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Development of Control Electronics and Program for Robotont's Height Adjustment Mechanism

Bachelor's Thesis (12 ECTS)

Curriculum Science and Technology

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Development of Control Electronics and Program for Robotont's Height Adjustment Mechanism

Abstract:

In today's dynamic landscape, robotics, and automation have become indispensable across various sectors, from enhancing efficiency in manufacturing processes to improving patient care in healthcare, the impact of these technologies is profound. Robotics and automation have the potential to revolutionise various sectors by boosting productivity, ensuring precision, and enhancing safety. However, the full potential of these technologies remains underutilised due to significant barriers, particularly the shortage of a skilled workforce capable of operating and the lack of tools that can be used in robotic engineering and experimentation.

To address these challenges, the control electronics for the scissor-lift mechanism made by fellow student Kertrud Geddily Küüt was built and programmed as a multifaceted educational and research tool with a practical use in various fields of work. Enabled by our programming, we equipped it with user-friendly controls that allow for precise platform control, facilitating immersive learning experiences and hands-on experimentation. As a core component of the Robotont open-source initiative, it serves as a catalyst for practical learning in robotics and automation.

In summary, our work on the electronic controls and programming of existing scissor lift mechanism fills a crucial gap in robotics education, empowering students and professionals with the skills necessary to thrive in today's technology-driven world. By providing a user-friendly platform for practical experimentation, it not only enhances learning outcomes but also fosters collaboration and innovation within the robotics community.

Keywords: Robotics, lifting mechanism, mobile robot, automation, open-source, open hardware, educational robotics

CERCS: T125 Automation, robotics, control engineering;

Juhtelektroonika ja programmi väljatöötamine Robotondi kõrguse reguleerimise mehhanismile

Lühikokkuvõte:

Tänapäeva dünaamilises maailmas on robootika ja automatiseerimine muutunud erinevates sektorites asendamatuks, alates tootmisprotsesside tõhustamisest kuni patsientide eest hoolt kandmise parandamiseni tervishoius. Robootika ja automatiseerimine võivad tootlikkuse tõstmise, täpsuse ja ohutuse suurendamise kaudu revolutsiooniliselt muuta eri sektoreid. Tihti aga alakasutatakse neid tehnoloogiaid, sest esinevad mitmed takistused nagu näiteks töövõimelise kvalifitseeritud tööjõu puudumine ning inseneritöös ja eksperimenteerimises kasutatavate tööriistade puudus.

Nende väljakutsete lahendamiseks ehitati ja programmeeriti juhtelektroonika Kertrud Geddily Küüdi poolt valmistatud käärtõstemehhanismi mehaanilisele osale. See võimaldab antud süsteemi kasutada mitmekülgse õppe- ja uurimisvahendina erinevates töövaldkondades. Tänu lõputöö jooksul loodud programmidele ja koostatud elektroonikale varustati see kasutajasõbraliku juhtseadeldisega, mis võimaldavad platvormi täpselt juhtida, hõlbustades kaasahaaravat õppimiskogemust ja praktilisi katseid. Avatud lähtekoodiga algatuse Robotont põhikomponendina on see hea ühenduspunkt robootika praktilise õppimise ja automatiseerimise vahel.

Kokkuvõttes võib öelda, et meie töö olemasoleva käärtõstemehhanismi elektrooniliste juhtimisseadmete lisamise ja programmeerimisega täidab olulise tühimiku robootikahariduses, andes õpilastele ja spetsialistidele oskused, mis on vajalikud tänapäeva tehnoloogiapõhises maailmas arenemiseks. Pakkudes praktiliste eksperimentide jaoks kasutajasõbralikku platvormi ei paranda see mitte ainult õpitulemusi, vaid soodustab ka koostööd ja innovatsiooni robootikakogukonnas.

Võtmesõnad: Robootika, tõstemehhanismid, mobiilne robootika, automatiseerimine, avatud tarkvara, avatud riistvara, haridusrobootika

CERCS: T125 Automatiseerimine, robootika, juhtimistehnika;

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ABBREVIATIONS

PC – Personal Computer

ROS – Robot Operating System

GUI – Graphical User Interface

VR – Virtual Reality

LCD – Liquid-Crystal Display

GPIO – General Purpose Input\Output

PCB – Printed Circuit Board

RGBD – Red Green Blue Depth

PWM – Pulse Width Modulation

1 INTRODUCTION

Robotics and automation are becoming vital in various fields, including manufacturing, healthcare, transportation, and agriculture. These technologies boost efficiency, productivity, and safety. With the aid of artificial intelligence and machine learning, robots can execute repetitive tasks with high precision, paving the way for groundbreaking advancements [1].

This thesis focuses on the development of the control electronics and the program for the existing scissor-lift mechanism made by fellow student Kertrud Geddily Küüt [2]. The program is designed to enable the mechanism to raise and lower a platform through user commands issued via an intuitive touch-screen interface. The control electronics of the scissor lift's control system serves as both an educational tool and a research platform, making it an invaluable asset for university teaching and professional training.

In this project, the main focus is on developing electronics for the control of the system and on programming an interactive environment for the user to utilise the Robotont lifting platform in an educational environment.

To equip future professionals, we have developed a program for the scissor-lift mechanism designed as a comprehensive educational and research tool. This system, featuring an easy-to-use touch-screen interface, allows for precise control of platform elevation, making it perfect for interactive learning and experimentation. As part of the Robotont open-source project, this mechanism promotes practical experience in robotics and automation.

