



BULGARIAN ACADEMY OF SCIENCES
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TECHNOLOGIES

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MULTIPURPOSE TELE-OPERATED SERVICE ROBOT

ABSTRACT

of a

DISSERTATION

for acquisition the educational and scientific degree "doctor"

by scientific specialty "Application of the principles and methods of
cybernetics in various fields of science"

Professionally direction: 5.2. "Electrical engineering, Electronics and
Automation"

Scientific supervisor: **Prof. Dr. Nayden Shivarov**

Sofia, 2024.

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The dissertation consists of 142 pages, including 132 figures and literature with 94 titles.

The defense of the dissertation will take place on 2024 from hours in Hall of Unit 2 of IICT-BAS at an open meeting of a scientific jury consisting of:

- 1.
- 2.
- 3.
- 4.
- 5.

Reserve members:

- 1.
- 2.

The materials for the protection are available to those interested in room 215 of IICT-BAS, ul. "Acad. G. Bonchev", bl. 25A.

Author: ***Petko Ivanov Stoev***

Title: ***MULTIPURPOSE TELE-OPERATED SERVICE ROBOT***

Relevance of the dissertation topic

Robotics and, in particular, service robots are an important part of strategic policies and documents for the development of the technological sector: "Society 5.0", "Industry 4.0", "Industry 5.0", PROGRAM 2030 of the United Nations, Strategic Program of the European Commission for the period 2019-2024, "2030 Digital Compass: Europe's Path to the Digital Decade", "European Digital Strategy", "Europe Fit for the Digital Age", Horizon Europe Programme, European Green Deal, EU Circular Economy Action Plan. Their development and implementation is a major factor in advancing technology, improving safety, increasing efficiency, and addressing important societal, economic, and environmental challenges. As a rapidly developing field, multi-purpose tele-operated service robots will have an increasing presence and play an increasingly important role in the modern world.

Purpose and tasks of the dissertation

The aim of the dissertation is the development of a multi-purpose tele-operated service robot, designed to assist people in their work related to patrolling, monitoring, guarding and signaling objects, cleaning and sanitizing premises, lifting and carrying loads, distribution of medicines, transportation and storage of products, performing manipulation operations with elements.

The development addresses the following problem areas of multipurpose service robots: mechanical design, sensor system, industrial design and ergonomics, actuators and actuators, communication and telecontrol, human-robot interaction.

The achievement of the set goal is related to the implementation of the following specific tasks:

1. Getting to know the main characteristics and specific features of tele-operated service robots
2. Designing the main components of the mechanical design of the robot:
 - Universal mobile platform
 - Module with lifting platform
 - Rotary table module
 - Cleaning module
 - Scissor lift module
 - Niryo anthropomorphic robot module
3. Choice of drive, actuators and sensor system of the robot
4. Development of industrial design of the robot
5. Development of remote control of the tele-controlled multifunctional mobile robotic platform
6. Creating robot operating modes
 - Development of control algorithms
 - Compilation and implementation of computer simulations and verification of control algorithms

PUBLICATIONS OF THE PHD STUDENT ON THE THEME OF THE DISSERTATION

At international conferences abroad:

Stoev, P., Chikurtev, D., Stefanov, T., Dimitrov, D. & Vitanova, D. (**2023**). Remote Control of a Teleoperated Multi-Purpose Mobile Robot Platform Using a Web-Based Graphical Interface, via MQTT and Web Sockets. The 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME) 2023

Stoev, P. , Yovchev S., Chikurtev, D., Chivarov, N. Development of a Teleoperated Mobile Robot with Module for Cleaning Animal Husbandry Complexes. TechSys **2022** , Accepted for publishing

Nayden Chivarov, Denis Chikurtev, Petko Stoev, Vasil Lozanov, Stefan Chivarov. ROBCO Drone - Service Robot for Transport and Delivery of Grocery Products, 7th International Conference on Engineering and Emerging Technologies **2021** – ISTANBUL – TURKEY

At international conferences in our country:

Stoev, P. Development of a Lifting Module of a Mobile Robot for Warehouses. ADP **2022** , Pages 259-261, ISSN: 2682-9584

Vasil Lozanov, Nayden Shivarov, Denis Chikurtev, Stefan Shivarov, Petko Stoev. Industrial design of service warehouse robot "ROBKO", Annual international scientific conference of BAFA "Georgi Benkovski" **2021**

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INTRODUCTION

The multi-purpose tele-controlled service robot is a versatile robotic system designed to perform a wide range of tasks and services in different fields and areas through human-to-operator remote control.

This dissertation discusses fundamental problems related to mechanics, industrial design, ergonomics, mechanical compatibility and telecontrol of multipurpose tele-controlled mobile robots. The development of a multi-purpose tele-controlled service robot is presented, through which can be carried out, monitoring, security and signaling of objects, cleaning and sanitation of premises, lifting and carrying cargo, distribution of medicines, transportation and storage of products, performing manipulation operations.

The present dissertation work is structured as follows:

CHAPTER 1: The main aspects of the mechanics and design of multi-purpose tele-controlled service robots are discussed, including the specific features and systems of service robots, mechanical compatibility and mechanical systems for their movement, the design and ergonomics of robots, communication in service tele-controlled robots. The specificity of human-robot interaction in the context of multi-purpose tele-guided service robots is indicated.

CHAPTER 2: In Chapter Two, the design of the developed multi-purpose tele-controlled service robot is presented. The mechanical system of the robot, its actuator and actuators, its sensor system and the realized design are described in detail.

CHAPTER 3: Chapter Three presents the control of the multi-purpose robot, and for each mode and selected module are developed by the doctoral student algorithm of operation, software and hardware control. The remote control of the teleoperated multifunctional mobile robot-platform is considered. Simulations were conducted in a computer environment, on the basis of which the control algorithms were verified.

CHAPTER I: THEORETICAL OVERVIEW

1.3 Main features of multipurpose robots

A key feature of multi-purpose robots is their modular design, which enables users to easily add or remove components. This modularity allows the robot to be customized for specific tasks and makes the implementation of improvements or adaptations easier. Multi-purpose robots are equipped with a variety of handling elements, such as robotic arms with multiple degrees of freedom and adaptive grippers. Through this flexibility, they can handle different objects and perform a variety of tasks. Depending on the applications envisaged, multi-purpose robots may have different mobility systems. The choice of mobility depends on the terrain and the tasks that the robot will face. Multi-purpose robots include a variety of sensors for perception, navigation and interaction with the environment. Safety is paramount, especially when robots work alongside humans. Advanced algorithms for navigation,

obstacle avoidance and decision making contribute to their autonomy. Energy-efficient components, power management systems and battery technologies are integrated into mobile robots to optimize the robot's energy consumption. Multi-purpose teleoperated robots have advanced communication capabilities, including Wi-Fi, cellular and satellite connectivity, to achieve remote monitoring, control and data transmission. A new aspect related to the design of robots and in particular multi-purpose teleoperated robots is the integration of AI in order to improve their adaptability and decision-making capabilities. AI allows robots to learn from experience and improve their performance over time.

1.5 Mechanical compatibility

Mechanical compatibility is an essential aspect in the design of modular robots. It refers to the compatibility between the mechanical parts of the robot and the modules that attach or remove. Mechanical compatibility includes dimensional compatibility, strength and load-bearing capacity, standardized interfaces, service.

1.7 Design, ergonomics and regulatory requirements

As a mediator, design plays an essential role in building successful human-robot communication. It represents that specific link without which the perception, and hence the approach of man to the robot, would be different. Robot design is a responsible task, with numerous parameters to be tailored taking into account the environment in which the robot will be placed in order for human-robot communication to be carried out correctly. To unify and lay the foundations of standardization in the design of robots, ergonomic requirements, psychological aspects of shapes and colors, their psychophysiological impact and the emotions and actions of the user generated on this basis are considered.

1.9 Tele-control of service robots

Through telecontrol, service robots are expanding their implementation environments and the functionalities they can have. In the context of service robots, tele-control refers to the remote control of robot movements and actions by operator-human using a control interface. There is a wide range of remote control and guidance methods for robots, each method having its own specific advantages and challenges, contributing to the diverse range of telecontrol options.

1.10 Human-Robot Interaction in the Context of Multi-Purpose Tele-Operated Service Robots

Human-robot interaction is a multidisciplinary field whose goal is to achieve safe, productive and seamless collaboration between humans and robots. In the context of multi-purpose tele-operated service robots, the main directions for achieving effective human-robot interaction are related to the design of intuitive control interfaces that are convenient for the operator and require minimal effort; reducing the operator's cognitive load by introducing shared control modes where the robot autonomously assists in navigation and obstacle avoidance; providing real-time feedback to operators, including live video images from the robot's cameras, sensor data and status updates, haptic feedbacks; implementing safety mechanisms, including emergency stop buttons and obstacle detection systems, to ensure the safety of both the operator and the robot; implementation of encryption and access control, especially in cases where the robot captures sensitive data or works in a special environment; responsible use of robots in the context of ethical aspects of human-robot interaction, such as robot behavior, decision-making, and accountability.

CHAPTER II: DESIGN OF A MULTIPURPOSE TELE-OPERATED SERVICE ROBOT

2.1 Mechanical design

2.1.1 Universal mobile platform of the multi-purpose robot

The developed platform (Fig. 12) aims to enable the easy installation of additional modules that placed on the robot to allow the execution of specific tasks in different environments and to expand its functional capabilities. Depending on the module that connects to the platform, it can be with two, three or four plates. They are made of high density polyethylene (HDPE). The thickness of each of the plates is 9.5 mm and the end points for each plate describe a circle of 450 mm diameter. Each of the plates is fixed to the next plate by means of a group of four rods, 12.5 mm in diameter on each of the rods.



Fig.12 3D image of the designed mobile robotic platform

The distance the bars provide between the plates is as follows: 152 mm between the first and second and 127.5 mm between the second and third, the plates being numbered in order starting from the surface on which the robot is placed. Below the first plate is an additional plate measuring 336.6 mm x 177.8 mm with a thickness of 9.5 mm. The distance between the additional plate and the first plate is 78 mm measured from the bottom surface.

The height measured from the surface on which the robot is placed to the top of the first plate is 106 mm. In the first and second plate, an incision measuring 165 mm x 38 mm is made externally, tangentially to each of the plates. The cut in the first plate is used to place the drive wheels in an additional smaller plate attached under the first plate, on which the electric motors of the driving wheels are mounted, as well as the drive battery.

The platform is equipped with four wheels for moving the robot: two differentially driven wheels with a diameter of 155 mm and two auxiliary wheels located at the front and rear ends, with a diameter of 76 mm. The wheels are attached to an axle with a diameter of 12.75 mm. The constructed platform has a differential drive, which makes it possible to control the movements of the robot by adjusting the rotational speed of both wheels. The two driving wheels, as well as the battery that powers them, and the auxiliary wheels are attached under the first plate. The drive wheels are driven by two brush motors of 96 W each, with worm gear, operating at a voltage of 12V, equipped with 36-position encoders. The motor assembly generates approximately 85 inches/Lbs of torque. A chamber and a LIDAR are mounted on the upper plate, through which the telecontrol is carried out. Additional obstacle detection sensors are placed on the bottom plate.

2.1.2 Multi-Purpose Robot Modules

2.1.2.1 Lifting platform module

Through this module, the robot can deliver and store goods in shops and warehouses. For the purpose of lifting packed supplies, a 4th plate is added to the top plate of the mobile robotic platform. The fourth plate is mounted on four linear motors through 8 L-shaped profiles - 2 for each linear motor. The linear actuators are connected to the 3rd platform of the robot using specially designed slots, which are fixed on the 3rd platform by means of bolts. The dimensions of the slot designed for the linear actuator are 80mm x 46mm x 45mm (length/width/height). An additional build was made from the slot to the 3rd plate, concentric to the plate, for further stability of the slot. A channel of 18.4 mm width and 18 mm height was designed in which the lower part of the actuator was inserted, as well as a hole at the bottom of the 12.5 mm diameter slot used for attachment to the 3rd plate by means of a bolted connection. On both sides of the slot, holes measuring 6 mm are designed and are used to fix the linear actuator in place. In addition, an incision measuring 40mm x 12mm is made at the rear of the slot, through which the power cord of the actuators passes.



Fig.13 The designed slots for the linear actuators



Fig.14 Actuator of the lifting platform

The linear actuator used in the development is 12 volts with 90 kg maximum load capacity. The actuator uses a potentiometer for feedback. The dimensions of the actuator [81] in the retracted condition are 75 x 40 x 258. The stroke of the actuator is 100 mm. At the bottom and top are designed 6 mm holes through which it is fastened. L-shaped profiles for attaching the actuator to the 4th plate are 20mm x 20mm x 25mm with a wall thickness of 2 mm.

2.1.2.2 Rotary table module

The rotary table consists of two common parts - a main body in which the control and drive components are placed and a rotary disc with slits for storing and transporting products. The designed module is fastened to the robot by a frame which is mounted to the top plate. The frame design consists of two pairs of components for easier installation to the main body of the rotating table. The main body has dimensions 177mm x 177mm x 65mm / width x length x height /. The thickness of the sheet metal used is 2 mm. Attached to its bottom, located 6 mm from each of 4 rubber feet with a diameter of 20 mm and a height of 11 mm for additional stability.

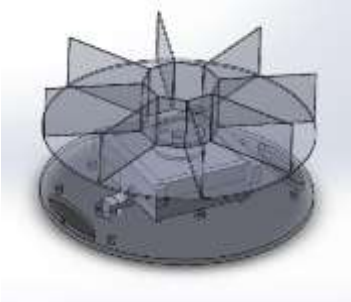


Fig.15 The rotary table and the way of mounting to the robot plate

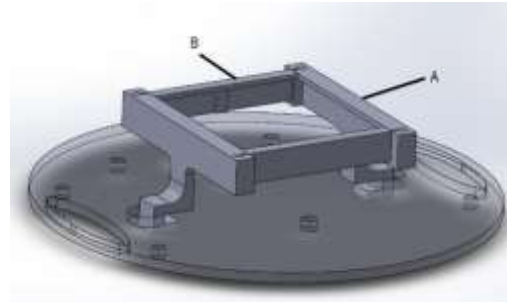


Fig.16 The frame for fixing the the rotary table- details A and B

Between the main body and the rotating disc the gear for rotational movement is located externally, with large and small gears having respective diameters of 85 mm and 13 mm. The distance between the bottom of the rotating disc and the top of the main body is 35 mm. The diameter of the rotating disc is 450 mm. In the center of the rotating disc is placed a regular octagon with a side of 50 mm. Each of the 8 slots, located 45 degrees apart, has an external arch length of 225 mm and a length measured from the center of the arch to the corresponding side of the octagon of 164.6 mm. The slots are also made of sheet metal with a sheet thickness of 1.5 mm. The height of each slot is 90 mm.

