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Technology transfer framework review for easy Cobot adoption by SMEs

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Abstract

Collaborative industrial Robots (Cobots) were introduced as an advancement to traditional industrial Robots. Some advantages that were incorporated in Cobots included the ease of human interaction, safer working conditions and considerable smaller sizes.

However, most Small & Medium Enterprises (SMEs) in Norway are not convinced of the merits of adopting these Cobots into their operations.

This study seeks to understand the marketable features of the UR10e, and link these features to the operations in Small & Medium Enterprises (SMEs). The study focused on the design and development of a tool that eases the adoption of the UR10e cobot by SMEs. This tool enables users with the barest technical knowledge and programming skills to manipulate the UR10e. This solution should increase staff recruitment concerns (revenue lost to new high, salary cost, specialized technical expertise etc.) of SMEs. An additional benefit of the tool developed is its opportunity to serve as a training platform for new staff or as a testing platform for unverified processes.

A literature review has been conducted to understand the evolution of industrial robots and the current applications of Cobots in various industries.

Keywords: Cobots, SME, human-machine interaction, Industry 5.0, technology transfer

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Acronyms

ABB: Asea Brown Boveri

AD: After the death of Christ

AI: Artificial Intelligence

cmd: command prompt dialog box

Cobot: Collaborative robot

EU: European Union

FANUC: Fuji Automatic Numerical Control

GUI: Graphical User Interface

HR: Human resources

IDE: Integrated Development Environment

IFR: International Federation of Robots

I/O: Input/Output

IP: Internet Protocol

ISO: International Organization for Standardization

KUKA: Keller und Knappich Augsburg

OPCUA: Open Platform Communications Unified Architecture

ROI: Return on Investment

RTDE: Real time data exchange

SCARA: Selective Compliance Assembly Robot Arm

SME: Small & Medium Enterprise

TCP: Tool Center Point

TTO: Technology Transfer Office

UR: Universal Robots

VM: Virtual Machine

1 INTRODUCTION

Collaborative robots (Cobots) are very versatile to various applications of different industries. As an improved version of the traditional robots, Cobots were designed to be safe for humans to work around [1]. It was designed for easy collaboration between human and machines.

1.1 Background

Over the years, industrial robots have been developed and improved to achieve the aim of aiding humans to do work. However, the safety risk associated with these traditional robots were great. People could be maimed or pinned to death when within the operating area of the robot.

With the introduction and advancement of industry 5.0, the collaborative robots (Cobots) were designed to minimize the safety risk with added benefits for not too large production facilities.

Manufacturers of Cobots are compelled as every other technology, to prepare a Technology Transfer documents and events to enable any business entity to easily purchase and use the tool to achieve some efficiency in their operation, create ease of work while saving cost.

1.2 Problem statement

Contrary to theory, there is some reluctance to the adoption of the Cobots by SMEs. This can be attributed to little or no knowledge by the SMEs about the technology transfer from the manufacturers offers to the SMEs [2].

1.3 Project description/benefits

This project seeks

i. to review and improve the existing technology transfer frameworks for Cobots
ii. undertake a survey to understand the possibilities to attract the SMEs towards the new generation robots
iii. set up a Cobot (UR10e) and showcase its application as an Industry 5.0 tool
iv. provide a tool to ease the transfer of knowledge to SMEs

1.4 Theory/Hypothesis

The marketable features of the Cobots have to be linked with the operation of the SMEs to increase patronage.

1.5 Assumptions

The following assumptions are considered as reasons for the low patronage by the SMEs to adopt Cobots:

i. High cost, time and knowledge implications of the adoption to the company
ii. Low efficiency by the industrial robots/Cobots/advanced manufacturing systems to the company's operation
iii. Inability to prepare and setup for multiple tasks
iv. Most operators who were trained on traditional robots prefer the traditional robots to the new generation robots

1.6 Objectives

This study aims to:

i. Review existing technology transfer frameworks for industrial robots/Cobots/advanced manufacturing systems
ii. Suggest improvements on how to increase the availability of knowledge on technology transfer
iii. Understand the setup of the UR10e and its applications
iv. Connect some marketable features of the UR10e to the operations of the SMEs

1.7 Scope

The scope employed shall involve:

i. Conduct a literature review on the evolution of industrial Robots and the current applications of Cobots in various industries towards Industry 5.0.
ii. Review how many SMEs employed the use of Cobots in their operations
iii. Perform a study on the current use of Cobots by SMEs and their challenges
iv. Install the UR10e Cobot and peruse its applications
v. Develop a tool to ease the knowledge transfer to SMEs
vi. Establish remote connections of the robot to monitor, operate and collaborate
vii. Demonstrate the applications and tools of the UR10e Cobot to industry players within the SME sector
viii. Collate feedback on the ease of use, further improvement opportunities and challenges

ix. Prepare a Report on the findings.

x. Prepare a PowerPoint presentation and present an oral presentation of the prepared work.