By offering a user-friendly, practical controls and program for this scissor-lift mechanism we tackle a key aspect of robotics education. It empowers students and professionals with the skills needed to excel in advanced technological environments. This open-source program not only enriches the learning experience but also encourages collaboration and innovation within the robotics community.

2 LITERATURE REVIEW

2.1 Robotont platform

Robotont [3] is an open-source hardware and software platform. Featuring an omnidirectional [4] mobile robot with ROS [5] capabilities, the project caters for advanced robotics education and research. The robot platform has a flexible design (Fig. 1) allowing users to reconfigure sensors and other units to add to the standard design of the project.

Robotont has shown to be a great education tool and a research platform, by being widely used for in-university teaching, professional training, and internet courses focused on ROS and robotics. It has also served as a subject or demonstrative tool in a growing number of student theses and as a platform for validating progressive robotics research, such as software frameworks and motion planning.

The widespread adoption of Robotont demonstrates the platform's technological maturity and its inherent support for the native ROS. Having this ROS support, Robotont can integrate various software features that can be accessible within the native ROS ecosystem. Robotont has preconfigured essential functionality for mobile robots based on it, such as teleoperation, 2D simultaneous localization and mapping [6], and tracking of fiducial markers [7]. Though the list of capabilities of Robotont is always growing from all of the new features being added into it.

Fig. 1. ***Robotont platform.***

Unique lifting mechanism [2], similar to a scissor lift, has been developed for Robotont. The mechanism allows the touchscreen to be moved up or down, the whole construction weighing no more than 3kg. The height of the mechanism is adjustable being 58 cm in lowest position and 124 cm in the highest position, which allows people to interact with a touchscreen without having to sit down or bend over.

The lifting mechanism extends beyond the limits of Robotont when the screen is lowered. However, when the screen is raised, the control screw stays within Robotont's boundaries. The mechanism is electrically controlled using a Pololu gear motor [8] with an integrated quadrature encoder. Additionally, a Waveshare 7-inch touchscreen [9] is mounted on the mechanism.

The motor's power consumption when raising the mechanism averages out at 19 W, with peak consumption being 30 W at supply voltage being 12 V with a current of 2.5 A. While the mechanism was lowered power consumption averaged out at 4 W, with peak consumption of 6 W at supply voltage being 12 V and current being 0.6 A.

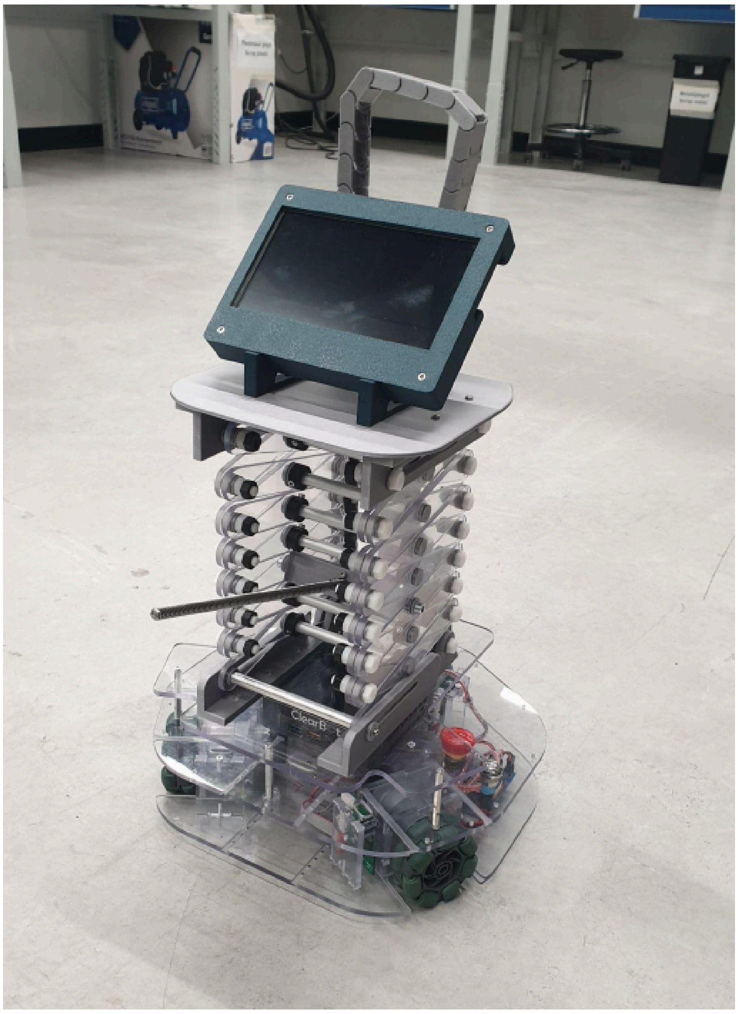

Fig. 2. ***Height adjustment mechanism platform for Robotont.***

2.2 Endstop switches examples and applications

The purpose of any endstop switch in a system is to detect when an axis has reached a minimum or maximum bound, providing the feedback back for the system to change its state [10].

Mechanical endstops [11] are the simplest and most common type of endstop commonly used in 3D printing. They operate as basic switches installed on each axis. At the start of a print, the printer moves each axis until the carriage hits the switch. These endstops are preferred due to their low cost and ease of use, connecting to the printer's motherboard with just two wires. Installation is straightforward, involving mounting an endstop on each axis and wiring it to the motherboard.

