) < 90 mm Hg or diastolic pressure (DP) < 50 mm Hg
2. Normal pressure: SP 90 – 129 mm Hg and DP 50 – 84 mm Hg.
3. Increased pressure SP ≥ 130 mmHg or DP ≥ 85 mmHg [15].

As a result, the user receives a forecast about the level of BP: low, normal or elevated. The accuracy of the classifier model is shown in Table 1.

Table 1. The quality of the classifier

Class	precision	recall	f1-score	Number of samples
Normal BP	0,86	0,82	0,84	28809
Low BP	0,69	0,66	0,67	1128
Increased BP	0,83	0,88	0,86	29176
Accuracy			0,85	59113
Average by class	0,80	0,78	0,79	59113
Weighted by class	0,85	0,85	0,85	59113

In accordance with Table 1, the prediction quality of the developed blood pressure level device is 85%.

3.3 Design of the disinfection robot

The disinfection robot is designed to automate disinfection in enclosed spaces. The design of the disinfection robot consists of a lower part on four wheels, which has a built-in tank for disinfection liquid, two lithium iron phosphate batteries, a fan and a system for spraying liquid (Figure 5). The upper part contains UV lamps with reflectors that can be rotated 180 degrees using a rotary mechanism and has two working positions. In the first operating position, the UV lamps are located outside relative to the housing (Figure 7), and in the second operating position, the UV lamps with reflectors are rotated 180 degrees relative to the first position. In this case, the reflectors with the housing form a closed cylinder, inside which there are ultraviolet lamps (Figure 7) and the system operates in recirculation mode, i.e. air is driven through the closed cavity using fans located in the lower part of the cavity. Sensors for detecting the presence of a person in the room are placed on the upper part of the housing. When detecting people, the disinfection robot turns on 1800 UV lamps with reflectors that irradiate the air inside a closed cylindrical cavity. At the same time, a fan is turned on, which pumps air from the room into a cylindrical cavity. By emitting ultraviolet light with a TUV Philips bactericidal lamp (15 W, wavelength 253.7 NM (UV-C)) on a surface with a high, medium and low touch level, the robot disinfects the indoor air. To transport the disinfecting robot, in the same way, the transport robot enters the space of the lower part of the disinfecting robot, engages and moves it along the required route to the destination. Figure 7 shows a photo of an experimental sample of a disinfection robot. Figure 8 shows the arrangement of UV lamps with reflectors in the first and second working positions.

Fig. 7. Experimental sample of the disinfection robot.

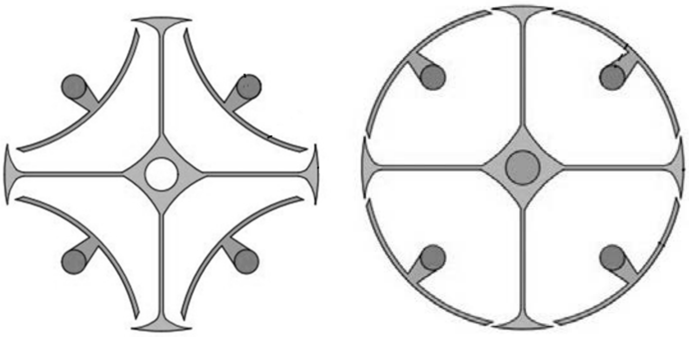


Fig. 8. Arrangement of UV lamps with reflectors: a – first working position, b – second working position.

A detailed description of the design of the disinfection robot is given in the article [16].

4 CONDUCTING EXPERIMENTS

To test the traction ability of the transport robot, experiments with recording changes in the speed of rotation, torques on the shafts of two motors when moving straight without load and when moving straight with the towing of a 40 kg disinfection robot were carried out. Figure 9 shows graphs of the speed change on the shafts of two motors when moving in a straight line without load. As can be seen from the graph, both motors have a transitional mode and then the rotational speeds go to a steady value. Acceleration lasts $9 \cdot 10^{-1}$ sec. Since the movement takes place in a straight line, the deviations of the rotational speeds of the two motors from each other are minimal. Figure 10 shows graphs of changes in torques on the shafts of two motors when moving in a straight line without load. As can be seen from the graph, both motors have a transitional mode and then the shaft torques move to a steady value. The torque from the initial value of 20 Nm drops to 5 Nm. Since the movement takes place in a straight line, the deviations of the values of the torques of the shafts of the two motors from each other are minimal.

