The Avatar Robot - a Clone of the Sapper's Arm

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Abstract. Devices with remote control can protect human life and health, because in dangerous, inaccessible and extreme conditions, they can be controlled remotely. The work of sappers who defuse mines is especially dangerous. The aim of the research is to create a robot-manipulator that repeats the movements of the limbs of a human-operator in real time for remote performance of work in dangerous conditions or hard-to-reach places. The Avatar robot consists of four mandatory systems: the first is a power source; the second is a "glove" that is worn on the human arm to control manipulator (for convenient bending, extension and rotating of arm, the design of the "glove" is based on the anatomy of the human arm); the third is a system that transmits movement information from the "glove" to executive manipulator; the fourth - executive device, that is, a robotic manipulator that copies the movements of a human arm. The Avatar robot complex can perform simple typical movements: grab, release, turn, pick up, move, pull, etc. At the same time, the robot can perform its work not only by hand, but also with tools.

Keywords: manipulator, encoder, driver, stepper motor, movements repeater, remote control.

1. Introduction

The work of a sapper is very dangerous, because if the task is performed carelessly, accidents can happen, or people can get seriously injured. There are other dangerous activities or places inaccessible to humans. In these cases, it is appropriate to use devices with remote control. The problem of safe demining is an urgent problem.

The operator can use various devices to control manipulators: panel with buttons, handles, joysticks, touchscreens and such work requires special training.

The human arm is the most perfect system for performing complex movements of various amplitudes with great precision, the executive mechanism of the manipulator is often made similar in structure to an arm. In this case, the simplest and most intuitive way of controlling the repetition of the manipulator movements is by an arm of operator.

The purpose of the research is to produce a manipulator robot, the executive mechanism of which has the kinematic structure of a human arm, and the control device ensures the repetition of the movements of the human operator's arm in real time.

The object of the research is a robot-manipulator with remote control.

The subject of the research is remote controlled robot-manipulator which provides accurate reproduction of human arm movements by the manipulator.

The practical significance of the work lies in the fact that the designed and manufactured operating complex of the Avatar robot has a simple and reliable control system (by reproducing the movements of the human operator's arm). The robot is assembled from available materials, can function without the use of computer technologies, which allows to eliminate damage in field conditions if necessary. And to expand its functionality, you can use additional control boards.

The structure of presented scientific paper consists of following sections:

- Literature Review;
- Research Methodology;
- Results and Discussion;
- Conclusions;
- References.

2. Literature Review

Currently, remote control devices are quite actively used, which can be controlled, for example, by joysticks and remote controls (See Fig. 1).

Fig. 1. Controllers for remote control devices

Remotely controlled executive devices can be drones, airplanes, cars, technological equipment and household appliances of the "Smart Home" system, satellites, missiles, etc [1].

Remotely controlled devices are present in all spheres of our activity, from toys to systems that protect and save human life, working in places inaccessible to humans. For example, in medicine, robots are used that perform surgical operations with the help of special manipulators, and a specialist surgeon can manage them remotely [2]. Currently, people have the opportunity to explore distant planets and their satellites with the help of probes that are controlled remotely [3]. When extracting radioactive resources, remote-controlled excavators are used to move the ore to avoid exposing people to radiation [4]. When conducting military operations on the battlefield, reconnaissance and strike drones, robotic mobile installations for the delivery of small cargo and demining are used [5-6].

In general, various devices that work by remote control should be used in conditions that are dangerous, inaccessible and extreme for humans. Such devices are also an integral part of the industrial and household Internet of Things. They increase the quality and comfort of our life. Various approaches to the development of remote-controlled robotic manipulators based on the human arm form are known [7-9].

In our analysis, in order for the manipulator to be able to perform complex translational-rotational movements in a wide range of amplitudes, that is, to work like a human arm, the simplest, most intuitive control system for the operator will be one in which the manipulator repeats the movements of the operator's arm. To do this, a device should be worn on the operator's arm, which will analyze the movement of each joint and transmit the data to a manipulator designed according to a shape of a human arm. We called this device a "glove". Figure 2 shows the functional scheme of the Avatar robot system.