To adjust the actuation distance of mechanical endstops, a bolt is typically added to the carriage. The bolt makes contact with the endstop to trigger it, and by screwing the bolt in or out, the distance and home position can be adjusted [11].

Optical endstops [12] are less favoured due to their higher cost and complexity, offering limited advantages over mechanical endstops. Their main benefit is non-contact triggering, which can increase durability and reduce the risk of damage. Optical endstops feature a U-shaped photointerrupter, comprising an infrared emitter and an optical detector. The endstop is triggered when the light beam between them is interrupted, typically by a thin blade on the carriage.

Hall effect endstops are a moderately popular option. Hall effect endstops are designed for manually turning on and off electrical circuits for automatically turning them off in case of overload, short circuit, voltage drop, as well as for starting and protecting asynchronous motors [*13*]. They use a Hall effect sensor and a magnet on the carriage. The sensor detects the magnetic field as the carriage approaches, triggering the endstop. Like optical endstops, Hall effect endstops are non-contact, reducing wear and allowing precise and repeatable home positioning. But the drawback of Hall effect endstops is their complexity and slightly higher cost compared to mechanical endstops, though they are cheaper than optical endstops. They require a PCB with components such as an operational amplifier and resistors.

2.3 Application of scissor lift mechanism in Robotics

The article "RoomShift: Room-scale Dynamic Haptics for VR with Furniture-moving Swarm Robots" [14] discusses the design and implementation of the RoomShift robot, which has a wheel-based robot and an extendable mechanical structure. The study describes RoomShift, a room-scale dynamic haptic environment for virtual reality. RoomShift's goal is to provide room-scale haptic experiences by deploying a swarm of shape-changing robots to reposition existing furniture and create customizable physical settings (Fig. 3)

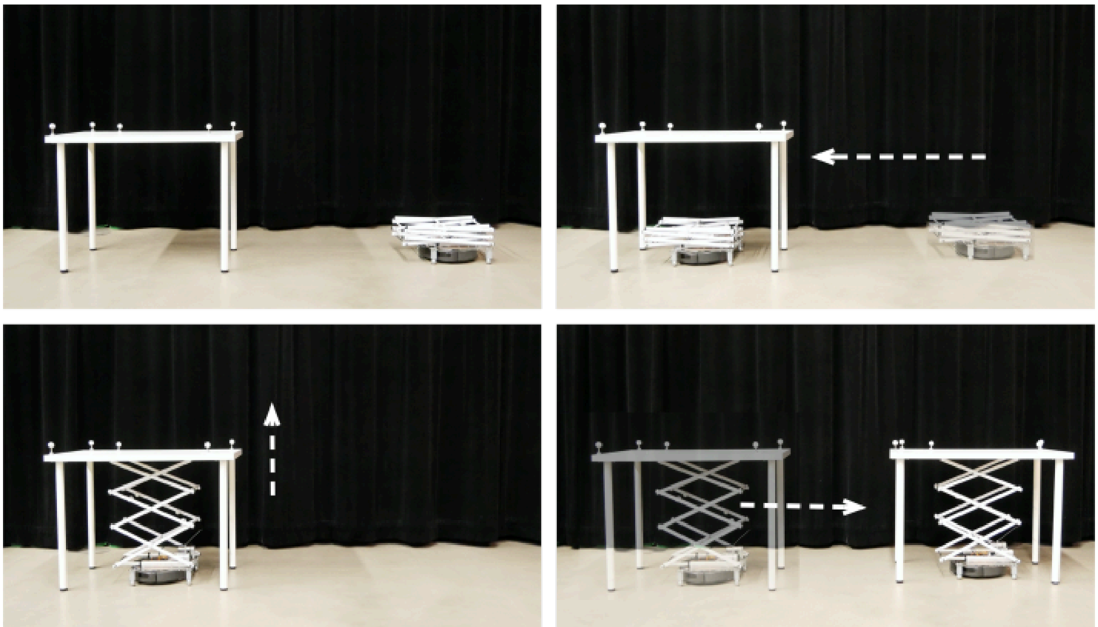

Fig. 3 ***A RoomShift robot drives beneath a desk, lifts it by extending the scissor structure, and moves it.***

The overall architecture of the project is shown on (Fig. 4.) The primary PC is running a Node.js server and Qualisys tracking software. The 6DOF tracks the data that the Qualisys captures and streams it to the Node.js server through WebSocket protocol. A web browser client using A-Frame renders the VR scene based on the tracking data. The user interacts with the VR scenario using an Oculus Go head-mounted display and its built-in VR browser.

WebSocket is used to create a real-time connection between the desktop computer and the Oculus Go browser, ensuring synchronisation. When changes occur in the virtual scene, the system reconfigures the physical scene by moving robots. Initially, the system determines the types of props and their target places depending on the user's relative position.