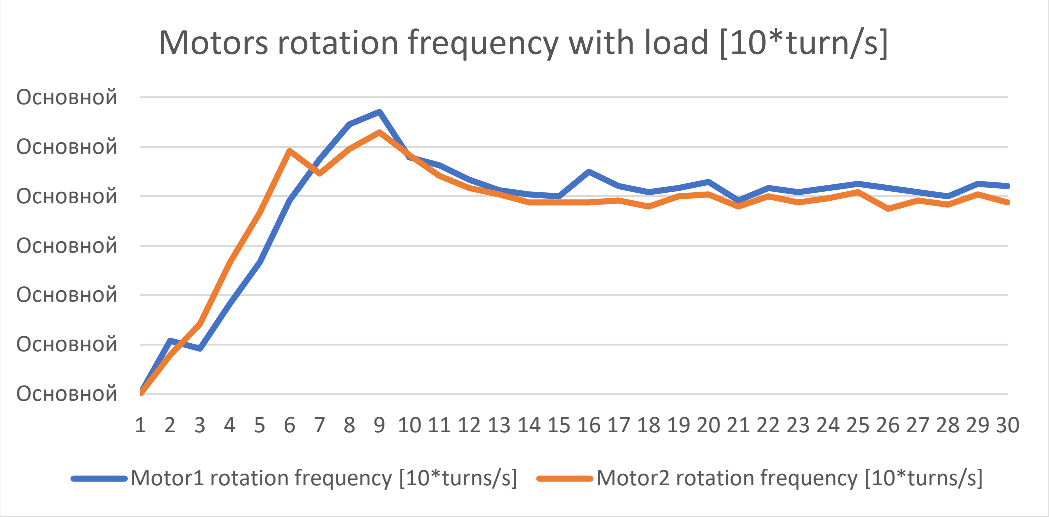


Fig. 9. Graphs of rotation speed changes on the shafts of two motors when moving in a straight line, without load.

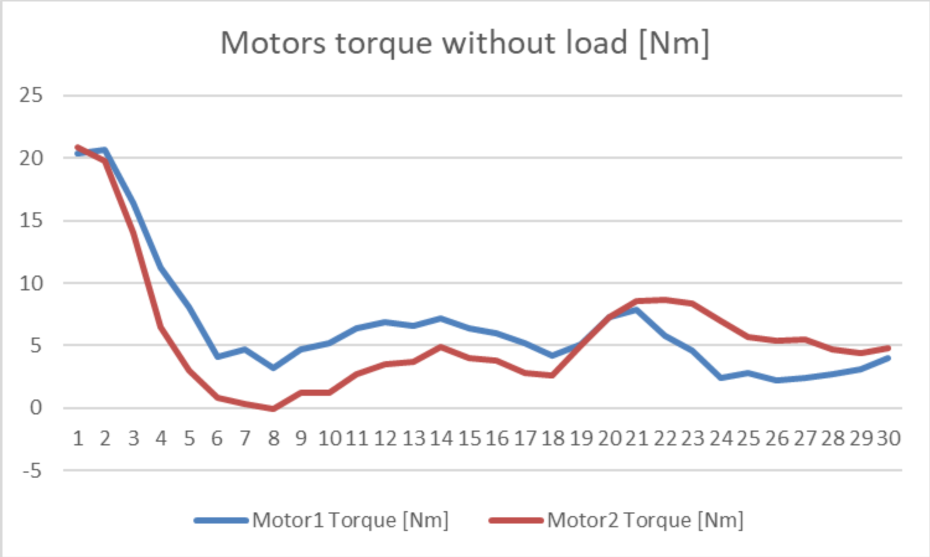


Fig. 10. Graphs of torque changes on the shafts of two motors when moving in a straight line, without load.

Figure 11 shows graphs of the speed change on the shafts of two motors when moving in a straight line with a load. As can be seen from the graph, both motors have a transient mode and then the rotational speeds go to a steady value. Acceleration lasts $14\cdot10^{-1}$ sec. Since the movement takes place in a straight line, the deviations of the rotational speeds of the two motors from each other are minimal. Figure 12 shows graphs of changes in torques on the shafts of two motors when moving in a straight line with a load. As can be seen from the graph, both motors have a transient mode and then the shaft torques move to a steady value. The torque from the initial value of 20 Nm rises to 37 Nm and then drops to a value of 5 Nm. Since the movement takes place in a straight line, the deviations of the values of the torques of the shafts of the two motors from each other are minimal.