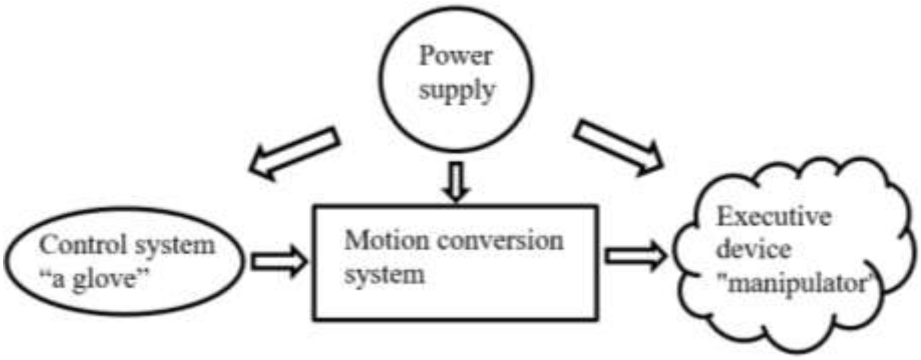


Fig. 2. Functional diagram of a complex of the Avatar robot systems

Sensors are located on the control system that detect the movements of our arm. Further, these signals must be converted and transmitted to the executive device, which will reproduce the movements of the operator's arm. All these elements will receive energy from the battery power supply.

Since the idea of creating a "mechanical hand" appeared as one of the ways to solve the problem of demining Ukrainian territories, additional requirements were placed on the manipulator. The device will work in the field conditions with explosive objects, so the main concept is to create a complex of systems of the Avatar robot without the use of computer technology to improve the reliability of the entire system. It is also worth making a robot from the most simple, cheap and available materials so that possible damage can be easily eliminated.

After analyzing methods of remote control of devices, it was concluded that the manipulator will be controlled by a human arm. For this, a special splint should be put on the human arm, which will copy the movements (turns and bends) of our arm, and transmit information to the executive device.

The so-called "glove" should be designed taking into account the anatomical structure of the hand (See Fig. 3) [10].

The selected control principle will contribute to the fastest possible training of the operator in controlling the robotic manipulator for remote operation.

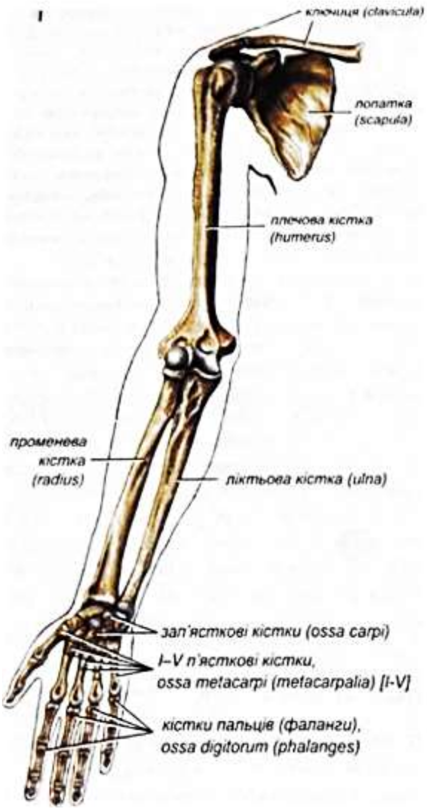


Fig. 3 Anatomy of a human arm [10]

3. Research Methodology

First of all, we decided to design a 3D model of the entire complex of the final version 2.2 (it is worth noting that there were 4 versions of the complex in total) in the SolidWorks software [17] in order to know exactly what and where should be placed and attached various elements. We started by modeling the control system shown in Figure 4.

The control system is conveniently attached to the human arm using special rubber-fabric belts [11]. The encoder responsible for the rotation of the elbow (Fig. 4, item 5) was successfully used, but this encoder will not be connected to the main control system, it will need to be controlled by another hand, since the rotation of the manipulator elbow can be carried out more than 360°, and a human elbow cannot rotate like that.

The movement transmission and conversion system was also modeled in the

SolidWorks software (See Fig. 5).