The frame for mounting the rotary table to the top plate of the robot was built using a 3D printer. It consists of two pairs of identical elements: part A and part B, which slide into each other. Part A has a U-shaped profile. The frame fixing the rotary table is attached to the top plate of the mobile robot by means of the two U-shaped profiles, the inner sides of which are tangential to the holes into which they enter. Part B enters the specially designed channels of part A, thus tightening the opposite parts and assembling the frame. Detail A is a combination of a T-shaped profile that is placed in the main body of the rotary table and a U-shaped profile for attachment to the upper plate. The T-shaped part has the following dimensions: 213mm x 20mm x 35mm. The thickness of the profile is 5 mm. The U-shaped part has a radius of 17.5 mm in the part, tangent to the hole and a total width of 28.5 mm. The frame assembly channels are 15mm x 6.5mm.

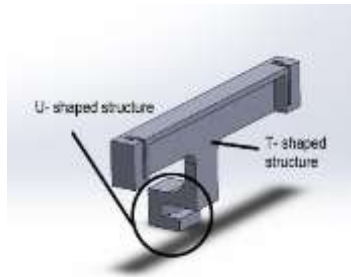


Fig.17 Detail A

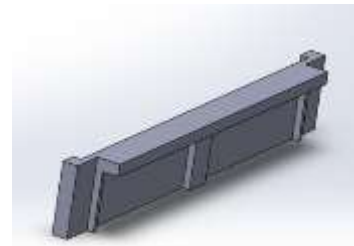


Fig.18 Detail B

Detail B has the following dimensions, described by its end points: 187 x 16,5 x 30 mm /length x width x height/. Three additional ribs are designed on the inside of the workpiece to further support the horizontal fixation of the rotary table. The thickness of the part profile is 3 mm, and for the ribbed parts with additional support it is 6 mm.

By designing such a 3D printed frame, in both cases of its operation and robot movement, the desired stability and fixing of the rotary table is achieved.

2.1.2.3 Cleaning module

The cleaning module consists of several separate systems that can operate simultaneously or independently. The first system is a combination of two identical rotating brushes [84] connected by a mechanism which allows them to be lowered or raised depending on whether the robot is only moving or in the sweep mode. A second auxiliary system is a combination of a portable tank with a tank pump which, if necessary, discharges detergent or water through nozzles [85][86] located in front of the rotating brushes. The other subsystem that contributes to the sanitation process is an adjustable rubber brush that, like rotating brushes, moves vertically using a linear actuator, and a second UV lamp is mounted to the tank, at the rear of the robot.

The mechanical system with rotating brushes (Fig. 19) is designed to provide contact with the surface, which is cleaned at any time when it is active and the robot performs the sanitation process. At the lowest position, when the brushes are active, the design provides sufficient pressure to carry out the technological procedure.

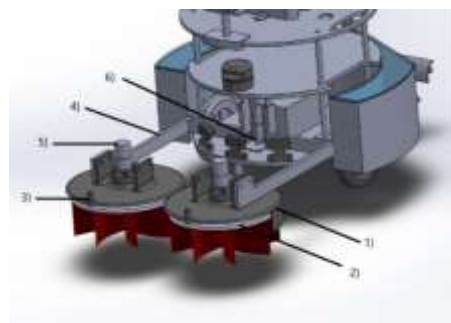


Fig.19 1- brush cover, 2- cleaning disc, 3- nozzle for detergent, 4- Structure of lifting arms, 5- electric motor, 6- linear actuator

The activation of the detergent discharge system is carried out by an operator and is determined by the type of room being sanitized. Feedback in this case is based on the telecontrol of the robot and the mounted camera. On the top plate, the robot is equipped with an antibacterial UV lamp to remove various pathogens in the environment, which is not in contact with the brushes of the developed module. An adjustable rubber brush, which, like the rotating brushes, moves vertically using a linear actuator, and a second UV lamp are mounted to the tank, at the back of the robot. The rubber brush is used to push the used detergent from the surface cleaned with rotating brushes. The additional second UV lamp is directed directly to the surface of the floor, which the robot cleans, using as the last technological operation in the cleaning process.

The rotary brush system consists of the following few components. The first component is the cleaning disc with a diameter of 250 mm. On it is placed the brush cover with a diameter of 270 mm. From the brush cover, a semicircle with a height of 55 mm is extruded, which is facing the mobile robot to protect the robot from contamination during operation of the rotary brush. A nozzle is designed at the front end of the lid, through which, if necessary, the detergent is discharged from the tank. In the center of the bonnet are the electric motor and the plates for attaching the brushes to the lifting arms. A 12V with a speed reducer with a power of 150 rpm was chosen for the electric motor. The lifting and lowering of the brush is carried out by means of two lifting arms connected by a lever forming a rocker, fastened to a linear actuator. The actuator is fixed with a holder and placed between the sensors and the battery of the first platform.

When cleaning with brushes, their direction of rotation is determined by which side of the robot is closer to a wall of the room. Cleaning is carried out from the near to the far wall, that is, the brushes push the waste to the side, after which the robot moves in the opposite direction and the rotation of the brushes changes. This continues until it reaches the other end of the room. The principle is illustrated in Figure 20.

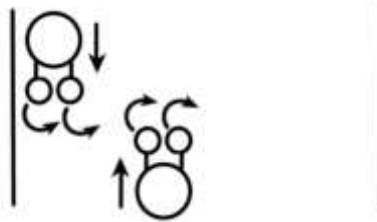


Fig.20 Principle of rotation of the cleaning brushes and the robot movement in the room subjected to a cleaning procedure

During the design of the module, the brushes are designed for use on hard surfaces. The movement of the robot in the premises of the complex and the implementation of the technological operations of the hygiene module are carried out both on the basis of internal navigation and telecontrol.

The second system of the hygiene module consists of a detergent tank and a tank pump, which are activated if necessary. The tank pump selected is 12V with a maximum flow rate of 5 l/min, which is mounted on the third plate. The detergent tank is placed on the bottom plate. Attaches to the mobile robot through 4 plates with holes that enter the rods between the first and second plate.

The rotary brush system consists of the following few components. The first component is the disc with the cleaning feathers. The disc has a diameter of 250mm and 5mm thickness of the plate, the total height is 105mm. In the center of the disc is an extruded bushing with a diameter of 9 mm and a height of 15, which is mounted to the flange transmitting the rotational movement from the electric motor by means of two bolts M3 passing transversely through the assembly (Fig. 22).

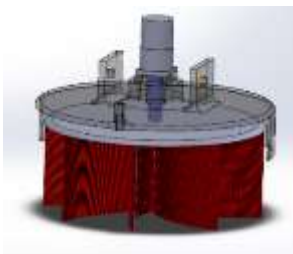


Fig.21 Rotary brush assembly

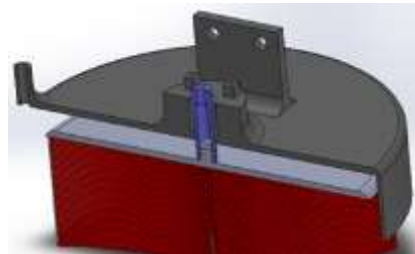


Fig.22 Rotary brush section cut

The flange connecting the brush with the electric lifter has a length of 55 mm. The small diameter is 15mm, and the large one, which rests on a bearing and covers it as a cover with a diameter of 21mm. The part that is on the bearing is 4 mm thick. For bearing, a needle bearing with an internal diameter of 15 mm, an outer diameter of 21 mm and a thickness of 22 mm is selected, which is placed in a socket designed for this purpose contained in the structure of the cover. The brush cover has a diameter of 270 mm and a thickness of 5 mm. The semicircle of the lid with a length of 55 mm, which faces the mobile

robot, has been extruded in order to protect the robot from contamination when working with the rotary brush. In the center of the lid there is a cylindrical body with an outer and inner diameter of 60 and 21 mm respectively, and a height of 26 mm. To the upper surface of the cylindrical body are constructed 4 sockets measuring 8mm x 8mm x 9mm. In the sockets are placed holes with a length of 30 mm for bolts M3, through which the electric motor is installed. A 12V with a 150 rpm reducer was chosen for electric motor [87]. The attachment of the rotary brushes to the lifting arm is carried out by plates measuring 60 mm x 65 mm x 7,5 mm, 115 mm apart, which contain holes with a diameter of 10 mm. Depending on whether the rotary brush is clamped on the left or right side, the corresponding fastening plate is used.



Fig.23 Side view of the robot with the rotary brush

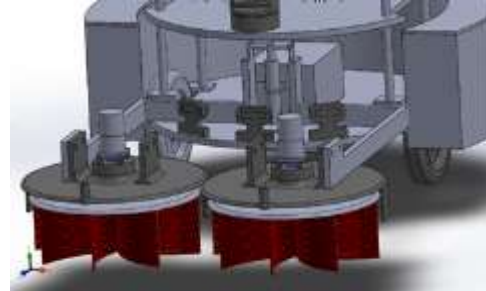


Fig.24 Assembly of a module with rotary brushes lowered, mounted to the lifting mechanism

The lifting and lowering of the brush is carried out by means of two lifting arms (Fig. 23.), connected by a lever forming a rocker, clamped to a linear actuator. The actuator[88] was fixed by means of a specially designed plate holder (Fig.25), being placed between the sensors and the battery on the first platform. The arms are made of 30mm x 10mm x 1.5mm profiles. The arms are fastened to linear plugging bearings, which are mounted to the front two rods (Fig. 24). In order for the brush to make contact with the cleaning surface, it is necessary that the piston of the linear actuator reaches the extreme lower position. In this position, the actuator is 113.5 mm from the plate from the hole in the piston. When lifting in the extreme upper position of the piston, a 30 mm stroke is set. This provides enough space for the robot to move without attaching the brush blades when the cleaning mode is not active.

An auxiliary system was added to the cleaning rotary brush by means of a pump [89] and a tank to be switched on if necessary (Fig.26a and Fig.26b). 12V was chosen as the pump with a maximum flow rate of 5l/min. The pump is mounted on the third plate by means of 4 M3 bolts. The water tank has an inner side cocentric and equal to the plates of the mobile robot, with the end points describing a circle with a diameter of 600 mm.



Fig.25 Holder for linear actuator

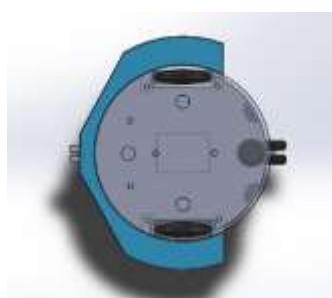


Fig.26a. Water tank, mounted to the robot platform

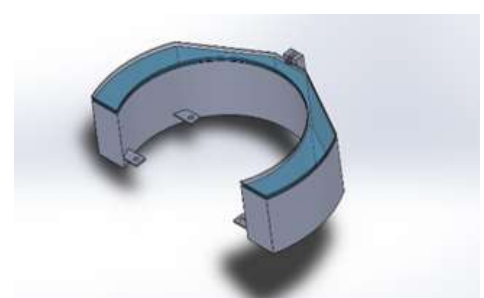


Fig.26b. Water tank

The height of the tank is 170 mm and 30 mm from the base are welded 4 plates with holes that enter the bars between the first and second plates and thus attach it to the entire mobile platform. At the rear, the tank has an element through which the lid of the tank is attached.

2.1.2.4 Scissors lift module

The hoist is made of two frame structures - frame A and B, with identical external dimensions and profiles that make them up, and the other components of the overall assembly are fixed to them. The

profiles used for the outer frames are 20mm x30mm x2mm. The frames measure 400mm x 240mm and their corners are beveled in order for the frame to be as close as possible along the contour of the robot plate. In the folded position, the loader is 60 mm high from the robot platform to which it is mounted, and in the maximum raised almost 172 mm. Frame A is attached to the upper plate of the mobile robot by means of 4 L-shaped profiles measuring 25x 35 x 3, each of the 4 profiles being clamped with 3 bolts M6.

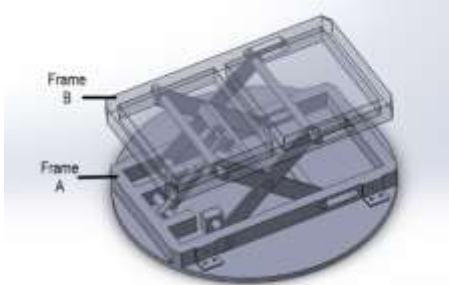


Fig.27 Assembly of the scissors lift

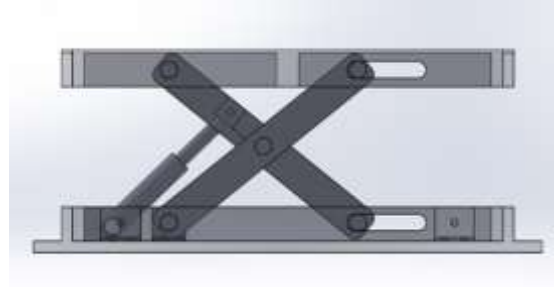


Fig.28 Front view of the mechanism with components of the scissors lift

Identical for both frames at one end of each of them in the profiles are milled grooves, which accommodate the bearing bodies and axles for which the corresponding two sliding arms are clamped for lifting frame B, and at the other end holes with a diameter of 15 mm are drilled. The length of the milled channel is 70mm, in which a needle bearing with an outer and inner diameter of 21mm and 15mm respectively is impaled. At the other end of frame A, internal to the structure, the linear actuator [90] is clamped. The actuator piston has a diameter of 12 mm and a stroke of 100 mm. The linear actuator is attached to two profiles - 20mm x 30mm with a length of 50mm, the center of grip being 13mm from the robot plate i.e. under the central axis of the profiles to ensure a larger bevel when the scissors are retracted. An additional profile is welded to frame B transversely in the middle to increase the strength and strength of the structure when lifting loads. In the upper part on frame B is welded sheet material with the same shape and thickness of the sheet 3 mm, on which to be laid the different products. The lifting arms measure 235mm x 30mm x 4mm with R8 edge rounding. In each of the arms are drilled 3 holes with a diameter of 15 mm - one central and two at each of the ends at a distance of 214.80 mm from each other. To two of the arms is welded profile 20mm x 20mm, to which the piston of the linear actuator is attached. Weight sensors [74] are placed on the upper surface in contact with the products raised by the robot to protect the mobile robot from overloading

2.1.2.5 Module with anthropomorphic robot Niryo

For the purpose of the developed service robot the anthropomorphic robot Niryo One [92] was chosen with the following specification: 6-axis robot with six degrees of freedom. The dimensions of the lengths of the components constituting the structure are as follows: base - 103 mm, arm - 80 mm, first joint - 210 mm, second joint - 180 mm.



Fig.29 Anthropomorphic robot Niryo One



Fig.30 Robot Postures

The back panel of the Niryo One contains many different physical interfaces:

- Top button;
- LED;
- 4 USB ports;
- GPIO panel (Total 6 digital pins);
- Power adapter connector.
- Switch output 12 V;
- Dynamixel XL-320 connector;
- Dynamixel XL-430 connector;
- Power switch;
- CAN busbar connection for Niryo Steppers;

The robot weighs 3.3 kg. The possible maximum reach with a mounted gripper is up to 440 mm. At the bottom of the Niryo One are placed 4 suction cups and rubber feet, through which it is connected to a specific work surface. The maximum rotation angle for each of the joints is as follows: J1: -175° to 175° , J2: -90° to 36.7° , J3: -80° to 90° , J4: -175° to 175° , J5: -100° to 110° , J6: -147.5° to 147.5° . The location of the joints is shown in Fig. 30.