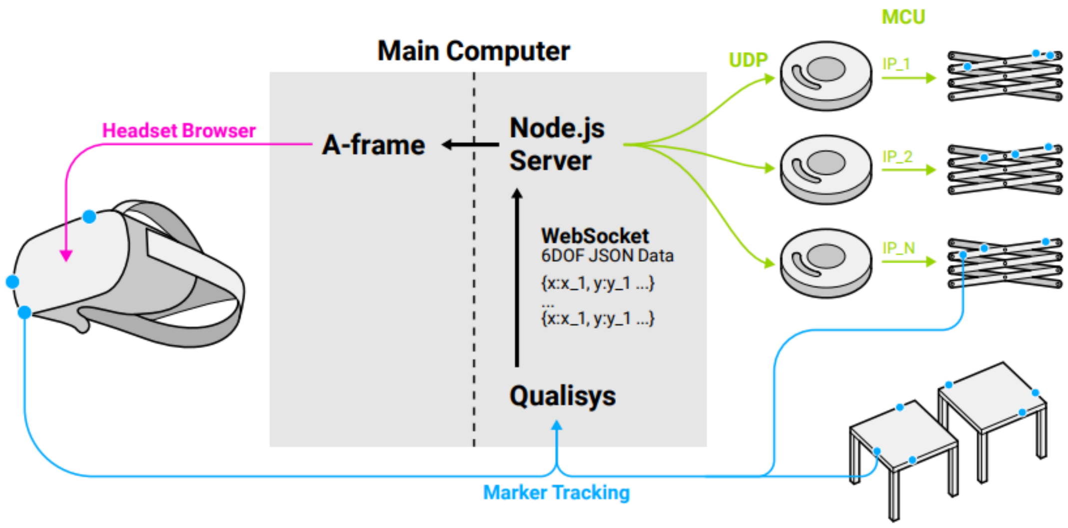

Fig. 4 ***Communication software scheme of RoomShift.***

The article "Scissor mechanisms enabled compliant modular earthworm-like robot: Segmental muscle-mimetic design" [*15*], an implementation of scissor-lift mechanism is featured in soft-robotics.

To accomplish peristaltic locomotion, two key designs are necessary: actuation and transmission mechanisms. The actuation mechanism features an actuator adapter that links the servo to the scissor mechanisms, allowing for controlled structural deformation. Each segment needs to be independently controlled, even though they are interconnected through the transmission unit, to facilitate sequential contraction and extension.

A high-stroke actuation system is required to drive all components, including electronics, mechanical devices, and the transmission unit. The MKS DS450 servo is selected for its high resolution and quick response. Four servos are needed to ensure the smooth operation of each circular muscle structure.

In the basic muscle-mimetic unit, illustrated in (Fig. 5a), each servo is embedded within the structure. Beam 1 and Beam 2 function as connecting rods and servo adapters, resulting in a compact design. Beam 1 is 3D printed from brass, while Beam 2 is made from stainless steel. This unit is used to test the accuracy of the actuation system.

The Tracker Video Analysis and Modeling Tool is used to examine the kinematic properties of the basic unit through image processing technology, as depicted in (Fig. 5b).

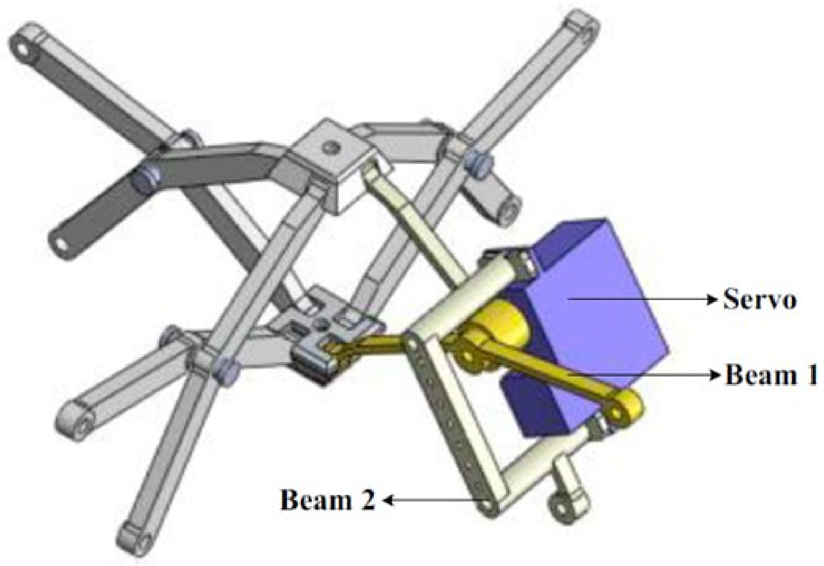

Fig. 5a. ***Basic muscle-mimetic unit***

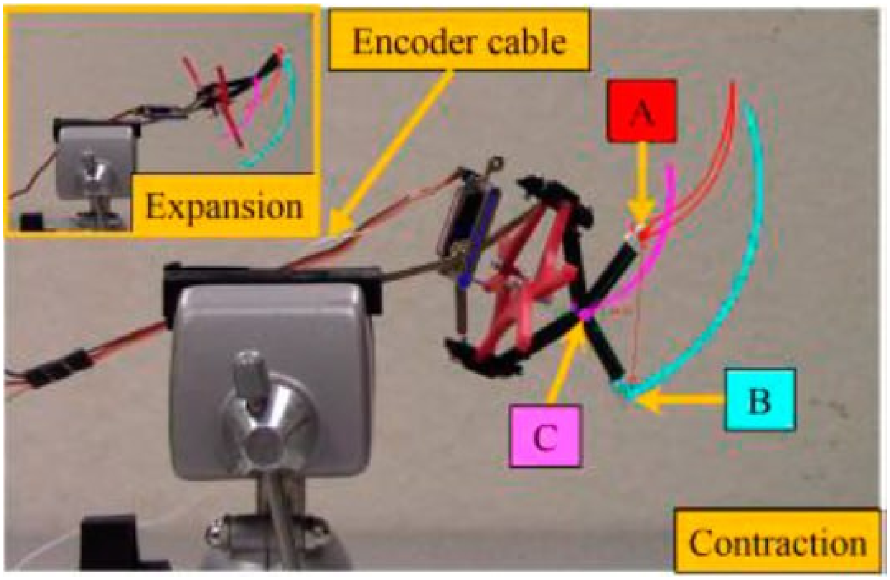

Fig. 5b. ***Basic muscle-mimetic unit test***

2.4 Application of GUI in Robotics

The article “Graphic interface development for teaching robotics related computer vision techniques” [16] discusses the development of applications to enhance understanding of computer vision techniques for robotics. The project goal was to create an intuitive and user-friendly graphical user interface (GUI) for a mobile robot for various educational levels of practical lessons. The purpose of the robotic setup is to explore the environment from the perspective of the robot using different computer vision techniques in real time.