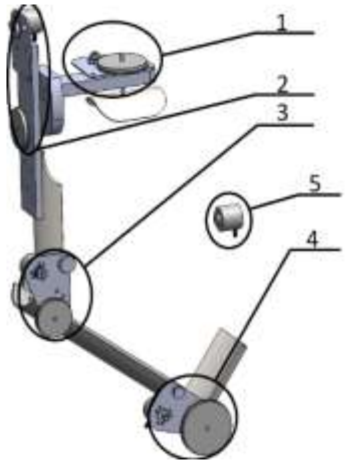


Fig. 4. 3D model of the control system version 2.2:
1 - shoulder rotating block, 2 - arm lifting block, 3 - elbow lifting block, 4 - finger lifting block, 5 - elbow rotating block (controlled by the other operator's hand)

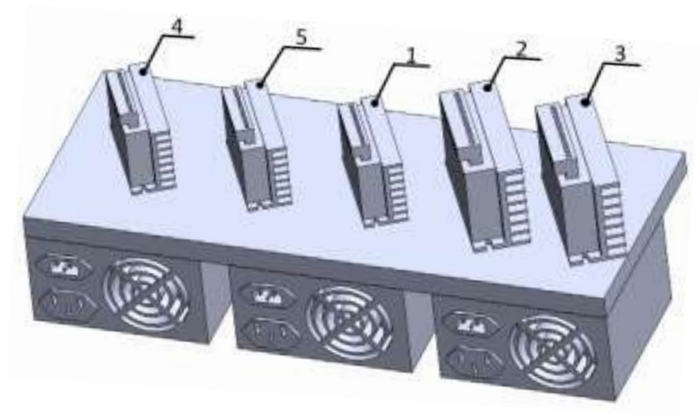


Fig. 5. 3D model of the system of conversion and transmission of movements version 2.2:
1 – the driver transmits the shoulder rotating signal, 2 – the driver transmits the arm lifting signal, 3 – the driver transmits the elbow lifting signal, 4 – the driver transmits the finger signal, 5 – the driver transmits the elbow rotating signal

The movement conversion and transmission system consists of 5 drivers: 1 – driver TB6600 (Fig. 5, item 4) which is responsible for fingers lifting; 2 - driver TB6600 with a reinforced cooling radiator (Fig. 5, item 5, item 1) responsible for rotation of the elbow and shoulder and two drivers DM556 (Fig. 5, item 2, item 3) responsible for lifting hands in the shoulder and elbow area. This choice of drivers is due to the fact that different engines perform different power work. For example, raising the elbow and shoulder are the most loaded mode, and the fingers are the least loaded mode. All drivers are placed on a set of power suppleis.

Modeling a new version of the manipulator robot was also a mandatory and important task. Figure 6 shows a digital 3D model.

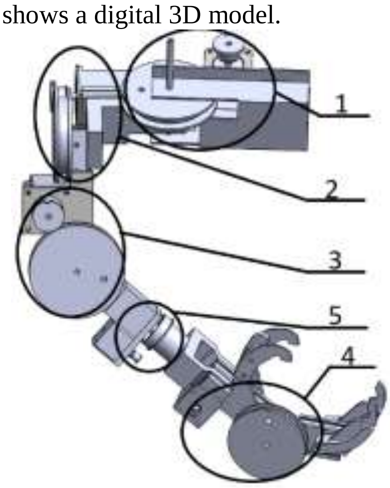


Fig. 6. 3D model of the Avatar robot manipulator version 2.2:
1 – shoulder rotating block, 2 – arm lifting block, 3 – elbow lifting block,
4 – finger lifting block, 5 – elbow rotating block

The robot manipulator consists of 5 stepper motors. A stepper motor which we placed between the elbow and the fingers, that is, on the forearm. So it can rotate the robot's fingers more than 360°, because it is controlled by an operator using another hand, not by a "glove".

The general view of modeled complex of Avatar robot systems version 2.2 is shown on Figure 7.