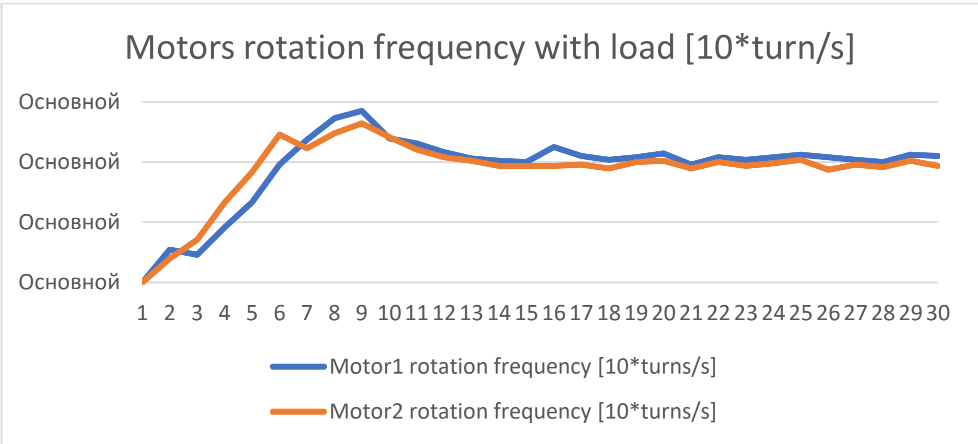


Fig. 11. Graphs of rotation speed changes on the shafts of two motors when moving in a straight line, with a load.

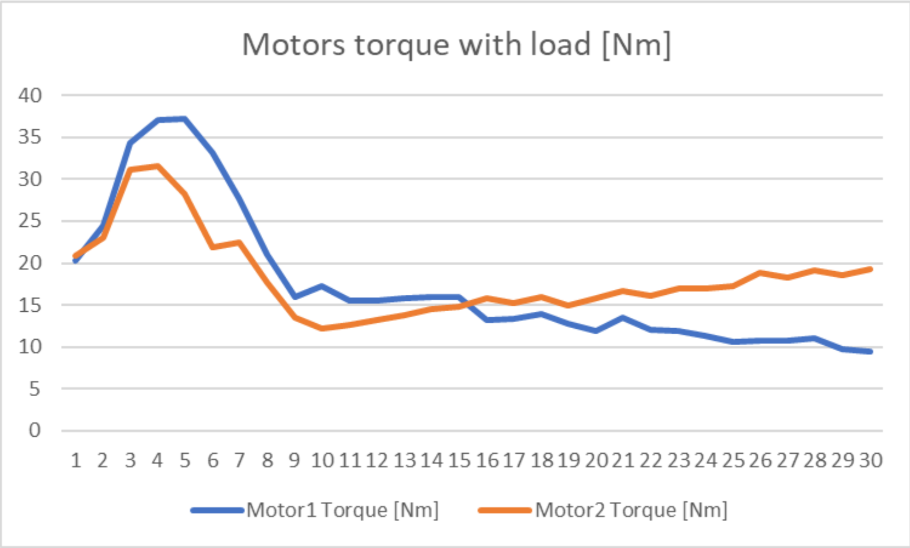


Fig. 12. Graphs of torque changes on the shafts of two motors when moving in a straight line, with a load.

The numerical data obtained was used to identify models of the transfer functions of motors in the states under load and without load – based on the data of measuring the behavior of the drive on the step signal. Identification of the transfer functions of the motors allows you to build a model of the dynamics of the robot's movement and use it in the control loop, which ensures its accuracy. In this study, we have implemented the transfer characteristics of robot motors into the calculation of a set of potential movements (a set of possible paths that robot could follow) for the RRT (Rapidly-Exploring Random Tree) algorithm of the motion planner. With the help of the RRT algorithm, the transfer functions of the robot drives were integrated into the procedure for calculating the potential paths of the robot. The resulting RRT implementation made it possible to plan the robot's movement on a previously known map, taking into account obstacles, the robot's own dynamics, ensuring that the planner can take into account the criteria for the robot's movement dynamics. The obtained models were used to plan the movement of a mobile robot using the RRT method. Figure 13 shows an example of using the RRT method to plan movement in an environment with obstacles (red walls), green highlights the trajectory of movement from the starting point (marked with a circle) to the target point (marked with a star). An example of using the RRT method for traffic planning in an obstacle-free environment. green - the trajectory of movement from the initial (circle) to the target point (star). Graph points are blue connected by trajectories (black lines).