The GUI design is shown on Fig. (5). To build the graphic interface, two images are used: a background image saved in the root directory of the ROS package and the image received from the RGBD sensor. The interface shows the user two image elements: one raw image read from the sensor and a processed image using computer vision techniques. The processing techniques can be selected by users in the lower left quarter of the interface. This GUI also has a control panel for the robot's teleoperation.

As a practical implementation, this project showed overall satisfaction in users of different educational levels. Many of the respondents noted that the GUI application was very useful for practical lessons.

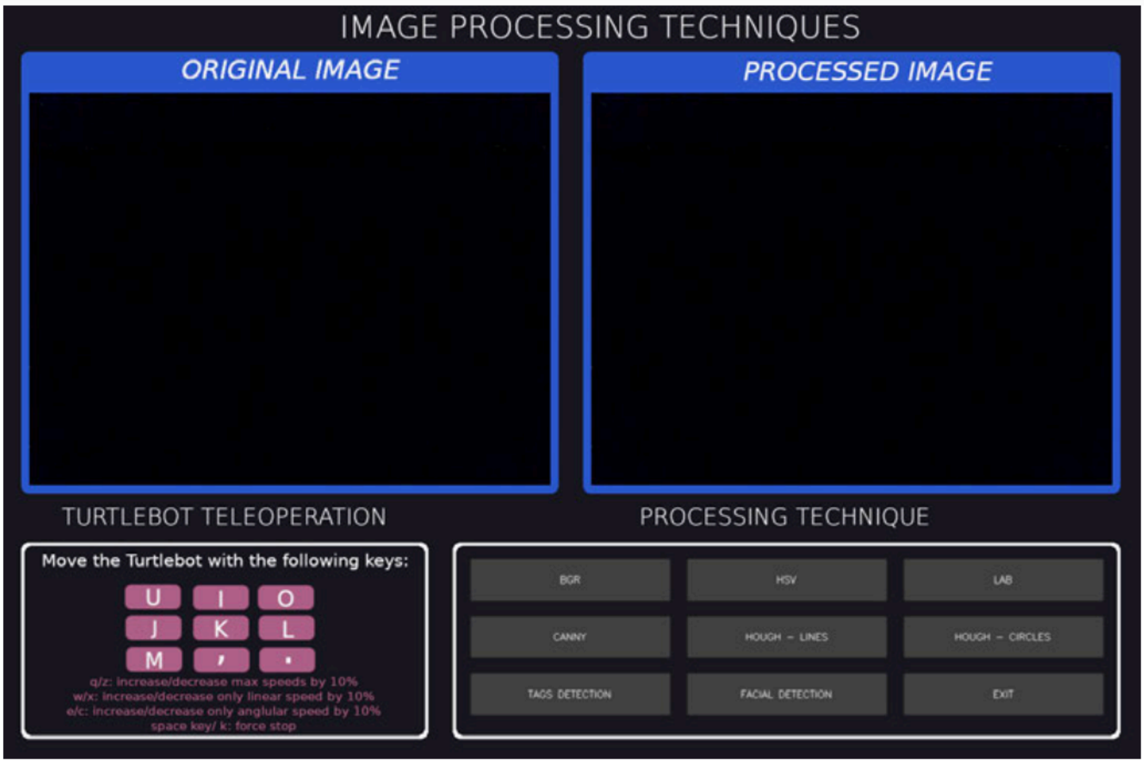

Fig. 5 ***Graphical user interface design.***

3 OBJECTIVES AND REQUIREMENTS

3.1 Objectives

This thesis is a continuation of an ongoing work on the lifting mechanism. The purpose of this project is to equip and manage electronics for the existing lifting system of the Robotont platform. The scissor-lift mechanism should be able to raise and lower the platform by command of the user, using a touch-screen attached to it. The lifting system will be used as a teaching tool and a research platform, frequently used for university teaching and professional training, as a part of the Robotont open-source project.

3.2 Requirements

- To function correctly, the system requires the following components: an encoder motor, a motor driver (in this case the native Robotont one), a microcontroller, and a touchscreen LCD display.

- From a software perspective, various parts of the mechanism should be connected using Python code, with the LCD touchscreen serving as a user-friendly interface for interacting with the machine.

- Simple logic of the required workflow is seen on Figure 6. After receiving the secondary input from the user, the motor should start operating. If the platform reaches a certain height, it will trigger the switch. Based on the switch's status, the system should determine whether to continue operating or stop altogether until the next input from the user.