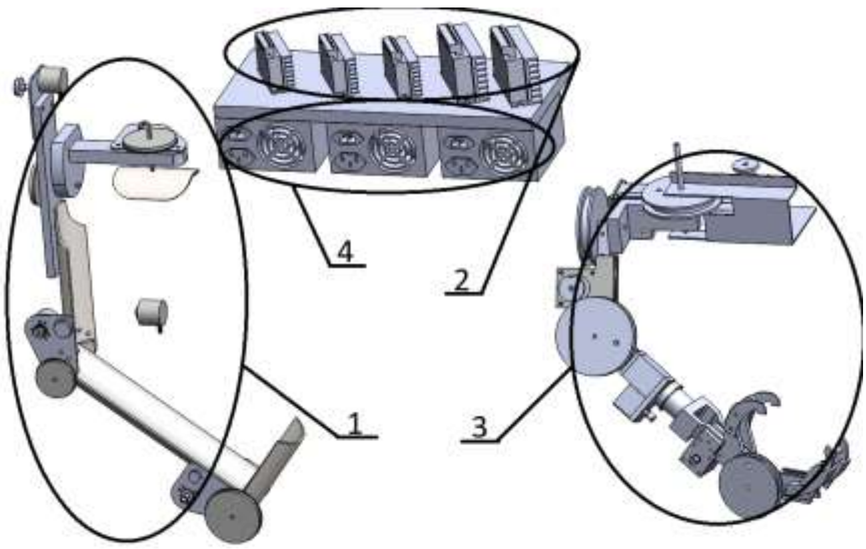


Fig. 7. 3D model of the Avatar robot systems complex version 2.2:
1 – control system, 2 – movement transmission and conversion system,
3 – manipulator robot, 4 – power sources

The general complex of version 2.2 is modeled and consists of the component systems, namely: the control system, the system of transformation and transmission of movements, and the manipulator robot (See Fig. 7).

4. Results and Discussion

After designing of all components of the Avatar robot in the SolidWorks software, we moved to the next stage - manufacturing.

We installed all the necessary drivers on the motion conversion and transmission system and created a convenient design. We also attached power sources to it. General view of this system is shown on Figure 8.

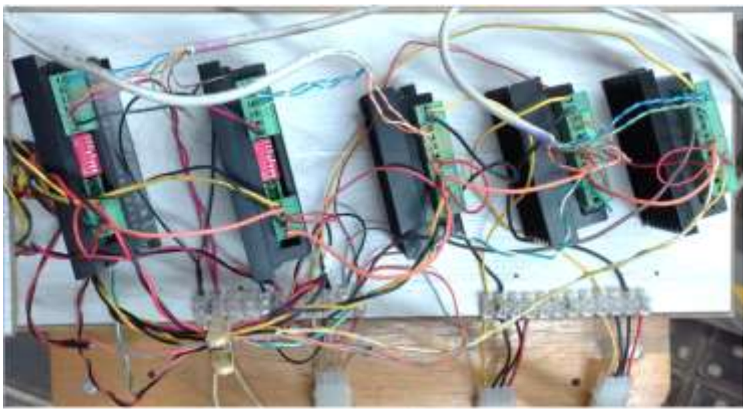


Fig. 8. Movement transmission and conversion system (version 2.2)

As for the control system, one more encoder was added (in comparison with older versions). And it was decided that it will not be fixed on the "glove", but it should be controlled by the free hand of the human operator (See Fig. 9). The weight of the control system, the "glove" is 1.8 kg.

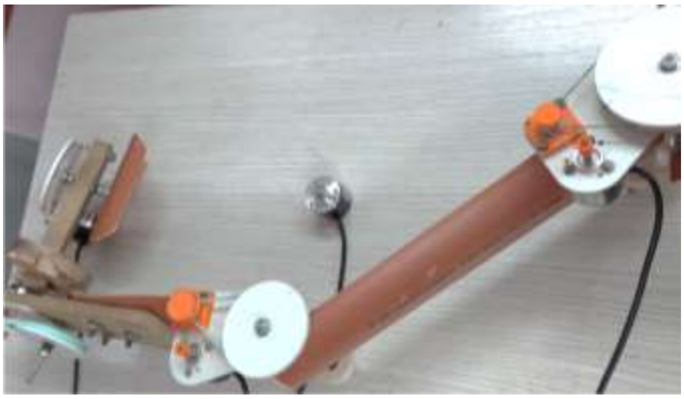


Fig. 9. Control system (version 2.2)

Next, we started improving the systems of robot-manipulator. For this, it was necessary to change the structure of the forearm (in comparison with older versions), while adding and fixing a stepper motor. Figure 10 shows the finished real model of the robot arm.