Fig.31 The fastening principle used to fix Niryo One to the top platform



Fig.32 Niryo One fixing holder

The holder for attaching and providing the extra stability required for the Niryo One is a combination of a U-shaped profile that enters a hole in the upper plate, and an L-shaped profile, the upper part of which is corradial and in contact with the base at joint J1, thus fixing the robot in a stable position. The holder is mounted to the plate through its U-shaped part, which is clamped with M5 using the vise principle. The dimensions of the U-shaped part are 23.5 mm x 25 mm / width x length / and thickness 7 mm. The L-shaped profile has the following dimensions: 71mm x 32mm x 22.5mm / height x length x width / and 7mm thickness. The designed holder in combination with the suction cups and rubber feet of the anthropomorphic robot ensures the necessary stability during operation.

2.2 Movement and power-driven mechanisms

The mobile robotic platform chosen is of the differential control type [49]. This type of platform has two motors located on the left and right sides, which drive independently of each other the two side wheels. To achieve stability of the platform we use two auxiliary wheels at the front and rear. This wheel arrangement allows rotation in place, but on uneven surfaces contact between a wheel and the ground may be lost.

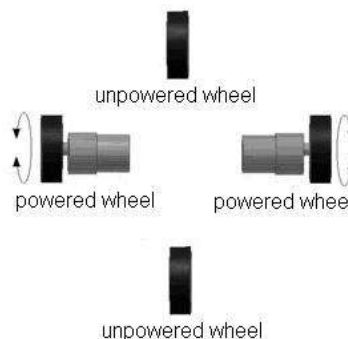


Fig.33 Movement of the mobile robo-platform

- Forward movement of both driven wheels - achieves forward movement of the robot.
- Movement of the two driven wheels back - achieves movement of the robot backwards.
- Movement of one wheel forward and the other backward - achieves rotation of the robot in a small

circle, the center of which is located between the two driven wheels.

- Movement of one wheel slower than the other - achieves rotations of the robot in the direction of the slower wheel. How fast it rotates depends on how big the difference between the two speeds is.

The control of a differential mobile platform is complex because coordination and cooperation between two separately driven wheels is required [50].

2.3 Sensor system

Sensor systems are a critically important part of any mobile robot project. They help to perform all the functions of interaction with the environment – monitoring the spatial position and orientation of the robot, maintaining a trajectory, detecting obstacles, safety of the robot and the people working with it. Depending on their main function, the sensors that are used in mobile robots can be divided into several categories: tactile sensors, proximity sensors, acceleration and orientation sensors, laser scanner (LIDAR), visually based systems, wheel encoders, ultrasonic sensors.

2.4 Industrial design of the robot

2.4.1 Fundamental aspects

With a multi-purpose mobile robot, the goal should be the cleanest and neutral design that fits into the working environment of different types of equipment. The structure building the robot's appearance is segmented into separate panels. Compared to the specific segment that makes up the plastic of the design, there are specific accents that correspond to the motor units, sensors and modules of the multi-purpose robot. The graphic lines depicted around the openings of the ultrasonic sensors serve as an accent for their utilitarian placement in the design. At the rear of the structure is positioned a hole with a lid that provides access to the jack for charging the robot as well as for a view of the display showing the percentage of battery charge. In the realization of the vision and construction of the multi-purpose robot, the molds of the plastic are realized in a way that ensures maximum possible protection of the components housed inside from solid and dust particles, which will ensure its proper functioning.

CHAPTER III: CONTROL OF THE MULTI-PURPOSE SERVICE ROBOT

3.1 Tele-operation of the multi-purpose mobile robot platform through a web-based graphical interface, via MQTT and web sockets

3.1.4 Implementation of MQTT over WebSocket in JavaScript

In this development, an interface for controlling a two-wheeled mobile robot with a DC motor using MQTT.js and WebSockets is presented. [45] [70] The interface includes a text box for theme selection, a speed control slider, and four directional control buttons. The theme chosen by the user is the channel through which the interface publishes speed and motion values.



Fig.36 The overall process of communication between the elements



Fig.37 The developed user interface

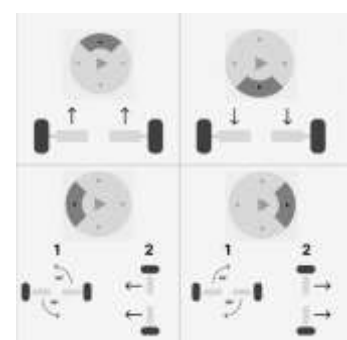


Fig.38 Movement of wheels

The movement speed is set through the JavaScript "Change" event, which takes the value from the slider field and triggers a POST query directed to the "publisher" route. A JSON object is sent that contains the subject name and a message that is an integer value determining the speed. Similarly, the direction of movement is determined by one of four buttons, each of which is indicated by a different

arrow indicating the desired direction. Each button contains a command with a template for the required movement of the engine in the given direction. When one of the buttons is pressed, a POST request is sent to the selected topic during the "MouseDown" event. After the button is released, the "MouseUp" event is triggered, which sends a command to stop the motors, and in response, the device stops moving. Figure 37 illustrates the created user interface for the program. The interface allows users to manage the speed and direction of the robot. The topic chosen by the user is used to publish the speed and movement values. The robot subscribes to the a topic and receives the values sent by the interface. As a message protocol MQTT is used, and WebSockets provides a two-way communication channel between the interface and the robot. Figure 38 illustrates how the engine wheels move depending on the button pressed. Pressing the "up" button causes both wheels to rotate forward, resulting in the robot moving forward. Pressing the "down" button causes both wheels to rotate in the opposite direction, resulting in the robot moving backwards. Pressing the "left" button causes the right wheel to rotate forward, while the left wheel rotates backwards, as a result of which the robot turns left. Conversely, pressing the "right" button causes the left wheel to rotate forward while the right wheel rotates backwards, resulting in the robot turning right [44].

The flow chart (Fig.39) illustrates the main steps related to the control of a mobile robot through the provided interface, including setting a theme, speed regulation, driving direction control, posting values and acting on these values to control the robot wheels. As shown in Figure 40, after starting the robot the controller automatically establishes a connection with the MQTT broker. Once connected, when a subscribed topic message is received from the broker, the specified Callback function is performed.

As a result of the input data received, a command is sent to execute the movement of the engine as needed.

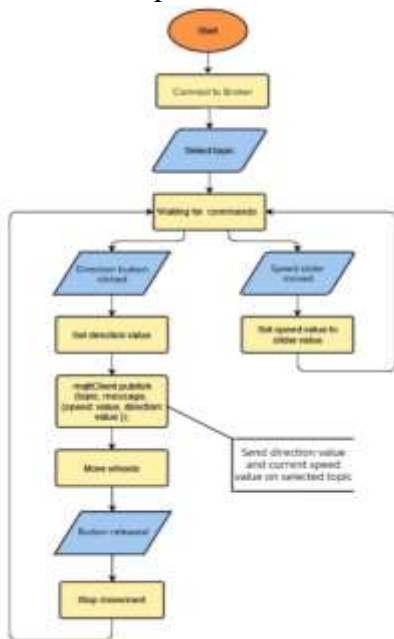


Fig.39 Workflow of the process

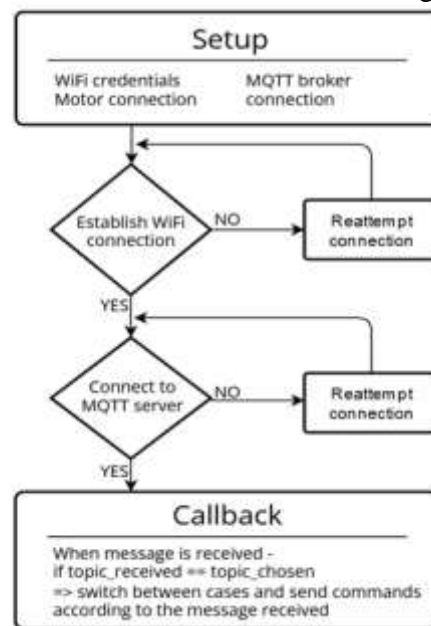


Fig.40 Firmware diagram

Actions such as contacting a broker, subscribing to a topic, and posting messages are saved and displayed in a console. Figure 41 shows the logs for subscribing to a particular topic, pressing the "Forward" button and running it after a few seconds. The time of the action is also displayed.

```

Console:
14:34:24: Connected with MQTT Broker: "ws://192.168.41.129:9001/mqtt"
14:34:41: Subscribed to MQTT Topic: "home/car1"
14:35:07: Published "FORWARD, 50" to MQTT Topic: "home/car1"
14:35:07: MQTT Message Received, Message: "FORWARD, 50" MQTT Topic:
"home/car1" QoS Value: "0"
14:35:21: Published "STOP, 0" to MQTT Topic: "home/car1"
14:35:21: MQTT Message Received, Message: "STOP, 0" MQTT Topic:
"home/car1" QoS Value: "0"

```

Fig. 41. Console Register

3.2 Control of the multi-purpose robot in drug delivery mode

The rotary table is a module that can be mounted to the mobile robot-platform with tele-control (Fig. 42) and is an important component for the distribution of items such as medicines for different patients relative to the given hospital room.



Fig.42 View of the rotation module attached to the mobile robot-platform

3.2.1 Algorithm of robot operation

The robot operating algorithm in drug delivery mode is presented in Figure 43 and includes the following steps:

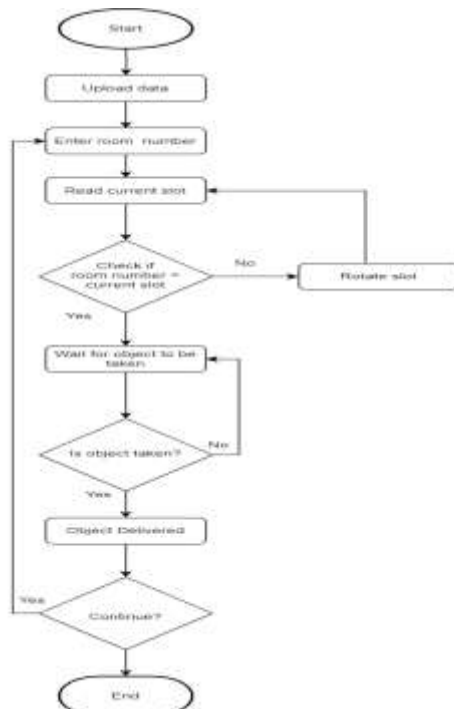


Fig.43 Flowchart of the operation of the module

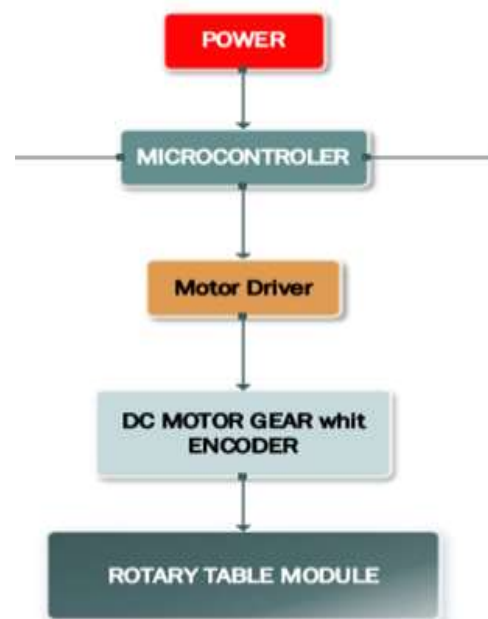


Fig.44 Scheme of the main components of distribution module

- Installation and startup of the module:

After the successful installation of the rotary table to the mobile robot-platform and the power supply, the module control program is started.

- Loading items:

The operator places the drugs or other items to be carried and distributed in the individual slots of the rotary table.

- Select Mode:

The program interface provides a choice of different modes of operation, depending on the objectives of the operation. For example, the operator can choose an automatic mode for the distribution of objects based on preset parameters or a manual mode, where the operator has control over the process.

- Start the work cycle:

After the operator selects the desired mode, he starts the duty cycle by pressing the corresponding button in the program.

- Rotation and distribution:

The way the rotary table works is to rotate until the selected objects in the given slot reach in front of the robot. On the basis of an encoder it is known about the position of the given slot. Through the interface, it is saved in which slot objects for which room and which patient are intended.

- Submission of the items:

The robot moves towards the patient or the place where the objects are to be provided. The rotary table feeds the objects. After the patient takes their pills using the tele-controlled robot's camera, the operator validates that the pills have been taken..

- Repetition of the process:

If there are more slots for the patient after handing over the item, the rotary table continues to rotate and feed the next item until all items assigned to the given room and patient are allocated.

- Completion of the work cycle:

After all subjects have been successfully allocated, the program outputs a message to complete the operation. The operator sets the robot to move to the next location on the basis of semi-autonomous tele-control or directly navigates it via direct tele-control

- Turn off the module:

The operator can disconnect the module after the successful completion of the duty cycle.

3.2.2. Simulations and results of verification of the module and algorithm of operation

The simulation setup aims to verify the management and behavior of the module. The simulation was carried out on the basis of several softwares, through their paralytic and synchronized implementation. In the simulation, the following softwares are bound:

- SolidWorks-CAD: Software used to construct the robot platform and module
- Proteus 8.16: Software for electronic design and automation (EDA/ ECAD). Proteus allows creating circuits, designing printed circuit boards, etc. It is used in this simulation by providing powerful functionality when simulating microcontrollers by applying hex files to already built circuits.
- Arduino IDE: Environment used to write the code illustrating the algorithm
- HHD Software's Virtual Serial Port Tools: It is a comprehensive set of software tools designed to manage and emulate virtual serial ports. Virtual serial port tools can create virtual serial devices and connections that fully emulate the functionality of hardware physical devices.
- Blender 3D: 3D modeling software that allows writing scripts using the Python API. Provides the ability to communicate with Proteus.

The first step is to create the code in the Arduino IDE. In order to be able to realize the simulation in the code, the BlendixSerial.h library is introduced, which allows the communication between the simulation of the hardware in Proteus with the 3D environment of Blender 3D, in which the constructed robot is placed.


```

#include <BlendixSerial.h>
#include <Servo.h>

BlendixSerial blendix;
Servo myservo; // create servo object to control a servo
int timeOn = 50;
int timeOff = 50;
String servoPrompt = "Enter sequence of servo degrees (1-8): ";
bool autonomousMode = false;

void setup() {
  Serial.begin(9600);
  myservo.attach(10);
}

void loop() {
  Serial.println("Enter 1 for Autonomous mode or 0 for Manual mode: ");
  while (Serial.available() == 0) {}
}

int modeInput = Serial.parseInt();

if (modeInput == 1) {
  autonomousMode = true;
  autonomousLoop();
} else if (modeInput == 0) {

```

Fig.45 The BlendixSerial.h library implemented in the IDE created in Arduino

For manual mode, 0 is entered in the Proteus virtual terminal, and for autonomous distribution mode, 1 is entered. Each of the slots that are loaded by the operator in drug distribution corresponds to a specific angle based on the number of slots that are on the rotation disk. Figure 46 illustrates the value of the angle corresponding to the specific slot.