2 LITERATURE REVIEW

This literature review seeks to review relevant literature on the evolution of industrial Robots and the current applications of Cobots in various industries towards the realization of Industry 5.0. The review considers four major thoughts: Industrial Robots (Introduction, Evolution and Drawbacks & Opportunities), Cobots (Applications and Future Outlook), SMEs (Composition and Challenges) and Technology Transfer (Adoption, Challenges and Framework).

2.1 Industrial Robots

IS0 8373 defines an industrial robot as a fixed or movable unit that is automatically controlled, reprogrammed and manipulated programmable in three or more axes to perform multipurpose functions [3]. The International Federation of Robots has various categories of robots but maintains the ISO definition of industrial robots [4].

2.1.1 Introduction

Since the inception of performing work, humans have always strived to ease the way of doing things [5]. Sometimes the new skill introduced may provide a simpler or a complicated solution.

Prior to the first industrial revolution, the achievement of work relied on human- and animal-labour [6]. This production strategy relied solely on the skill of a person and the amount of energy supplied by an individual or group of people, animals or a mix of humans and animals. Simple machines defined by Britannica dictionary as a single or multiple device(s) with minimal or “no moving parts that are used to modify motion and the magnitude of a force in order to perform work” [7] were employed. During these periods (stone age, etc.), the people developed some artifacts to ease how work was done [8]. It is also argued that as far back as 85AD in the home of Hero of Alexandra, there were some devices which used mechanisms such as pulleys, hydraulics, and levers to automate fun-providing equipment [9]. These artifacts developed the ancient Greek word “*automatos*” [10,11]. Over the years, many other inventors would create automations with some notable ones being Leonardo Davinci in 1801, Albert the great in 1282 and Roger Bacon by 1294 [10].

By 1750, the first industrial revolution was witnessed by the introduction of the steam engines to substitute the labour of man and animal alike in activities of transportation, production, etc. [6,12]. This was the start of reducing the excess labour by man/animal while increasing productivity.

Between 1871 to 1914, the second industrial revolution changed the production sector, with the introduction of standards and advancements to mass produce goods [6,13]. It was(is) considered the beginning of the technological revolution.

During the third industrial revolution (from around 1950 to around 2021), aside from the discovery of nuclear energy, the era was revolutionized by the automation of processes and the digitization of information [14]. Industrial robot; a significant tool in automation, was born. As the intellectual romance between art and science ripples, although the concept of automation already existed, the premier use of the word "*robot*" was in 1921 by a Czech writer, Karel Capek. His introduction of the idea came in the work, *Rossum's Universal Robots (R.U.R)* [15]. The movie *Metropolis*, produced in 1926 made the term "*robot*" a global phenomenon [16,17]. This could also augment the thought that humans have been fascinated by machines having a likeness of a living form and been able to perform tasks and movements of that form [10]. Scientists, technologists and engineers considered the play of mixed value and noticed the plausible possibilities of such an instrument been designed and produced [18]. In 1961 the first industrial robot was introduced into the General Motors production line after it was developed by George Devol and Joseph Engelberger in 1959 [19].

The concept of the fourth industrial revolution was introduced in 2016, with the harmonic connection of an entire industrial network through the internet of things (IoT) to achieve the desired purpose [20]. Prior to the consideration of this concept, industrial robots were characterized by some crucial features which included the inability to share a common space with man because of the safety risk [21]. To provide a solution to this problem while improving collaboration with human interactions, the first collaborative robot (loaded with more sensors, actuators and micro-controllers) was developed by J. Edward Colgate and Michael Peshkin in 1996 [22].

The fifth industrial revolution has been conceptualized as the era that gives humans the decision and control of how the production process would occur, contrary to how humans had to adjust their lifestyles to suit the machine operations [23]. Current models of collaborative robots possess the possibilities of been controlled from a remote location based off the virtual environment created for the user (positioned several miles away from the cobot) [24]. In contrast, the earlier models could only be powered, taught, controlled and monitored on site.

2.1.2 Evolution

Although, Karel Capek introduced the word, “robot”, Isaac Arminov heavily promoted the term “robotics” through his science fictional literature works which further encouraged scientists, technologists and engineers towards the production and study of the field.[10]

Contrary to the thought by some scholars that robots have always been an element of automation and not that the fascination with human-like machines plays no significant role [10,17], it is crucial to note that the design and capabilities are based on “fascination with human-like" properties. This can be noted in the widely use of the term “robot arm”, designed with the attributes of a human arm but enhanced.

After the first industrial robot was developed by George Devol and Joseph Engelberger in 1959, in 1961 it was introduced into the General Motors production line for light fixtures such as interior parts, knobs and door handles of the vehicles, by performing a step-by-step operation from commands stored on a magnetic drum [19].

Coincidentally in 1966, the first Norwegian industrial was built by a barrow production company, Trallfa [25]. This robot had some outstanding features, the most crucial of which was its teachability. The functions of these features were introduced in the upgrade of the models produced in the following years [26].