Fig. 10. Manipulator robot (version 2.2)

In general, the arm of the manipulator robot and its base weigh 8 kg, and the maximum distance of grasping the object with the hand is 60 cm. The arm of the robot is as long as a human arm, so that the movements can accurately correspond to reality. We made the orange parts of the robot on a 3D printer [12-13].

It is worth noting that the robot can work at the distance necessary to perform tasks (experimental distance was 10 m), where electric current and signals pass through wires. This choice was made for several positive reasons:

- during consultation with sapper specialists regarding the design of the mobile manipulator robot, a wired method of power transmission and control was chosen. A number of types of demining work already require the transportation of explosives to the hazardous work area, which are triggered by a signal sent via a cable;

- in case of possible damage to the robot during work, it can be pulled manually to a safe place by the cable;

- since the power transmission is via a cable, there is no need to have expensive batteries on board of mobile manipulator robot;

- again, since the transmission of control signals is via a cable, there is no need to place expensive control boards on the mobile platform.

Although there are certain disadvantages:

- the cable can get tangled, and therefore, of course, it would be appropriate to use wireless communication (5G, long-range WiFi …);

- it is necessary to design and manufacture a special cable unwinding and winding system.

Also, the structure of the robot's fingers was changed to a more functional one, namely, so-called "teeth" were added to make it easier to grasp objects.

It was in this way that the working set of Avatar robot systems version 2.2 was made.

In order to check the functionality of systems, the Avatar was given a task, which it successfully coped with. In order to see a video how the robot performs the task, you need to follow the QR code shown on Figure 11 A.

A human operator controls the robot at a distance of 10 meters. A camera is fixed above the robot, which transmits the image to a large screen located near the operator.

The task is to grab an object with the robot's hand, namely a plastic bar and throw it into a cylindrical storage.

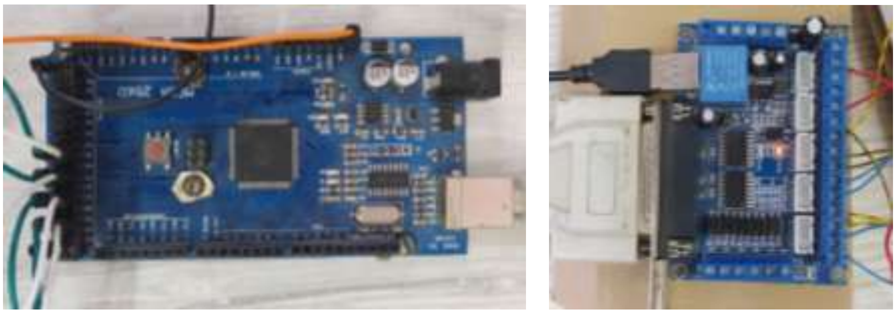
A video was also recorded demonstrating movements and scrolling that the manipulator robot can perform (See Fig. 11 B, C).

A) B) C) D)

Fig. 11. QR code links: A) to a video of the Avatar robot test, version 2.2 and to video of an overview of all movements of the robot Avatar: B) - general video, C) demonstration of the movements of the robot arm; D) robot "training mode" & testing video

As you can see in the video, the robot copies all the movements made by the human operator wearing the "glove". We determined that the robot can lift objects weighing 1.5 kg with an outstretched arm (in comparison of older versions) (the increase in the power of the motors is due to the use of a 36V and 9.7A power supply unit). But if only weaker motors, namely fingers, are involved, then the robot can lift 0.5 kg.