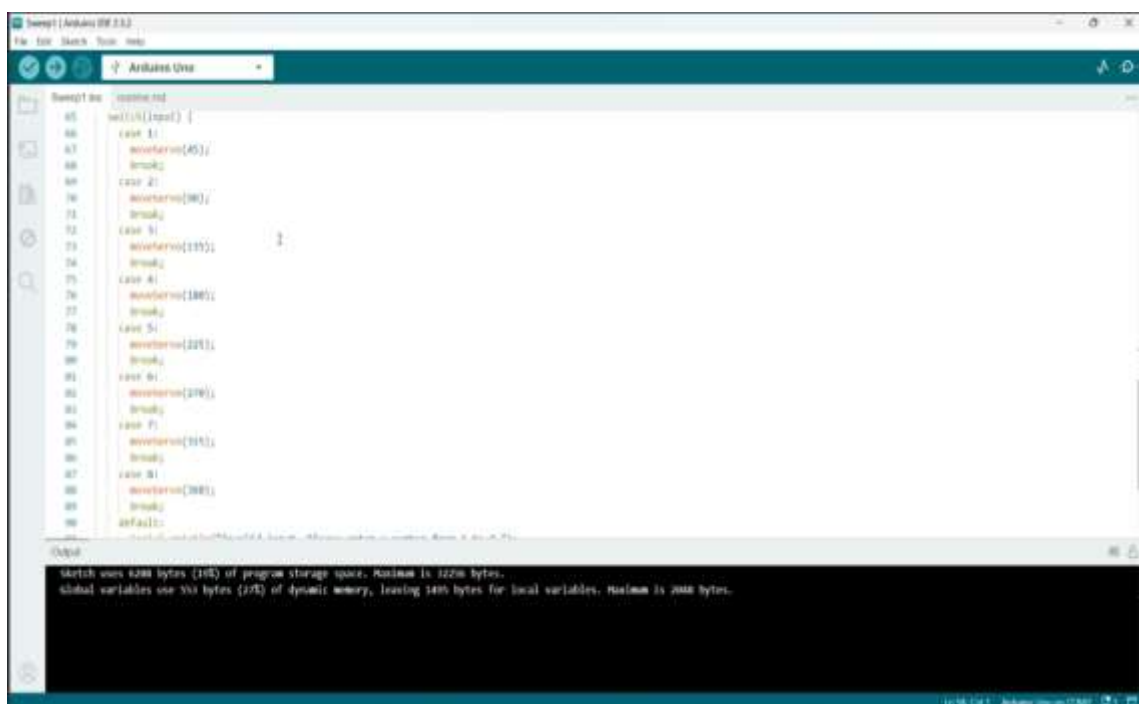


Fig.46 Slot angle values

A second step after setting up the program in the Arduino IDE environment is the construction of the hardware system and its wiring in the Proteus environment. For this purpose, Proteus libraries are used, in which there are ready-made components - motors, sensors, controllers, etc. Figure 47 shows the created hardware scheme connecting the components that make up the module as well as a virtual terminal for entering and visualizing the data.

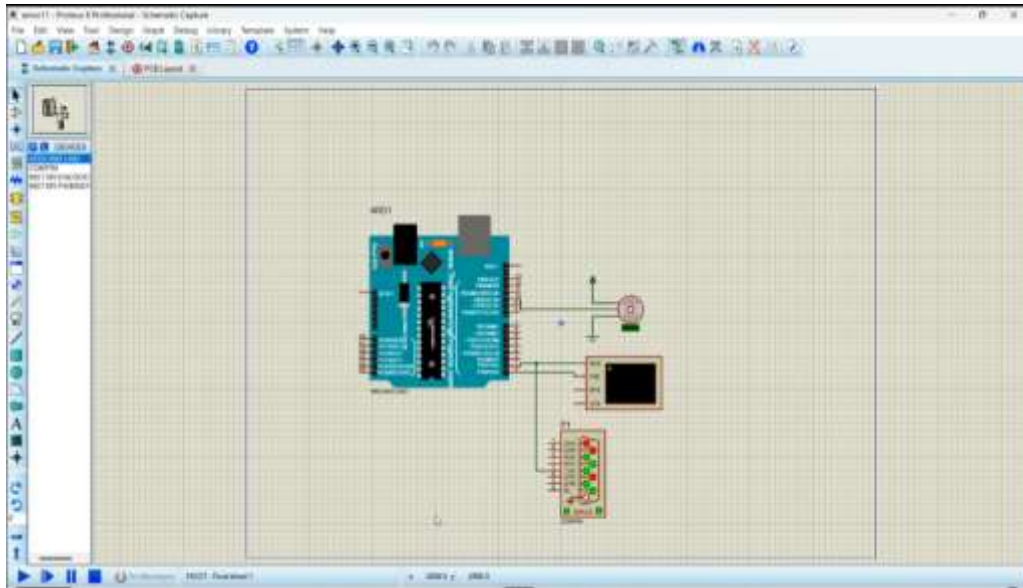


Fig.47 Hardware scheme of the drug distribution module

Once all the components are connected properly and the hardware system building the module is ready, the next step is to load the program written in the Arduino IDE in the Proteus environment, where we perform the simulation. Loading the program is done by pressing the right click on the microcontroller in the environment of Proteus. As a result, the Edit Component menu comes out, through which we load the arduino file.

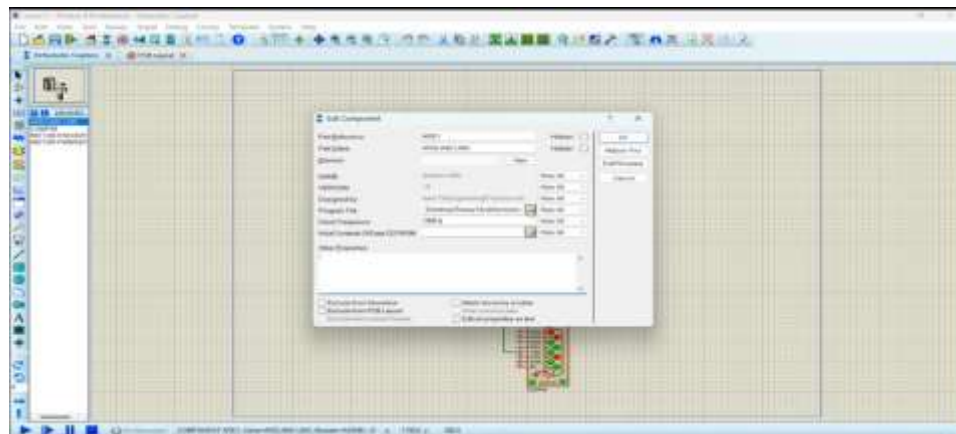


Fig. 48: Uploading the program written in the Arduino IDE in the Proteus environment

The next step is to open the 3D model of the robot in the 3D environment of Blender. In order for the model to move in the way we want, the constructed parts in Solidworks must be exported separately and assembled into a new one in the Blender 3D environment where the necessary constraints to the 3D objects are set and the objects that will be managed by the program and will move in the specified way are specified. The rigging steps for the model to move along a certain trajectory based on the control program that is implemented in the Proteus simulation are the following:

In object mode, an "armature" is created (a skeletal structure that manages a 3D object).

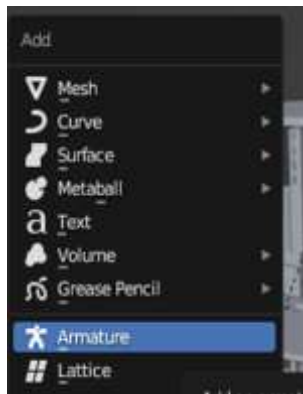


Fig. 49 Menu for generating an armature structure



Fig.50 The generated armature for controlling the 3D object

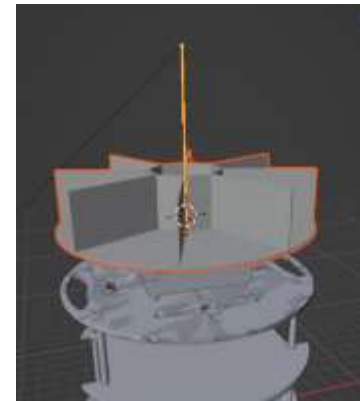


Fig.51 Positioning of the armature in the 3D object

Once the fittings are created, it is moved to the place where we want the movement to take place and placed towards the overall construction of the model we wish to be rigged (Figure 50 and Figure 51). In object mode, once the desired model is selected, the armature is switched to the pose mode (Figure 52). A choice of bone to be erupted, i.e. attached to the model (Figure 53), is then selected. Finally, ctrl+p is pressed and a "bone" is selected (Figure 54)

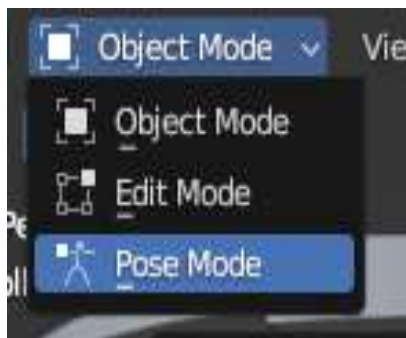


Fig.52 Choosing Pose menu

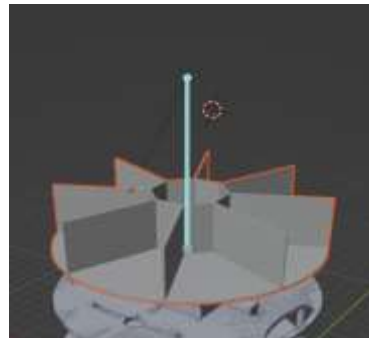


Fig.53 Choosing a bone which is to be rigged

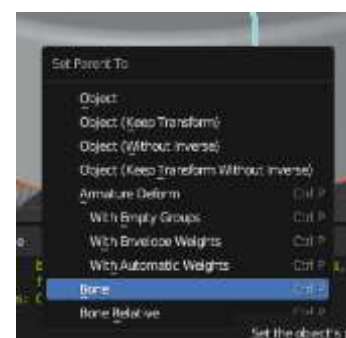


Fig.54 Menu for choosing a "bone"

After the model is rigged, we add the application to Blender BlendixSerial. The BlendixSerial library is designed to work together with the blendixserial add-on in Blender. It allows controlling objects in Blender through serial communication with Arduino or other microcontrollers. By emulating the COM ports from HHD Software's Virtual Serial Port Tools, together with BlendixSerial begins the connection between the simulation in Proteus and the 3D constructed robot with attached module in Blender

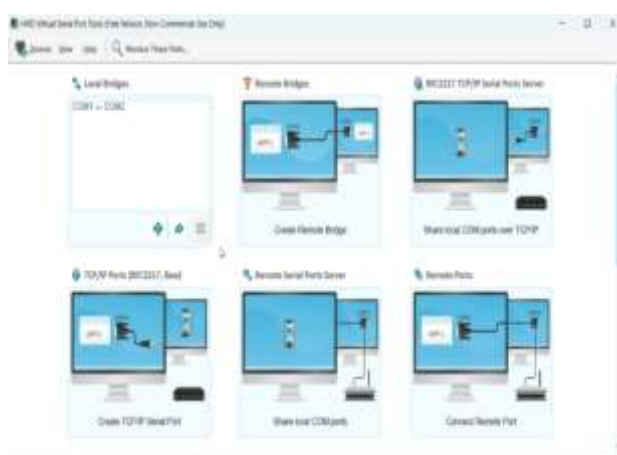


Fig.55 The emulation of the COM ports

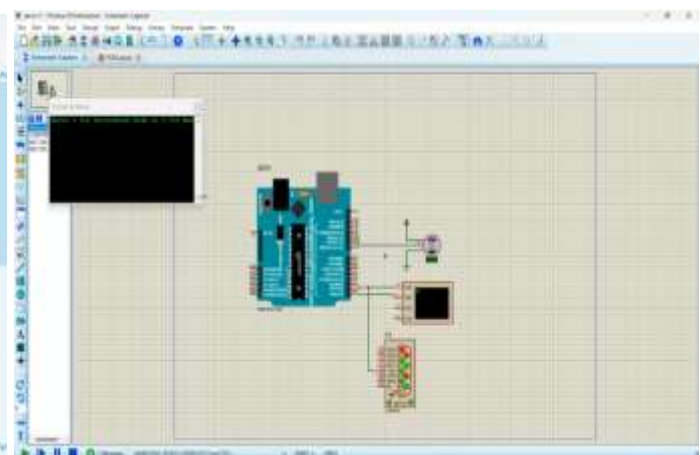


Fig.56 Start the simulation

The simulation in Proteus is started. (Figure 56). Using the virtual terminal, the running program is visualized, which is written in Arduino and implemented in Proteus through the generated hex file. The terminal waits for 0 or 1 to be entered for manual or autonomous distribution mode. In order to visualize the changes in the 3D model of the constructed robot in the BlendixSerial drop-down menu, we must have pressed Connect Serial and Start Movement, as well as indicate the emulated port, which is illustrated in Figures 57, 58 and 59.



Fig.57 Selection of COM port in Blender

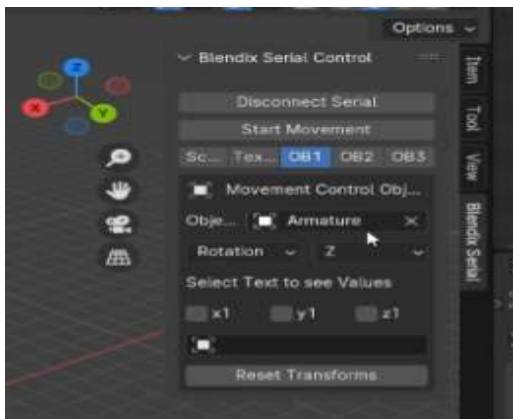


Fig.58 BlendixSerial before startup

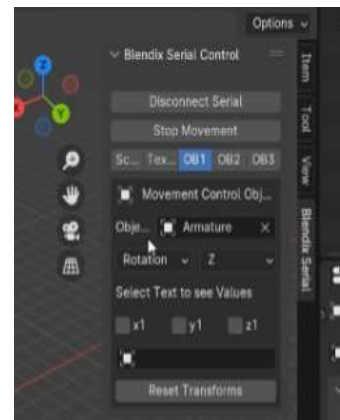


Fig.59 BlendixSerial after startup

After entering 1 and starting the autonomous allocation the program waits for the introduction of the sequence of slots with drugs loaded into them, which are for the patient to which the operator sends the robot. (illustrated in Figure 60).