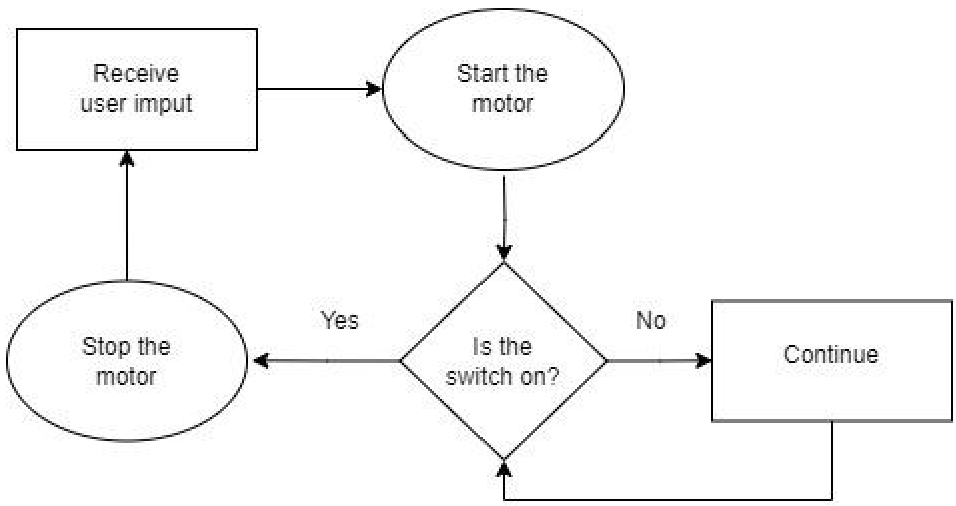

Fig. 6 ***Simple logic block diagram of the required workflow.***

4 DESIGN AND IMPLEMENTATION

4.1 Materials

For the design development of the system, the following materials were used to achieve the desired outcome of the project.

Electronics:

- Subminiature Basic Switch SS-5GL [17]
- Robotont Motor Driver v.1.0 [18]
- 19:1 Metal Gearmotor 37Dx52L mm 12V with 64 CPR Encoder [8]
- RaspberryPi [19]
- Inch IPS LCD Touch Screen Display Panel 1024×600 [9]
- 10k Ohm pull-down resistors
- Jump wires

Other related hardware:

- Height adjustment mechanism for Robotont (platform)
- HDMI cable

Software specifications:

- Python-based code
- RaspberryPi OS

4.2 Workflow

4.2.1 System logic development

Considering the previous requirements mentioned on (Fig. 6), the final communicational architecture of the system is demonstrated in details further below on (Fig. 7.) After receiving the initial input from the user using the user interface the signal goes to the microcontroller after which, depending on the signal that is being sent by either the limit switch, motor drive or the GUI it's passing the signal to the motor driver which in turn activates the motor.

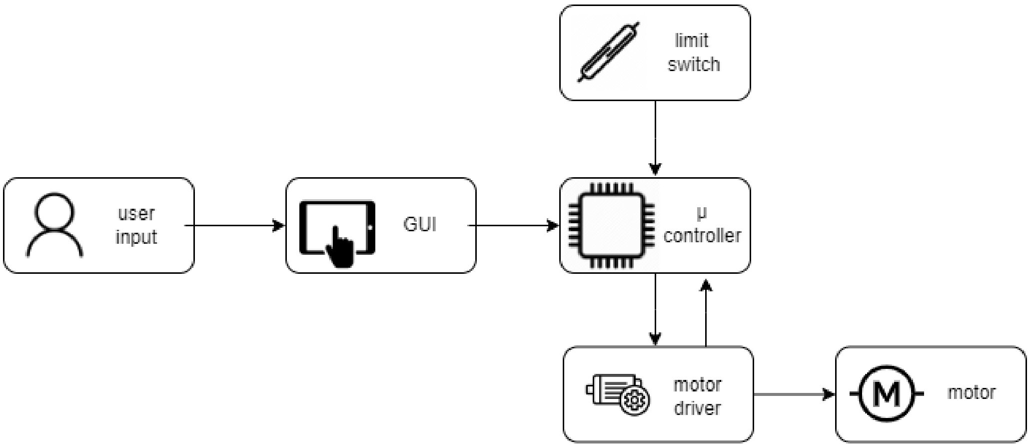

Fig 7. ***Architecture of the communicational logic of the system.***

4.2.2 Electrical configuration

In order to establish the communication between devices and hardware elements, some wiring work was done. For the wired connection between the single-board computer (Raspberry Pi), limit switches and the motor driver, a protoboard was developed. It consists of two rows of pins, one for the GPIO logic, the other for ground Additional pins were also added for pull-down resistors for the pinout of both switches to ensure the logic level on a pin under any circumstances. The protoboard serves as a temporary connecting joint, a prototype for the future development of printed circuit board (PCB).

On the diagram (Fig. 9) the schematic of connections is demonstrated.