While conducting experiments on the robot Avatar, the idea arose to try to record certain combinations of movements of the control system coming from the encoders to the stepper motors on the manipulator robot. For the experiment, we used two boards, namely Arduino Mega 2560 (See Fig. 12 A), [14] and 5-coordinate interface board BL-Mach-V1.1 (See Fig. 12 B) [15].



A) B)

Fig. 12. Boards: Arduino Mega 2560 (A), BL-Mach-V1.1 (B)

The human operator wears the control system on his own arm and performs a certain sequence of actions that he needs. At this time, the robot repeats these movements, but at the same time, the signals from the encoders on the control system are recorded in the computer memory through the Arduino Mega 2560 board. The board reads the pulses of the encoders, using the software code that is loaded into the controller above the mentioned board. The obtained data were converted into G-code for Mach3 software [16-17].

After running the code, the manipulator robot performed all the previously assigned movements, but without human intervention and the control system. Figure 11 D shows the QR code of the link to a video of this robot "training mode" and testing of the manipulator robot. According to the results of the experiment, we understood that many such combinations can be recorded. Now the human operator has a choice: to control the robot directly, using the control system, or with the help of previously learned combinations.

5. Conclusions

Remote manipulator robots should be used for work in dangerous and extreme conditions. In Ukraine, there is a need for such devices for demining territories. Designed us Avatar robot was developed primarily for such purposes.

During the design, additional requirements for the device that will work in the field conditions are taken into account: reliability, ease of manufacture and repair (possibility of functioning without the use of computer technologies), availability of materials and components.

Stages of the evolution of the design and manufacture of the Avatar complex:

- in version 1.0, a robot model was designed and created from available materials, namely plywood, and a number of tasks were given to it, which it successfully coped with.

- in version 2.0, a new robot was created and manufactured from plastic multi-walled pipes, pulleys and belts. On the manipulator for experiments, the axis of rotation of the shoulder was rotated by 90° (relative to the axis of rotation of version 1.0).

- in version 2.1, in addition to Robot Avatar, a digital clone of Robot Avatar was designed and created, which in reality worked similarly to the digital 3D model. Added a feedback system. When the robot touches an object, the operator, whose arm is in the control system, feels it due to vibration. It was also given a strength test where a robot lifted 1 kilogram on an outstretched arm. On the manipulator, the axis of rotation of the shoulder is returned to the position it was in version 1.0.

- in version 2.2, the working distance of the manipulator robot was extended to 10 meters (experimentally tested), but this distance can be extended to the required (60 meters). Added a fifth axis of hand rotation on the robot manipulator, an additional encoder to the “glove” control system, and another driver. After carrying out experiments, we found that the mass that the robot can lift with an outstretched arm is 1.5 kilograms. A method of "learning" a manipulator robot using an Arduino Mega 2560 board and reproducing movements without an operator using the BL-Mach-V1.1 interface board through the MACH3 software was discovered and applied.

It worth noting that all adjustments of electronic components (stepper motors, driver TB6600, driver DM556, encoders, control boards …) can be made using information from datasheets of that specific components.

All mechanical parts were designed by us in the "SolidWorks" software. A number of parts were printed on a 3D printer, plywood and plastic elements of the manipulator were made on a CNC milling machine.

For the practical involvement of the robot in performing dangerous work (for example, demining), the manipulator robot must be made mobile, that is, placed on a wheeled robotic platform.

The plans for further work also include the design and manufacture of various devices for the manipulator's limb to expand its functionality. Such devices can be special scissors, a "drill" type devices for unscrewing or twisting objects, a burner for thermal impact on the object that needs to be worked with.

The manipulator robot developed and manufactured by us can be used not only for handling dangerous objects. It can be delivered to hard-to-reach places (high-rise buildings, mines) using robotic platforms or drones to perform remote tasks. In this case, wireless transmission of control signals to stepper motors should be provided.

Upon successful approval of the above plans, which will be implemented later, it is needed to design of Avatar robot with two manipulators, which will further expand the functionality of the development.

Also, in order to ensure high power characteristics of the manipulator, it is planned to develop and manufacture cycloidal gearboxes, which will be mounted on the motors of the robot arm.

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