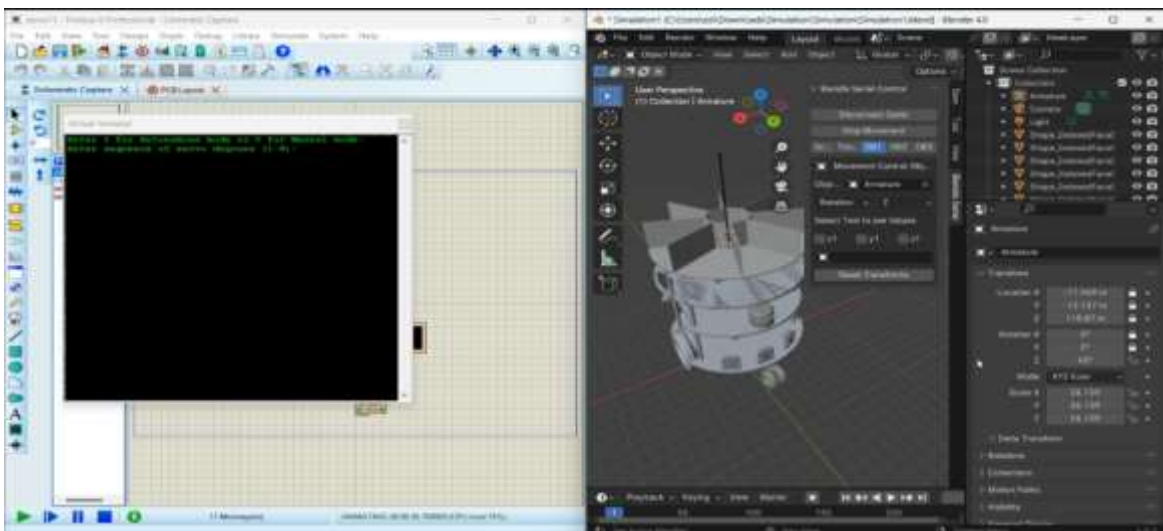


Fig.60 The synchronized environments of Proteus and Blender

Figure 61 shows the autonomous distribution mode for 3 slots. Once we have entered the numbers of the slots in which we have put the drugs, the program executes them consistently. The virtual terminal shows the sequential execution of the 3rd, 6th and 1st slots, and after each spin to the respective slot terminal it indicates that the movement is successful / completed. 45 degrees corresponds to the first slot and can be seen both on the terminal on the left side of the screenshots and on the right side in the 3D environment of the blender in the z unlocked rotation of the object.

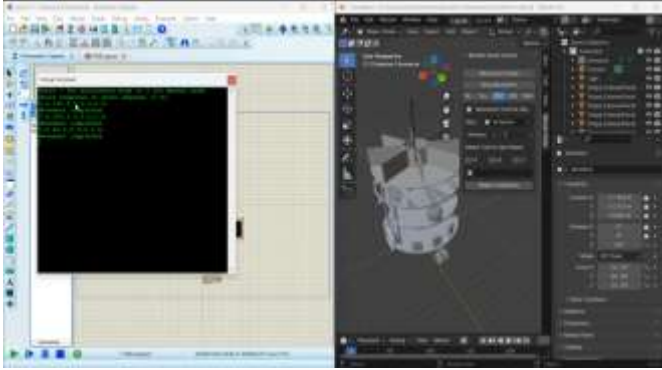


Fig.61 Autonomous distribution mode

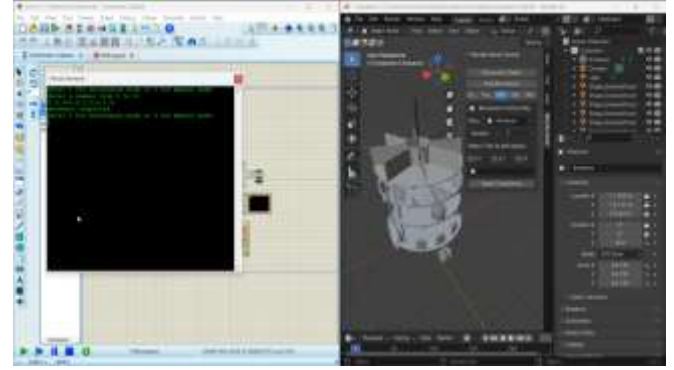


Figure 62: Manual distribution mode

In manual mode (which is activated when entering 0 in the terminal) the slot is entered , which we want to rotate in the front of the robot so that the patient can access it. In the image Fig. a slot 7 has been introduced, which corresponds to 315 degrees , which are visualized in the virtual terminal and in the menu responsible for rotation of the distributor table in the 3D blender environment. Once the movement is successfully completed the terminal awaits the next input for mode and then for slot number.

3.3 Control of the multi-purpose robot in surveillance, security and signalling mode

The surveillance and security module is an important component of the tele-controlled mobile robot platform, which provides the operator with the ability to choose between surveillance mode, video or photo recording mode, and active security mode..



Fig. 63 Mobile robot-platform with mounted module for surveillance and security

The developed algorithm of robot operation in bypass, surveillance, security and signaling mode is presented in Figure 64, and Figure 65 presents the main components that make up the module.

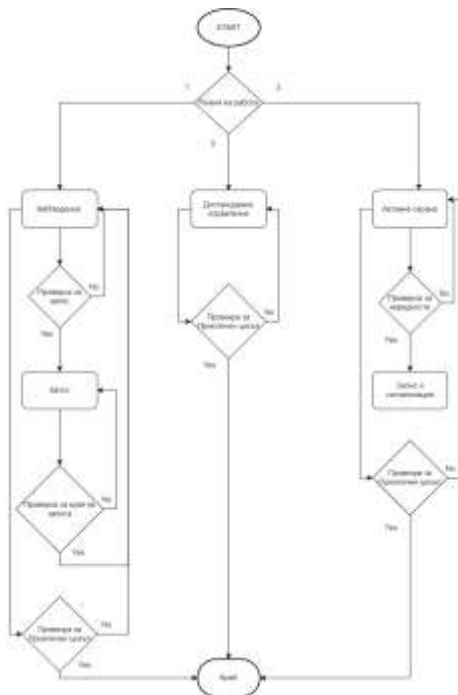


Fig.64 Flowchart of the operation of the module

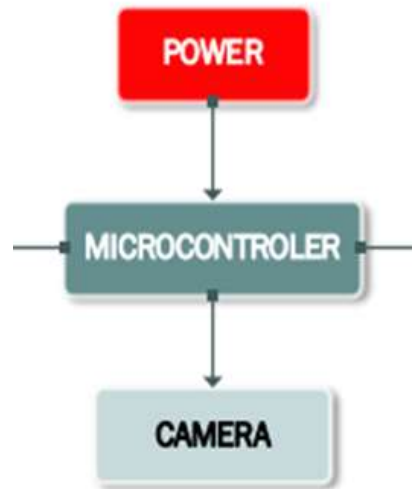


Fig.65 Scheme of the main components of surveillance module

Algorithm of robot operation:

- Installation and startup of the module:

The surveillance and security module contains a built-in camera that is mounted on the top plate of the mobile robot platform. After the successful installation of the module and the power supply, the module control program is started.

- Select mode:

The interface of the program provides a choice of different modes of operation. The operator can choose between surveillance mode, video or photo recording mode, and active guard mode.

- Start the work cycle:

After the operator selects the desired mode, he starts the duty cycle by pressing the corresponding button in the program.

- Surveillance and recording:

The camera of the surveillance and security module begins to broadcast a video signal that can be monitored in real time by the operator. In recording mode, the program can start recording video or photos that are saved for future use.

- Remote control:

The operator can control the tilt and rotation of the camera through the program interface. This allows the operator to point the camera at specific objects or areas.

- Active security:

In active guard mode, the robot can use additional sensors or algorithms to detect movement or illegal activities in the surveillance area. In case of detection of illegal activities, the module can provide a warning to the operator and start recording the incident.

- Completion of the work cycle:

After the operator has finished monitoring or recording, a message is displayed to complete the operation.

- Turn off the module:

The operator can turn off the module after the successful completion of the operating cycle. This module provides capabilities for monitoring and security at different locations and situations, providing real time to the operator or recording important data for future use.

3.4 Control of the multi-purpose robot in mode for transporting and lifting loads by a means of scissor lift

The general appearance of the robot in the mode for transport and lifting by means of a notch hoist is shown in Figure 66.



Fig.66 General appearance of the robot with a plate hoist module mounted to it

3.4.1 Algorithm of robot operation

The developed algorithm of operation is presented in Figure 67 and includes the following steps:

- It starts with the installation and startup of the module. After the operator brings the platform into operation and turns on the power, the program is started and the controller sends a signal to the driver of the linear motor (actuator).
- If the lifting platform is not in its starting position, the linear engine begins to lower the arms on which the lifting platform is attached. After performing this procedure, the platform is in "anticipation" mode, until a command is given by the operator. This procedure must also be carried out in case the platform has stopped its work in an emergency and the lifting platform has remained in the working position.
- When the robot receives a command "lift the load", the controller sends a signal to the linear motor driver. The motor begins to raise the arms on which the lifting platform is mounted until the weight sensor touches the load. It takes into account the weight of the load, and if it exceeds the norm, the program reports an error "Attention, excess weight!" Then the mechanism returns the lifting platform to "standby" mode.
- When the program receives a command "lift the load" and the weight sensor detects a weight in the norm, the mechanism raises the load to the blinded height and the robot can proceed to transport the load.

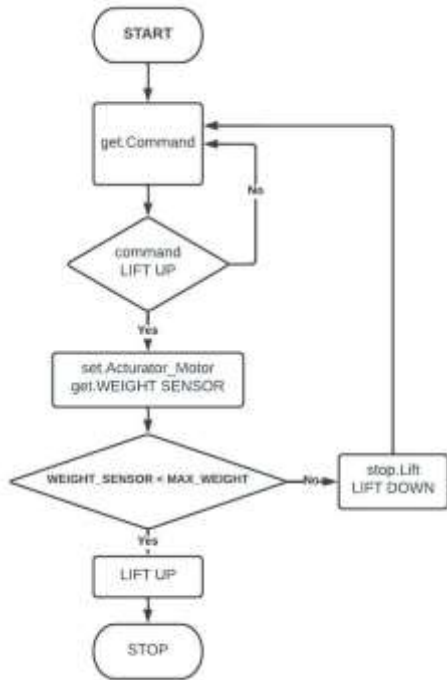


Fig.67 Flowchart of the operation of the module

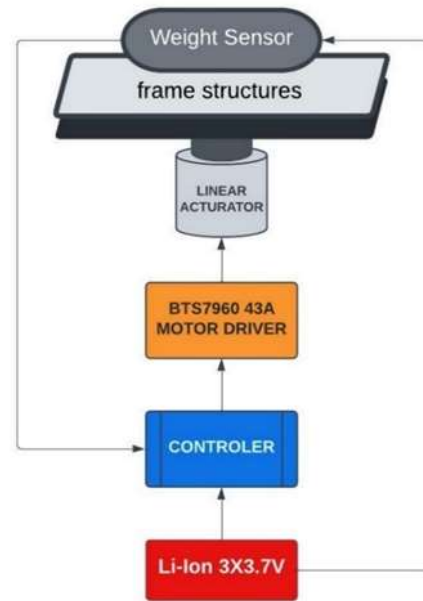


Fig.68 Scheme of the main components of lifting module

Figure 68 presents the hardware system of the lifting robot. The lifting module is powered by a Li-ion battery block consisting of 3 series connected cells with a voltage of 3.7V and a maximum current of 5A.

3.4.2. Simulation and results of the verification of the module and algorithm of operation

Through the simulation setup, the control and behavior of the module is verified. The simulation is performed on the basis of several softwares through their parallel and synchronized implementation. The following software are bound in the simulation: SolidWorks-CAD, Proteus 8.16, Arduino IDE, HHD Software's Virtual Serial Port Tools, Blender 3D.

The first step is to create the code in the Arduino IDE. In order to be able to realize the simulation in the code, the BlendixSerial.h library is introduced, which allows the communication between the simulation of the hardware in Proteus with the 3D environment of Blender 3D, in which the constructed robot is placed.



Fig.69 Creation of the code in the Arduino IDE

The code provides 2 user options, one for lifting and one for lowering.

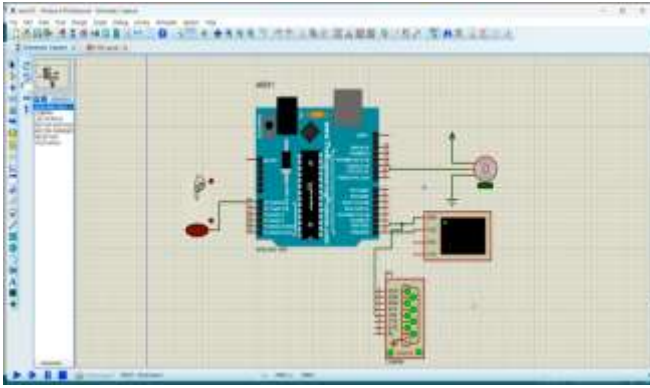


Fig.70 Hardware scheme in Proteus

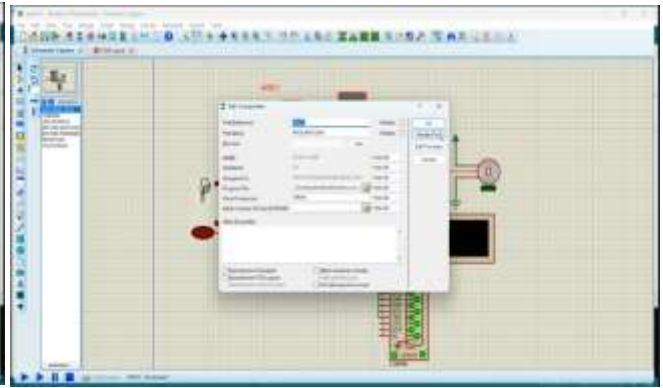


Fig.71 Uploading the program written, in the Arduino IDE in Proteus environment

A second step after setting up the program in the Arduino IDE environment is the construction of the hardware system and its wiring in the Proteus environment. For this purpose, Proteus libraries are used, in which there are ready-made components - motors, sensors, controllers, etc. Figure 70 shows the created hardware scheme connecting the components that make up the module as well as a virtual terminal for entering and visualizing the data. Once all components are connected correctly and the hardware system building the module is ready the next step is to load the program written in the Arduino IDE in the Proteus environment, where we perform the simulation. (figure71). Loading the program is done by pressing the right click on the microcontroller in the environment of Proteus. As a result, the Edit Component menu comes out, through which we load the Arduino file. The next step is to open the 3D model of the robot in the 3D environment of Blender. In order for the model to move in the way we want, the constructed parts in Solidworks must be exported separately and assembled into a new one in the Blender 3D environment where the necessary constraints to the 3D objects are set and the objects that will be managed by the program and will move in the specified way are specified. The rigging steps for the model to move along a certain trajectory based on the control program that is implemented in the Proteus simulation are the following:

In object mode, an "armature" is created (a skeletal structure that manages a 3D object). Once the armature is created, it is moved to the place where we want the movement to take place and placed to the overall construction of the model we want to be rigged. (Figure 72, Figure73 and Figure74).