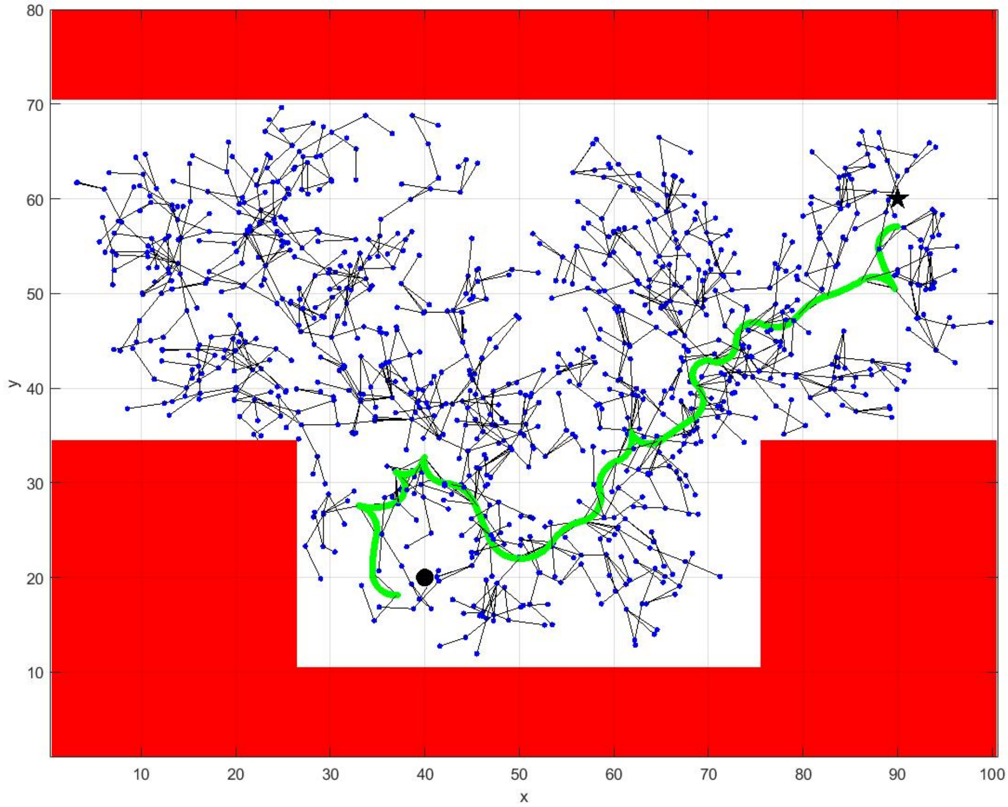


Fig. 13. is an example of the application of the RRT method for planning movement in an environment with obstacles (red walls), the trajectory of movement from the initial (marked with a circle) to the target point (marked with a star) is highlighted in green.

The experiments have shown that the design of the transport robot meets all the requirements, towing the disinfection robot with a maximum load does not significantly affect its traction ability. Only the acceleration time increases to a steady value.

5 CONCLUSIONS

According to the proposed concept for the development of medical robots, the designs of a transport robot and functional robots – an assistant robot and a disinfection robot - have been developed and manufactured. The experiments have shown that the design of the transport robot meets all the requirements, towing the disinfection robot with a maximum load does not significantly affect its traction ability. The results show that a transport robot with a towed robot can accurately follow the control commands. Solutions for autonomous navigation and motion planning, recognition of people and objects have been implemented. The construction of the RRT based on the identified transfer characteristics of the robot allows for high-precision control of the mobile robot. The developed solution has a fairly wide potential for functional scaling of intelligent functions of medical service robots. In the future, work will be carried out on the development of high-precision traffic planning systems taking into account moving obstacles. A modified SLAM solution will be developed that will allow you to determine changes in the room map based on the LIDAR sensor readings. Solutions for human-machine interactions will be developed through gesture recognition, determining the emotional state of a person from an image.

6 ACKNOWLEDGMENTS

This research has been funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (STP No. O.0971).

7 REFERENCES

[1] Efimov A., Gonnochenko A., Payson D., etc. Robots against viruses, from https://www.sberbank.ru/common/img/uploaded/analytics/about-issledovaniya/rav.pdf, accessed on 2022-03.