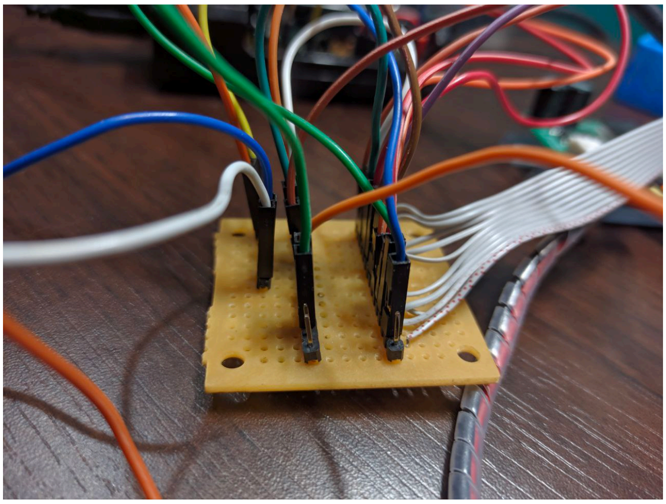

Fig 8. ***Protoboard wiring.***

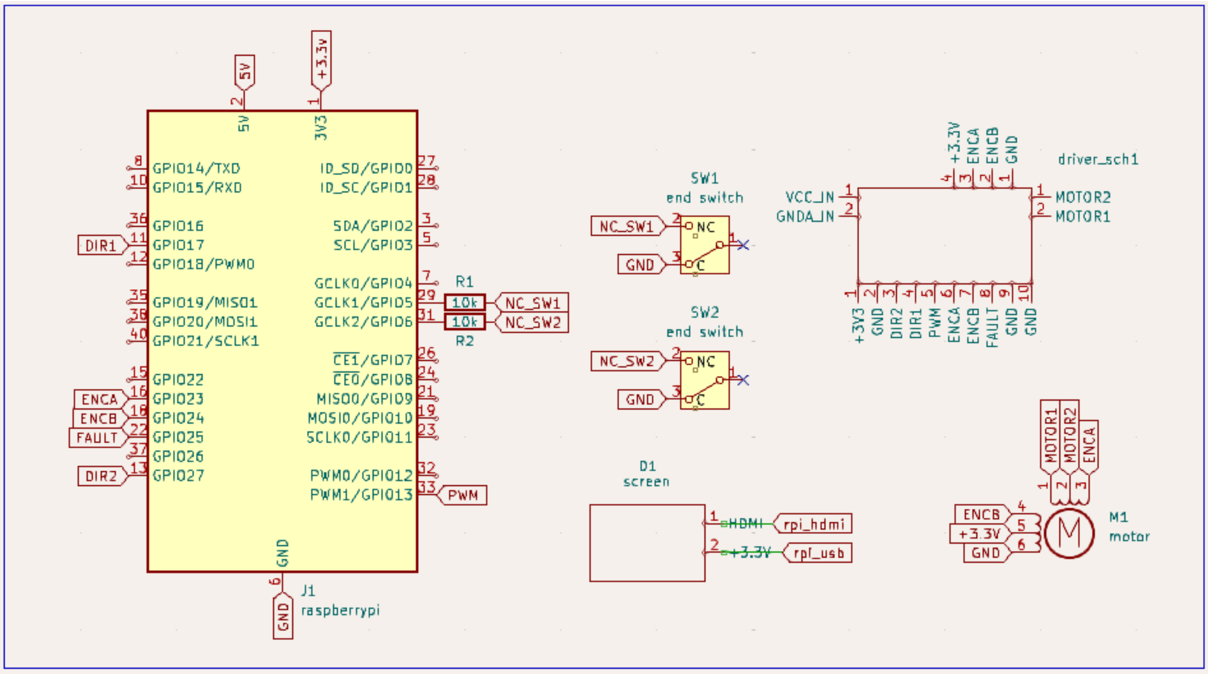

Fig 9. ***Schematic of electrical connections.***

4.2.3 Programming

The programming part is designed to control a motor using a Raspberry Pi and a graphical user interface (GUI). The motor can move up or down, and its motion is controlled via two buttons available for the user on the GUI. The motor stops automatically when it reaches a limit switch at either end of its range, or stops by demand of the user.

In the script several python libraries are initialised. RPi.GPIO library is used for controlling the GPIO pins on the Raspberry Pi. Various GPIO pins on the Raspberry Pi are designated for specific functions like setting the motor's direction, generating PWM signals for motor speed control, and reading inputs from limit switches and encoders. The GPIO pins are configured either as inputs or outputs based on their intended use. For example, pins controlling the motor's direction are set as outputs, while pins connected to limit switches are set as inputs. PWM (Pulse Width Modulation) is initialised to control the motor speed.

Tkinter for creating the GUI, and threading for handling concurrent operations.

As a main body of the code, several functions are in use. Motor control functions enable the motor to go either up, down or stopping it via using the PWM signal.

Implementing network communications between devices and using graphical user interfaces simultaneously in one system may result in some challenges in the ability of the program to run smoothly. To ensure there will be no blocking functions, threading was implemented in script. The structure of said functions can be observed on (Fig. 8) below. When the "Up" or

“Down” button is pressed, a new thread starts. This thread starts the motor moving upward and continuously checks the status of the upper limit switch. When the switch is triggered, the motor stops.

```
def upthread():
    global up_pressed
    start_motor_up()
    while not GPIO.input(LIMITSWITCH1_PIN) == GPIO.HIGH:
        pass #waiting for switch
    print("Swtich 1 is pressed")
    stop_motor()
    up_pressed = False

def downthread():
    global down_pressed
    start_motor_down()
    while not GPIO.input(LIMITSWITCH2_PIN) == GPIO.HIGH:
        pass #waiting for switch
    print("Swtich 2 is pressed")
    stop_motor()
    down_pressed = False
```

Fig 8. ***Threading functions.***

The main window of the GUI is created in fullscreen mode with a title "Motor Control".

A frame is added to the window to organise the layout. Two buttons are added to the frame: "Up" and "Down". Pressing these buttons starts the respective threads for upward or downward movement of the motor. (Fig. 9). The GUI enters a main loop, which waits for user interaction. The button “Exit” will kill all running processes and close the GUI. The program is designed to also handle keyboard interrupts, ensuring that the motor stops and the GPIO pins are cleaned up properly when the program exits.