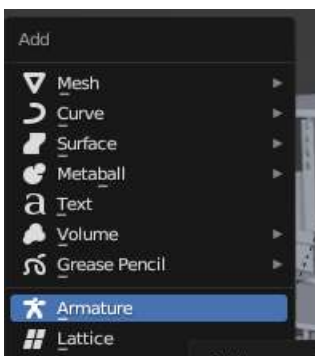


Fig. 72 Menu for generating an armature structure



Fig.73 The generated armature for controlling the 3D object



Fig.74 Positioning of the armature in the 3D object

In object mode, after selecting the desired model, the armature is switched to pose mode (figure 75). This is followed by a choice of bone to be erupted, i.e. attached to the model (Figure 76). Finally, ctrl+p is pressed and "bone" is selected(Figure 77)

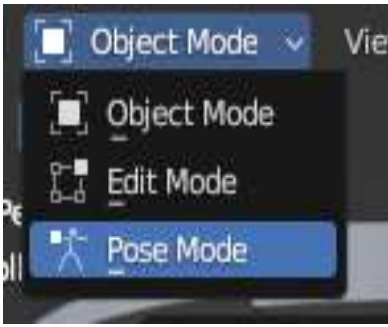


Fig.75 Choosing Pose menu

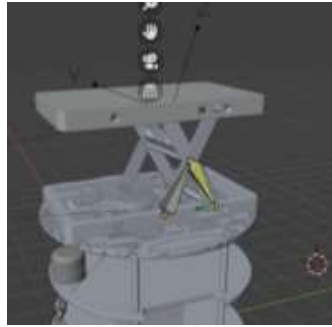


Fig.76 Choosing a bone which is to be rigged

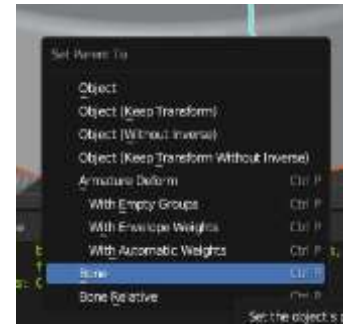


Fig.77 Menu for choosing a "bone"



Fig.78 The emulation of the COM ports

After the model is rigged, we add the application to Blender BlendixSerial. The BlendixSerial library is designed to work alongside the blendixserial add-on in Blender. It allows controlling objects in Blender through serial communication with Arduino or other microcontrollers. By emulating the COM ports from HHD Software's Virtual Serial Port Tools, together with BlendixSerial begins the connection between the simulation in Proteus and the 3D-engineered robot with attached module in Blender.

We run the simulation in Proteus (figure79). Using the virtual terminal, the running program is visualized, which is written in Arduino and implemented in Proteus through the generated hex file. The terminal is waiting for us to enter 1 or 2 to remove or lift the platform.

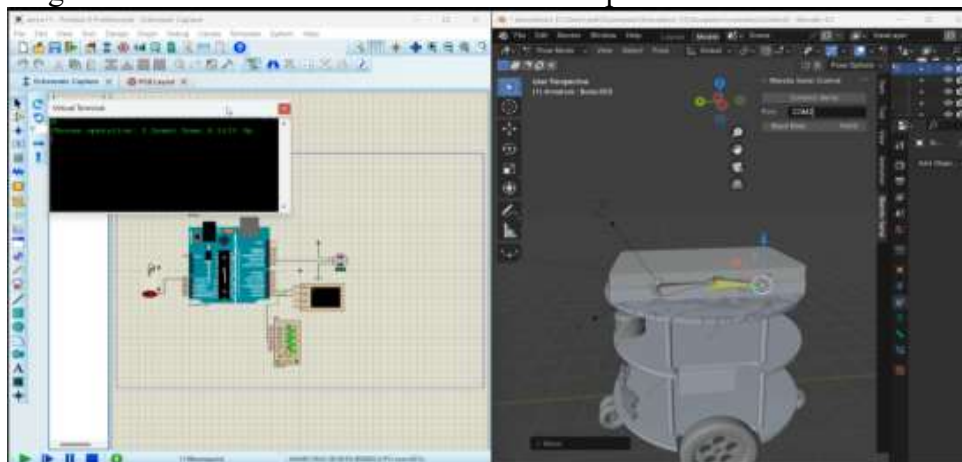


Fig.79 Running the simulation in Proteus and selecting a COM port in Blender

In order to visualize the changes in the 3D model of the constructed robot in the drop-down menu of BlendixSerial we must have pressed Connect Serial and Start Movement, as well as specify the emulated port.

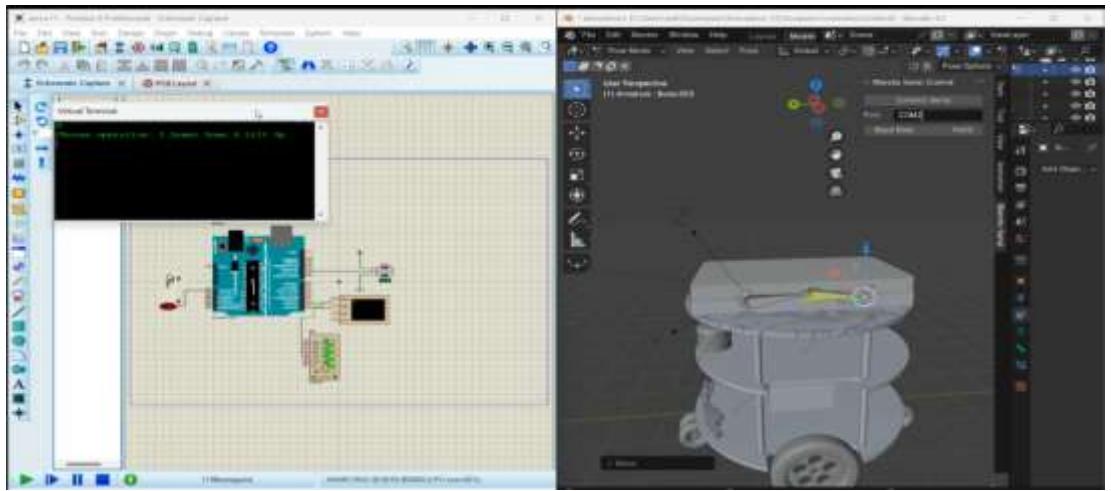


Fig.82 Starting position waiting for the introduction into the terminal

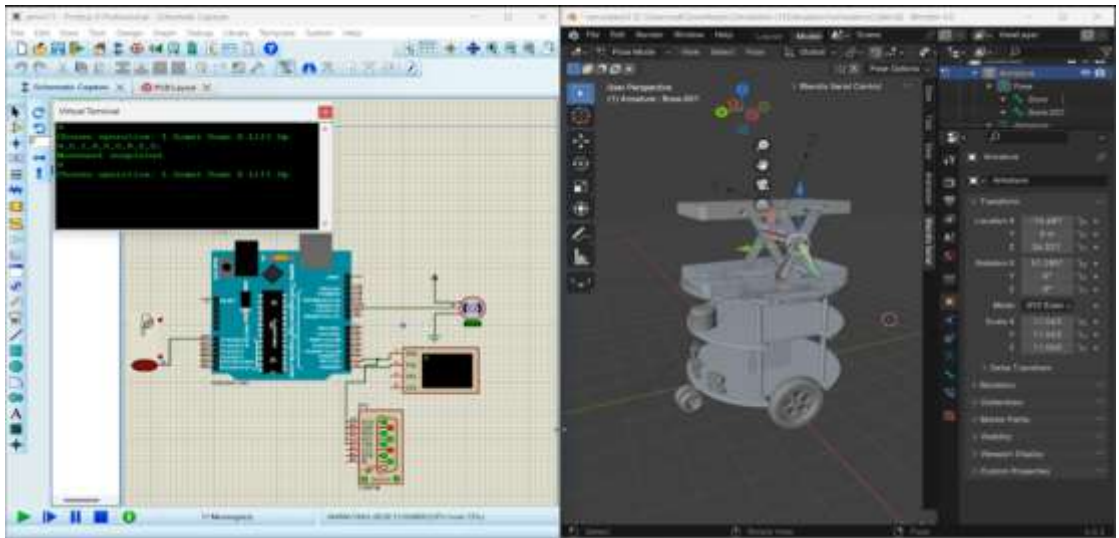


Fig.83 The robot with the lifted module

Figures 82 and Figure 83 depict the two possible robot positions, namely downthrown and raised platform. When the permissible weight is exceeded, the user receives a warning that the load placed on the platform is too much and the program temporarily stops its function until the excess load is removed – Figure 84.

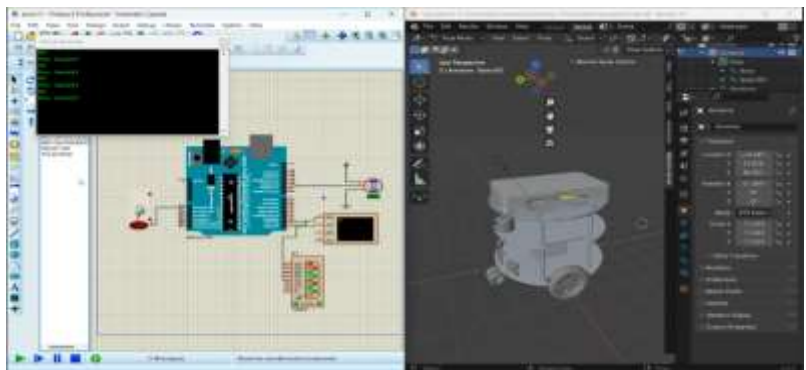


Fig.84 Terminated robot function until excess load is removed

Once the movement is successfully completed the terminal awaits the next command input by the user.

3.5 Control of the multi-purpose robot in storage and delivery mode via a lifting platform

The general appearance of the robot in the mode for storage and/or delivery of finished products is shown in Figure 86.

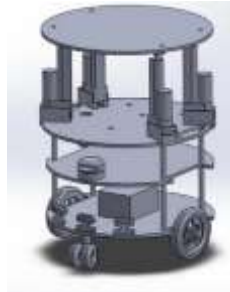


Fig.86 Robot with mounted module with lifting platform for the supply of finished products

3.5.1 Algorithm of robot operation

The developed algorithm of robot operation in production delivery mode by means of a lifting platform module is presented in Figure 87. Similar to the plate hoist, the module with lifting platform for storage and delivery goes through the same functional steps.

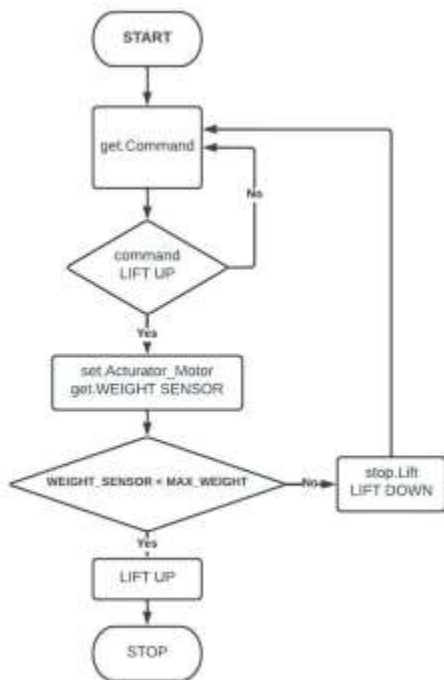


Fig.87Flowchart for controlling the module

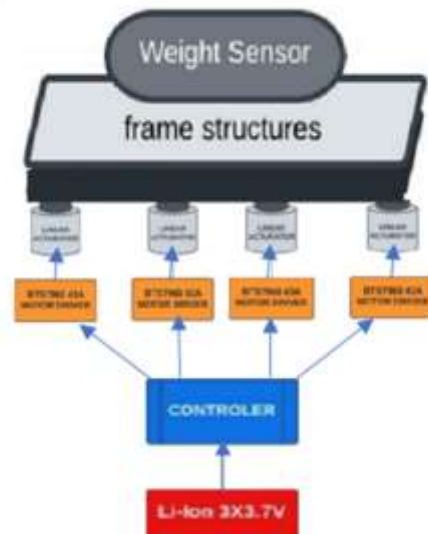


Fig.88 Diagram with the basic components building the module

Figure 88 presents the hardware system of the module. The service robot in storage and/or delivery mode includes a differential mobile platform, an industrial computer and controllers, an electromechanical drive system (DC motors with reducers and encoders), a 12V LiPo rechargeable battery and a sensor system. The linear actuator used was 12 volts with a maximum load capacity of 90 kg.

3.5.2Simulation and results of the verification of the module and algorithm of operation

The verification of the module and the algorithm of work was realized through the implementation of a computer simulation, for which the synchronized application of the following software was performed in parallel: SolidWorks-CAD, Proteus 8.16, Arduino IDE, HHD Software's Virtual Serial Port Tools and Blender 3D.

The first step is to create the code in the Arduino IDE. In order to be able to implement the simulation in the code, the `BlendixSerial.h` library is introduced, which allows the communication between the simulation of the hardware in Proteus with the 3D environment of the Blender 3D in which the constructed robot is placed.

When starting the simulation part in Proteus in the virtual terminal of the simulation, the operator chooses the type of operation / movement of the platform /: 1- for downloading 2- for lifting.

In the program, when the weight limit that can be taken by the platform, the terminal returns the message "Too heavy!" and does not allow the operation to be performed until the weight reduction in the permissible values.



Fig.89 The written program in Arduino IDE

A second step after the creation of the program in the environment of the Arduino IDE is the construction of the hardware system and its wiring in the Proteus environment. For this purpose , the Proteus libraries are used, in which there are ready-made components - motors, sensors, controllers, etc. - Figure 90 shows the created hardware scheme connecting the components building the module as well as a virtual terminal for entering and visualizing the data.

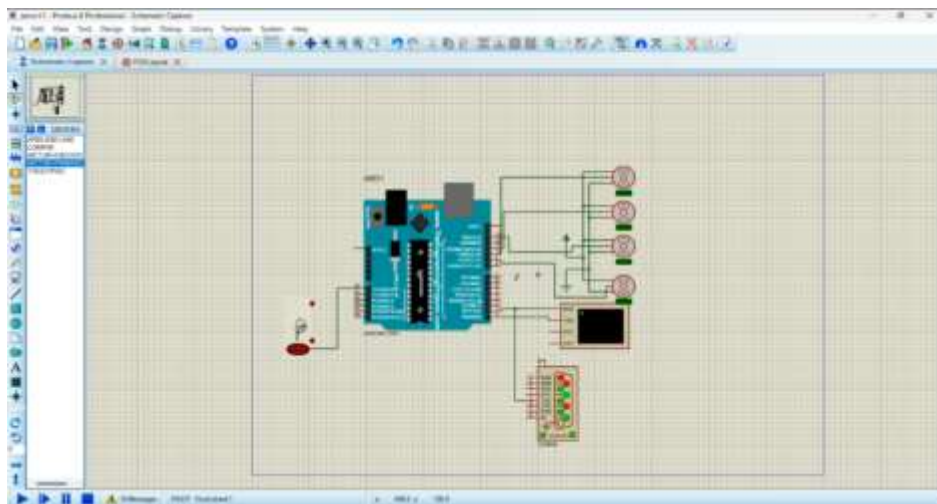


Fig.90 Hardware scheme

Once all the components are connected properly and the hardware system building the module is ready, the next step is to load the program written in the Arduino IDE in the Proteus environment, where we perform the simulation. Loading the program is done by pressing the right click on the microcontroller in the environment of Proteus. As a result, the Edit Component menu comes out, through which we load the Arduino file.