[2] Mubarakshina G. Sberbank has developed a prototype robot for disinfection of premises, from https://vc.ru/tech/119259-sberbank-razrabotal-prototip-robota-dlya-dezinfekcii-pomeshcheniy, accessed on 2020-04-10.

[3] Chanprakon, P.; Sae-Oung, T.; Treebupachatsakul, T.; Hannanta-Anan, P.; Piyawattanametha, W., (2019). An Ultra-violet sterilization robot for disinfection. In Proceedings of the 2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), Luang Prabang, Laos, 2–5 July 2019; p. 1–4.

[4] PAL Robotics. How to build a solution for fighting coronavirus using the TIAGo Base robot, from https://blog.pal-robotics.com/how-to-build-a-solution-for-fighting-coronavirus-using-the-tiago-base-robot/, accessed on 2022-05-05.

[5] Giuseppe, F., Hans-Henrik, H., Fabio, S., Jan Ola, S. (2020). Autonomous mobile robots in hospital logistics. IFIP International Conference on Advances in Production Management Systems, p. 672-679.

[6] Özkil, A. G., Fan, Zh., Dawids, S., Klæstrup, K. J., Christensen, K. H., Aanæs, H. (2009). Service Robots for Hospitals: A Case Study of Transportation Tasks in a Hospital. Proceesings of 2009 IEEE International Conference on Automation and Logistics, p. 289–294.

[7] Yuyao Shi, Hayat, A. A., Vinu, S., Elara, M. R. (2021). WaspL: Design of a Reconfigurable Logistic Robot for Hospital Settings. Cornell University, DOI: https://doi.org/10.48550/arXiv.2107.03002

[8] Fragapane, G., Hvolby, H.H., Sgarbossa, F., Strandhagen, J. O. (2021). Autonomous mobile robots in sterile instrument logistics: an evaluation of the material handling system for a strategic fit framework. Production Planning & Control, DOI: https://doi.org/10.1080/09537287.2021.1884914

[9] Gonzalez, D., Romero, L., Espinosa, M.M., Domı´nguez, M. (2017). An optimization design proposal of automated guided vehicles for mixed type transportation in hospital environments. PLoS ONE 12(5): e0177944, DOI: https://doi.org/10.1371

[10] Espressif Systems. ESP32 Series Datasheet v3.8, from https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf, accessed on 2022-05-18.

[11] Maxim Integrated. MAX86150 Integrated Photoplethysmogram and Electrocardiogram Bio-Sensor Module For Mobile Health Datasheet. https://datasheets.maximintegrated.com/en/ds/MAX86150.pdf, accessed on 2018.

[12] Bluetooth.com. Core Specification 5.3. from https://www.bluetooth.org/en-us/specification/adopted-specifications, accessed on 2014-12-02.

[13] Espressi. ESP-NOW User Guide 2016.07, from https://www.espressif.com/sites/default/files/documentation/esp-now_user_guide_en.pdf, accessed on 2022-05-18.

[14] CH9102 DataSheet. USB to High Speed Serial Port Chip CH9102. Version: 1A, from http://www.wch-ic.com/downloads/file/297.html, accessed on 2022-05-18.

[15] Williams, B., Mancia, G., Spiering, W., Rosei, E. A., etc. (2018) ESC/ESH Guidelines for the management of arterial hypertension: The Task Force for the management of arterial hypertension of the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH). European Heart Journal, Volume 39, Issue 33, 01 September 2018, p. 3021–3104, DOI: https://doi.org/10.1093/eurheartj/ehy339

[16] Tuleshov, A., Jamalov, N., Imanbayeva, N., Rakhmatulina, A. (2022). Design and construction of a multifunctional disinfection robot. Eastern-European Journal of Enterprise Technologies.Vol. 1 No, 1(115), p.16-23. DOI: https://doi.org/10.15587/1729-4061.2022.252045

[17] Tuleshov, A., Jamalov, N., Ibrayev, S., M., Seidakhmet, A., Kamal, A., Abduraimov A., Kanapiya, M., Imanbayeva, N., Rakhmatulina, A., Tolebayev, N. (2022). Multifunctional disinfection robot. Eurasian patent for invention No. 040808. July 29, 2022, Russia, 109012, Moscow, M. Cherkassky lane, 2.

Paper submitted: 20.06.2022.

Paper accepted: 11.09.2022.