To ensure any blocking accidents in the code execution, lambda function (Fig. 10) was introduced into the code. This function is an anonymous function that does not require any definition, unlike regular functions defined after the def method.

```
btn_up = ttk.Button(frame, text="Up",
style="TButton", command=lambda:
threading.Thread(target=upthread).start())
btn_up.grid(row=0, column=0, padx=50, pady=50)

#Down button
btn_down = ttk.Button(frame, text="Down",
style="TButton", command=lambda:
threading.Thread(target=downthread).start())
btn_down.grid(row=0, column=1, padx=50, pady=50)

exit_btn = ttk.Button(frame, text="Exit",
style="TButton", command=root.destroy)
exit_btn.grid(row=2, column=0, columnspan=2, pady=
(10, 50))
```

Fig 10. ***Buttons initialisation code.***

5 RESULTS

The Robotont system was equipped with a scissor-lift system, enabling it to raise and lower the platform based on user commands via an attached touch-screen interface. Designed as a teaching tool and research platform, the system is ready to be used in university teaching and professional training as part of the Robotont open-source project.

5.1 Demonstration

To demonstrate the functionality of the system, the testing was done on the whole physical setup of the lifting platform. Proving the concept and meeting the requirements, the lifting mechanism would run up and down by command of the user via the touchscreen. The limit switches also notify the system if it has reached its limits.

On (Fig. 11 and 12) the execution of the setup is demonstrated.

Fig 11. ***Touchscreen GUI.***

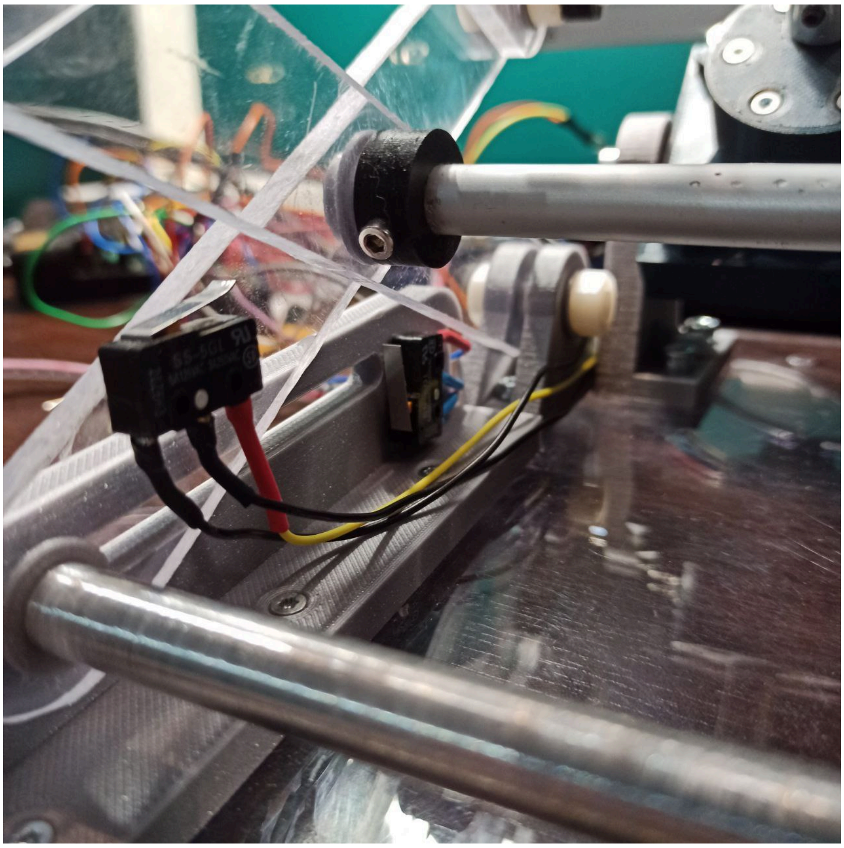

Fig 12. ***Limit switch placement.***

6 DISCUSSION AND FUTURE WORK

As a result of this project, the requirements were fulfilled and the control electronics and program for the height adjustment mechanism were developed.

6.1 Future work

The current system was developed for the specific needs of the Robotont project, but there is potential to make the platform more versatile as an open-source asset. While this thesis focused on the Robotont control electronics development, the system can be adapted for other mobile robots using scissor-lift with some changes to the source code. This adaptability is highly beneficial, offering the flexibility to overcome various limitations and making it suitable for more applications in general, making it more accessible to the engineering community worldwide. Therefore, an integration of the system into ROS would be the first in line action to make the project more adaptable for the open-source platform model.

From the control development point of view, various improvements could be done in the scope of the future work. There is a possibility to adapt an automatic height adjustment feature for the system, so it would make the robot-human interaction more pleasant for the user. The height adjustment should be based on the height of the user itself, who is interacting with a platform. The system is equipped with a encoder gearmotor that makes it possible for precise detection of the position of the motor in rotation. The encoder availability on the platform can potentially be a solution for future height management.

Furthermore, there is a possibility to replace the existing protoboard that serves as a connection point for the microcontroller and the motor driver with a PCB, so the physical connectivity of wires is more stable.

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Appendix

I. Source repository

The following repository contains all related files of the project.

https://github.com/ut-ims-robotics/volynets-thesis-2024-robotont-scissor-lift-control-system

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