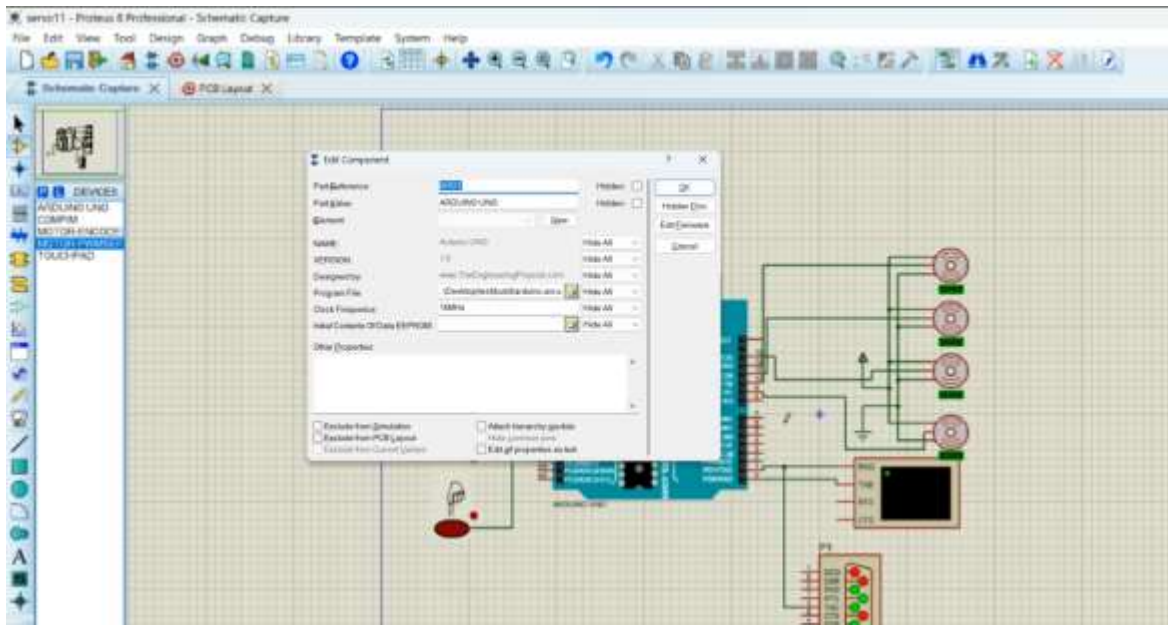


Fig.91 Uploading the Arduino program in Proteus environment

The next step is to open the 3D model of the robot in the 3D environment of Blender. In order for the model to move in the way we want, the constructed parts in Solidworks must be exported separately and assembled in a new way in the Blender 3D environment where the necessary constraints to the 3D objects are set and the objects that will be managed by the program and will move in the specified way are set. The rigging steps for the model to move along a certain trajectory based on the control program that is implemented in the Proteus simulation are the following:

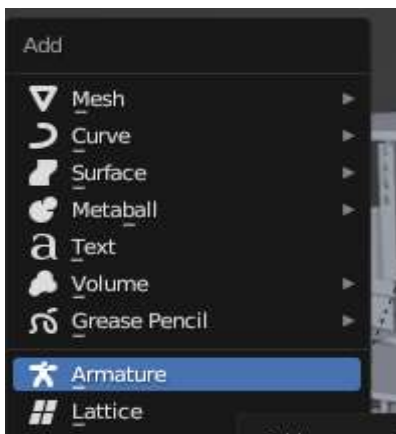


Fig.92 Menu for generating a bone structure

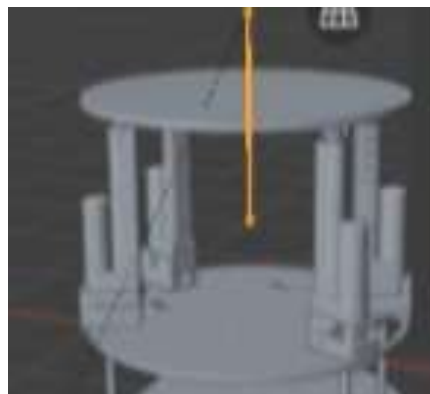


Fig.93 The generated armature for controlling the 3D object



Fig.94 Positioning of the armature in the 3D object

In object mode, "armature" are created. (Fig. 92). Once the fittings are created, it is moved to the place where we want the movement to take place and placed to the overall construction of the model we want to be rigged. (Fig. 93 and Fig. 94).

In object mode, after selecting the desired model, the armature is switched to pose mode (figure 95). This is followed by a choice of bone to be rigged, i.e. attached to the model (Figure 96). Finally, ctrl+p is pressed and "bone" is selected(Figure 97)

After the model is rigged, we add the application to Blender BlendixSerial. The BlendixSerial library is designed to work alongside the blendixserial add-on in Blender. It allows controlling objects in Blender through serial communication with Arduino or other microcontrollers.

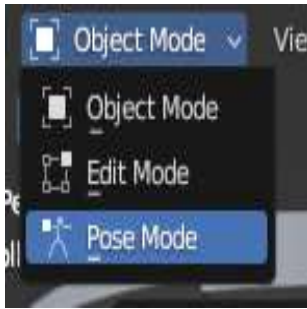


Fig.95 Choosing Pose menu



Fig.96 Choosing a bone which is to be rigged

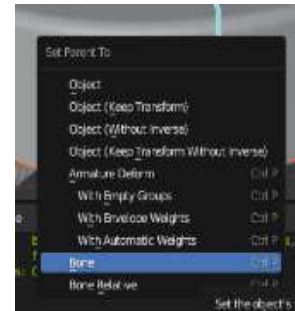


Fig.97 Menu for choosing a "bone"

By emulating the COM ports from HHD Software's Virtual Serial Port Tools, together with BlendixSerial begins the connection between the simulation in Proteus and the 3D-engineered robot with attached module in Blender



Fig.98 Emulating the COM ports

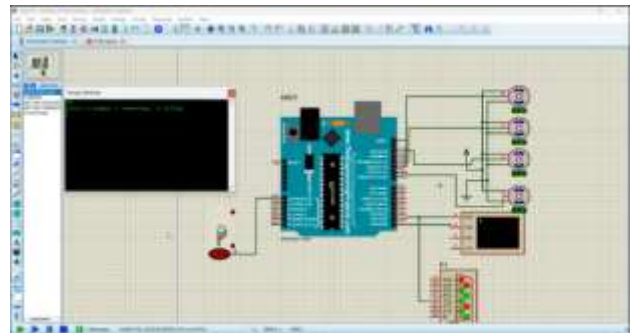


Fig.99 Start the simulation from Proteus

We run the simulation in Proteus. Using the virtual terminal, the running program is visualized, which is written in Arduino and implemented in Proteus through the generated hex file. The terminal waits for us to enter 1 or 2 to remove or erect a lifting platform.

In order to visualize the changes in the 3D model of the constructed robot in the drop-down menu of BlendixSerial we must have pressed Connect Serial and Start Movement, as well as specified the emulated port. By introducing "2" in a virtual terminal, the position of the lifting platform rises up the Z axis (in the case where the reported weight is less than 70% of the prepostima). Once the movement is successfully completed, the terminal awaits the next entry. Figure 103 and Figure 104 show by visualizing in the virtual terminal a situation where the weight is above the allowable and the operation is not allowed and the next situation in which the weight is in the set limit values and the movement is carried out.

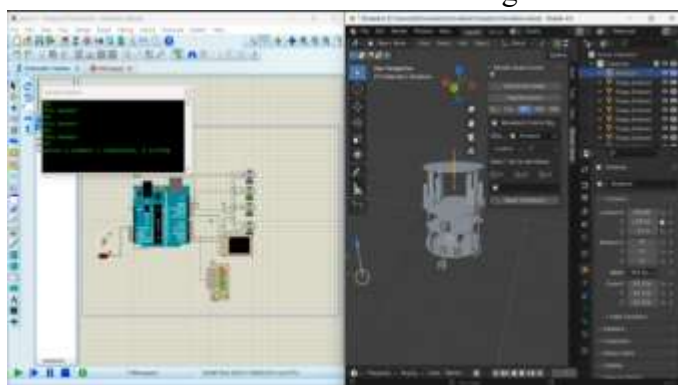


Fig.103 A situation in which the load is above allowed values and the operation is not permitted

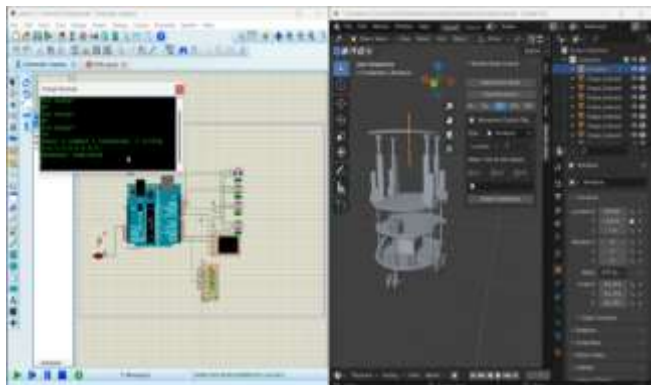


Fig.104 The movement is carried out- the load is in the allowed values

By introducing a "1" in the virtual terminal the position of the lifting platform returns to its original position. Once the movement has been successfully completed the terminal awaits the next input (Fig. 105)

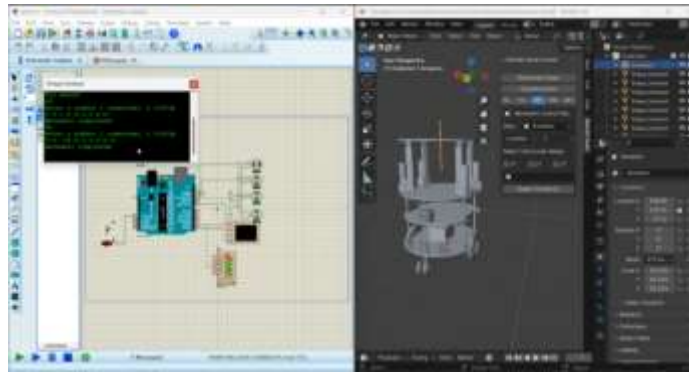


Fig.105 The terminal awaiting the next introduction

3.6 Control of the multi-purpose robot in cleaning mode

The general appearance of the robot with a cleaning module connected to the universal mobile platform is shown in Figure 107.

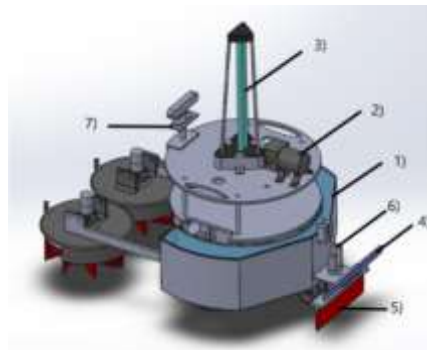


Fig. 107: 1- detergent tank with cover, 2- tank pump, 3- antibacterial UV lamp for sanitation of the surroundings, 4- antibacterial UV lamp for floor sanitation, 5- rear adjustable brush, 6- linear actuator for moving rear brush, 7- teleoperation camera

3.6.1 Algorithm of robot operation

The developed algorithm of operation in cleaning mode, presented in Figure 108, includes the following steps:

- It starts with the installation and startup of the module. After the operator has installed the cleaning module and put the platform into operation (power on), the program is started and the controller sends a signal to the actuator. The motor begins to lift the structure on which the rotating brushes are attached until the angle set by the program is reached. After performing this procedure, the platform is in "standby" mode until a command is issued by the operator. This procedure must also be carried out in case the platform has interrupted its operation in an emergency situation and the structure carrying the rotating brushes has remained in the working position.
- When the program receives the command "start cleaning", the controller sends a signal to the driver [93] of the motor. The actuator begins to lower the arm on which the rotary motors are mounted until the brushes touch the working surface. After the structure is lowered, the controller sends a signal to the drivers of the motors driving the rotating brushes. They are driven, reaching their maximum speed in 5 seconds. This prevents the load that would result from the sudden start of the engines.
- When the program receives the command "start cleaning with water", if the platform was in "standby" mode, the procedure in step 2 is repeated, and after the motors driving the rotating brushes reach their maximum speed, the controller sends a signal to the pump motor driver of the tank.

remote control option.

The cleaning functions built into the graphical interface are the following:

- Create a map: the operator manually walks the robot around the room until a complete map is created. Each procedure then uses the map made [16]. A sequential map scanning algorithm is used to ensure that cleaning procedures are carried out everywhere
- Start cleaning only with brushes
- Start cleaning with brushes and spraying with detergent
- Switching on and activating the disinfecting subsystem with UV lamps. Since there is a danger to humans and animals during this procedure, an algorithm of radiation protection is activated before starting the lamps. In this mode, the robot detects the presence of humans or animals. If detected, the UV lamps shall be switched off and signalled at the operator's graphical interface. For better perception, the robot is able to recognize markers and other objects [17].
- Cleaning including all systems / brushes, washing, UV lamps / of the sanitary module: In this mode, all systems of the cleaning module are activated, as well as all algorithms.

The feedback from the robot to the operator is realized by visualization of data from the sensors and devices of the robot. The operator can monitor the video stream from the robot's camera, track the location of the robot according to the navigation map, see if there is a set operation and to what extent it is completed. When a problem occurs while performing an operation or a malfunction occurs, it is also reported to the operator.

In addition to automated operations, buttons have been added to the graphical interface to control the individual functions of the modules. In this way, the operator can use the robot in manual teleoperation mode, to diagnose systems, etc.

3.6.3. Simulation and results of verification of the module and algorithm of operation

To verify the module and the algorithm of work, a computer simulation is compiled and implemented through the synchronized application of the following softwares: SolidWorks-CAD, Proteus 8.16, Arduino IDE, HHD Software's Virtual Serial Port Tools and Blender 3D.

The first step is to create the code in the Arduino IDE. In order to be able to implement the simulation in the code, the `BlendixSerial.h` library is introduced, which allows the communication between the simulation of the hardware in Proteus with the 3D environment of the Blender 3D in which the constructed robot is placed.

When starting the simulation part in Proteus in the virtual terminal of the simulation, the operator selects which modes of operation of the cleaning module to activate. The program has 4 modes, which are entered with a digit in the terminal:

- 1-start of cleaning (starts cleaning with brushes after the shoulder structure is removed);
- 2-UV cleaning (cleaning with the brush positioned at the back of the robot together with the UV lamp attached to it);
- 3-cleaning with water (starts the electric pump for cleaning with water through the nozzles positioned at the front of the rotary brushes);
- 4- UV lamp mode (cleaning the surrounding environment using the UV lamp mounted on the top plate of the mobile robot)

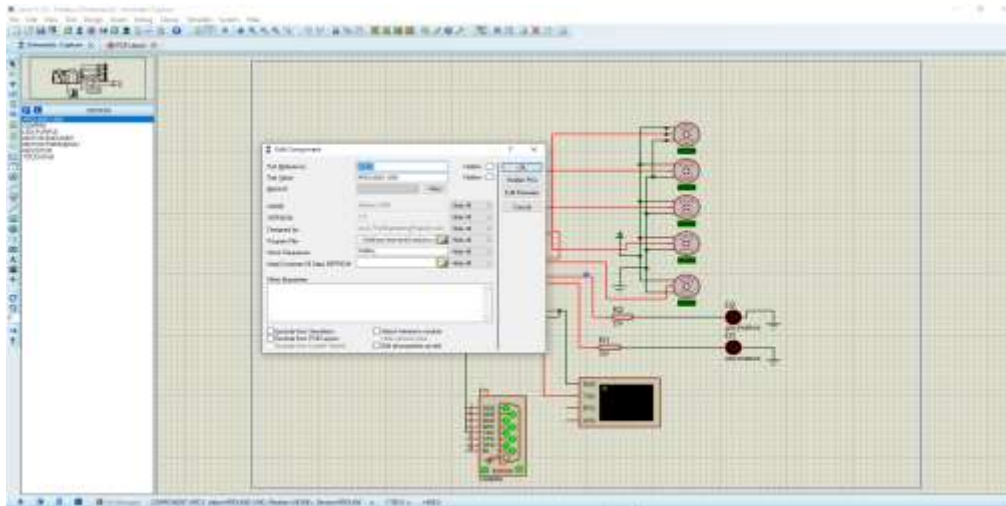
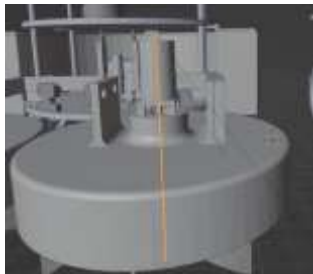
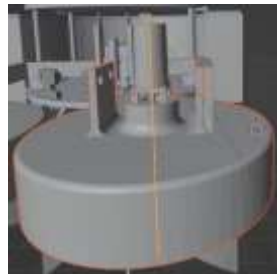


Fig.112 The loading of the Arduino file in the environment of Proteus

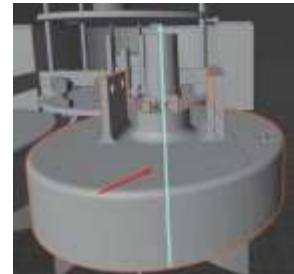
The rigging steps for the model to move along a certain trajectory based on the control program that is implemented in the Proteus simulation are as follows:



*Fig.114 The generated armature
For controlling the 3D object*



*Fig.115 Positioning of the
armature in the 3d object*



*Fig.117 Choosing a bone
which is to be rigged*

In object mode, an "armature" (a skeletal structure that controls a 3D object) is created. Once the armature is created, it is moved to the place where we want the movement to take place and placed to the overall design of the model we wish to be rigged (Fig. 114 and Fig. 115). In object mode, once the desired pattern is selected, the armature is switched to pose mode. This is followed by a choice of bone to be erupted, i.e. attached to the model (Figure 117). Finally, ctrl + p is pressed and "bone" is selected. After the model is rigged, we add the application to Blender BlendixSerial. The BlendixSerial library is designed to work together with the blendixserial add-on in Blender. It allows controlling objects in Blender through serial communication with Arduino or other microcontrollers. By emulating the COM ports from HHD Software's Virtual Serial Port Tools, together with BlendixSerial begins the connection between the simulation in Proteus and the 3D-engineered robot with attached module in Blender



Fig.119 Emulation of the COM ports

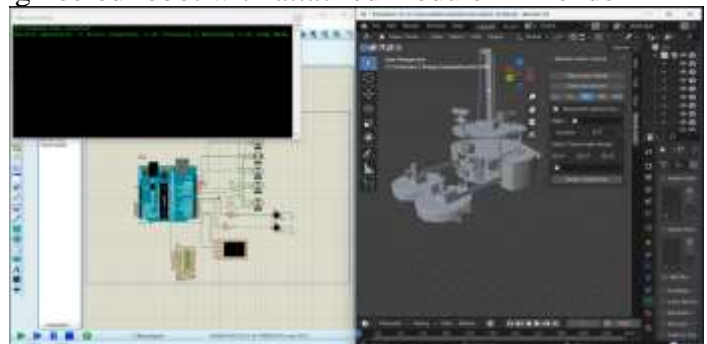


Fig.120 Start the simulation in Proteus

We run the simulation in Proteus. Using the virtual terminal, the running program is visualized, which is written in Arduino and implemented in Proteus through the generated hex file. The terminal writes that

the procedure has started and is waiting for us to introduce the cleaning mode we want to start. Possible modes of operation are:

start of cleaning, 2- UV cleaning, 3- cleaning with water, 4- mode UV lamp

Before starting the program, in accordance with the cleaning algorithm, the arms on which the cleaning brushes are mounted are automatically raised. After entering a cleaning command in the terminal, they are lowered to the extreme lower position, in which it is intended to start the rotation of the brushes and cleaning on the basis of a geometric analysis carried out in the process of designing the product. In order to visualize the changes in the 3D model of the constructed robot in the drop-down menu of BlendixSerial we must have pressed Connect Serial and Start Movement, as well as specified the emulated port. – (Fig.123)



Figure 123 Selection of COM port in the environment of Blender

After entering 1 and starting the cleaning through the front brushes, the shoulder structure is lowered and the rotation of the brushes begins. The terminal visualizes the moving of the arms and indicates that the action has been successfully performed. The move is also displayed in the menu in Blender, showing the move in height. After that, the next execution command is expected. (Fig 126) The image in figure 127 corresponds to the introduction of the cleaning mode with the brush positioned at the rear of the robot and the activated UV lamp.



Fig.126 The executed mode in the simulation environment and anticipation of next command



Fig.127 Start cleaning with brush and UV lamp in the simulation environment

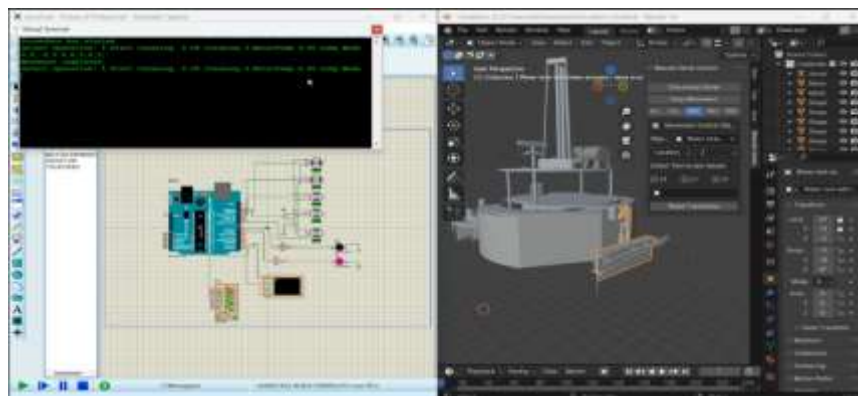


Fig.128 The activated mode for cleaning the ambient environment in the simulation

In the simulation part of Proteus, the lamp corresponding to the UV lamp in the 3D model is included

based on the code, and the visualization of the change is done with a change of color.

The introduction into the Proteus virtual terminal the mode for cleaning the environment by UV lamp is visualized as a corresponding lamp in the simulation, mounted on the top plate in Blender 3D changing color. In the case of water cleaning, the engine responsible for viewing the pump in the environment of the Proteus is activated. (Fig.128)

3.7 Control of the multi-purpose robot with attached module with antropomorphic robot

For operations requiring a certain level of precision, an anthropomorphic robot module is attached to the mobile robot platform.



Fig.129 The module with the attached Niryo One to the mobile robot

3.7.1 Controlling software

For the functioning of the anthropomorphic robot, the Niryo One Studio control software [94] running under different operating systems (Windows, MacOS, Linux) is used. The software shown in Figure 130 is used for setting up the robot, moving the robot, programming a sequence of commands, etc.

a) The left menu of the software window has the following robot control panels:

- Niryo blocks;
- Reserved positions;
- Saved sequences (with the possibility of automatic starting);
- Settings (Wi-Fi, Raspberry Pi, software versions);
- Calibration;
- Hardware status; Troubleshoot errors and logs.



Fig.130 Niryo One control software window

b) Robot control

When proceeding to the control of the robot, a calibration must be carried out in advance, after which an indicative LED (green or blue) indicates that the robot has been successfully started. The control software of the anthropomorphic robot Niryo One Studio, has a section providing information about the robot and contains the training mode shown in Figure 131.

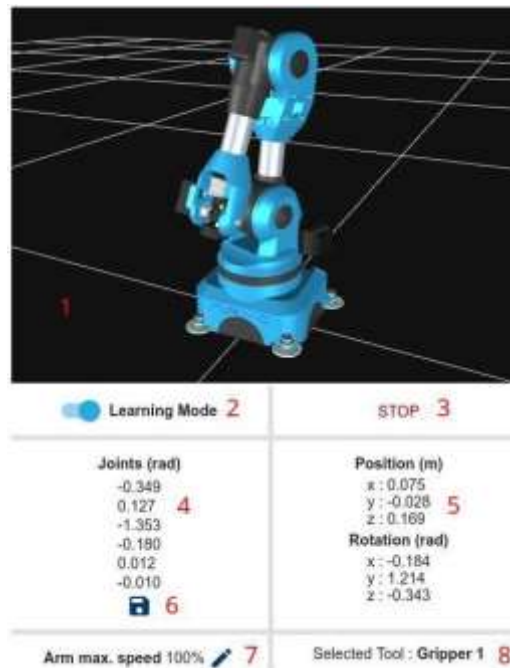


Fig.131 Permanent right section in the software window

- The software provides a 3D view of the robot. The 3D view helps to detect whether the manual/automatic calibration has been done correctly. If the physical positions of the robot differ and what is visible on the screen, the automatic calibration must be done again.
- When activating the "learning mode" button, the torque of all engines is deactivated. When the robot is in "learning mode", it can be moved freely. When the training mode is turned off, all motors are activated and the robot cannot move freely. When the training mode is turned off, all motors are activated and the robot cannot move freely
- At any time, when the "stop" button is activated, the current program of the robot is stopped.
- Current state of joints (J1-J6).
- Current position and orientation of TCP (Tool Center Point – the center of the specialized gripper - dispenser).
- A "keep current position" button allows to keep the current position, after which it can be reused later.
- Current maximum joint speed can be changed at any time (0-100%).
- Currently selected tool. C. Robot drive There are 3 tabs in the command panel of the robot control software. On the "Arm command" tab [94], an action can be selected from the "joints" tab or the "posture" tab. The "joints" tab allows to move each joint independently. The "pose" tab allows to move the position of the TCP relative to the initial x, y, z coordinates of the robot base.

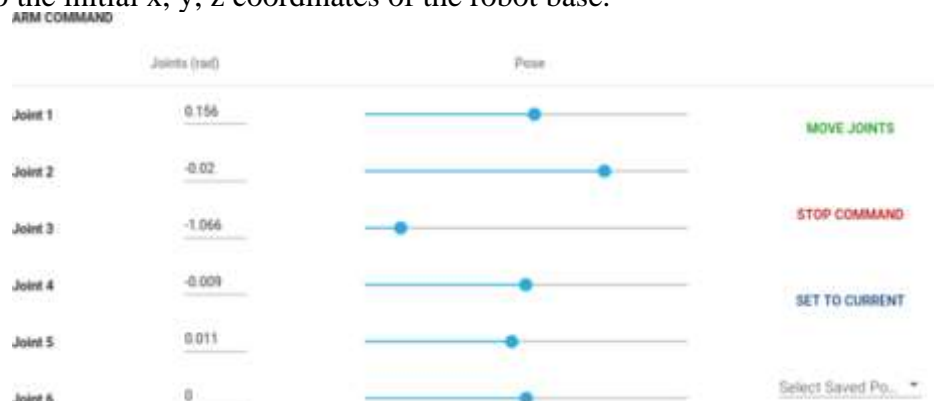


Fig.132 Arm command section in the control software

To execute a command, the following procedure is followed:

- Press the "set current position" button. The command will adjust the axes, position and orientation to the current state of the robot. This makes it possible to subsequently change the values from the current state (e.g. if desired, move only axis 5 or move TCP along the axis and keep the same orientation).
- Modification of joint or posture values (position + orientation).
- Pressing the "Move Joints" or "Move Pose" button to execute the move command.
- Once the command is executed, a notification is received at the bottom of the screen.
- At any time there is an option to cancel the current execution of the command by clicking on the "Stop" button. While running a current move command, a new command cannot be run. If you want to start a new command, you must first stop the previous one. There is also the possibility to choose a position that was previously reserved with the selection field "select a reserved position", thus replacing the first and second steps.

CONCLUSION

In this dissertation is presented the development of a multi-purpose tele-controlled service robot, through which can be carried out, monitoring, security and signaling of objects, cleaning and sanitation of premises, lifting and carrying cargo, distribution of medicines, transportation and storage of products, performing manipulation operations with elements.

The device of the robot includes a universal mobile platform and six modules, through which the robot performs completely different in nature and way of performing activities and operations. Its principle of operation is based on telecontrol.

The developed multi-purpose tele-control robot is used in completely different working environments – health facilities, retail chains, warehouses, livestock farms, expanding the range of application of service robots and contributing to their development and wide distribution. It is part of the service robots, which will increasingly improve working conditions and facilitate people's work.

In the future, the research on the service robot presented in the dissertation will be continued, and for this purpose a physical model of the robot will be realized and verified in real operating conditions.

CONTRIBUTIONS

- Major international documents, programmes and policies related to global development in the context of robotics and service robots within them have been studied and analysed.
- For each one of the robot operating modes, depending on the module used, a control algorithm has been developed and the execution sequence of each one is described.
- 4 softwares are tied - Proteus 8.16, Arduino, HHD Software's Virtual Serial Port Tools and Blender 3D for synchronized data transmission between them.
- Based on the parallel, collaborative and synchronized application of the five software (Proteus 8.16, SolidWorks, Arduino IDE, HHD Software's Virtual Serial Port Tools and Blender 3D), simulations have been compiled and implemented, through which the algorithms of the robot's work in its different modes are verified by the PhD student.
- A mobile robotic platform has been developed with the possibility of attaching different design and purpose modules.
- Six separate modules have been developed, with different functions, design and purpose, through which the robot can work in heterogeneous environments and perform completely different in nature and way of performing activities and operations.
- Tele-operation of a multifunctional mobile robotic platform through web-based graphical interface, via MQTT and web sockets has been developed

ACKNOWLEDGEMENTS

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