From that period, most of the robots produced were heavily hydraulic and pneumatic in mechanical operation [27]. However, the all-electric six-axis articulated robot nicknamed the "Stanford manipulator” was invented by Victor Scheinman in 1969 [28].

Innovation guides the evolution of things, industrial robots been part of the list. Different economic and technological plans of countries and socio-economic blocs continually seek innovative ideas to improve their status. This can be studied off the “Made in China 2025” policy and the “EU whitepaper” amongst others [28,29]. These directions also influence the upgrade and evolution of industrial robots.

Over the years, industrial robots that are developed can be classified based on their physical structure, into six categories [30]:

- Articulated – a robot with an arm that has at least three rotary joints

● Cartesian – it possesses an arm that has three vibrant joints and whose axes are tallied with a cartesian coordinate system

● Cylindrical – its core axes form a cylindrical coordinate system

● Polar – has a linear joint combined with two rotary joints to form an arm with a twisting joint connected to a base

● SCARA – it uses two akin rotary joints to provide compliance in a plane

● Delta - a robot with an arm that have concurrent prismatic or rotary joints

However, the needs that the robot would serve, plays a role in its identification. Also, the considered upgrades that would be applied to its succeeding models are influences to the identification.

The adoption of industrial robots has seen significant increase with sales souring by 15% in 2021 than in previous year but some factors (High power tariffs due to Russia-Ukraine war, Post Covid-19 recovery, etc.) may cause a decline in 2022 and 2023 [31].

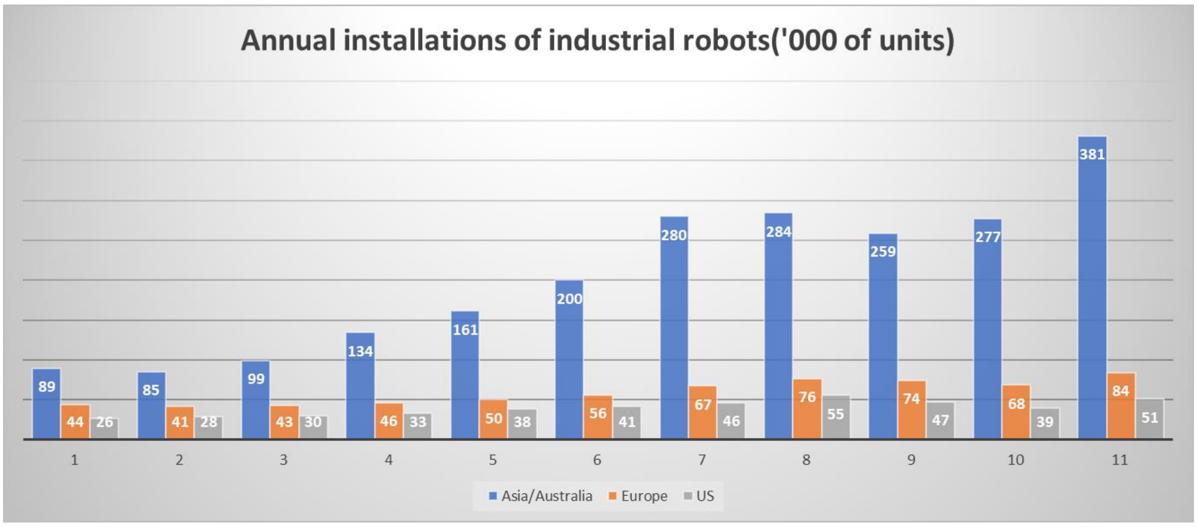


Figure 2.1 Industrial Robots Sales/Installations. (Source: IFR World Robots, 2022 [41])

Presently, about four companies account for about half of the total industrial robot market. These companies include KUKA in Germany, ABB in Sweden, FANUC and Yaskawa in Japan [28]. Interestingly, ABB shares a strong history with Norwegian company Trallfa [25, 26].

2.1.3 Drawbacks & Opportunities

Since the introduction of the industrial robot, efficiency can be noticed to periodically increase. However, some crucial drawbacks in its adoption and operation included:

- Safety – Due to the size of the robot physical structure, the weight of material, the power it was meant to provide etc., it is unsafe if it pins a person ultimately leading to maiming or death [32]. Also, as an unintelligent machine [33], it could not detect if a human is in danger or not.

- Cost of Purchase – The initial purchase and installation cost of the industrial robot is expensive and takes a long time for entities that purchase them to recoup the investment made [34].

- Space of Operation – Due to the size of the robot's physical structure, a wide space is required for the robot's operation to prevent it from running into other items and destroying them [35]. Also, for high-speed operations, enough room-space consideration is made to prevent run-ins and other damages [36].

- Skill acquisition & sharing – A high level of programming of the robot is required to operate it [37]. This required some level of expertise by the operators and made it difficult to operate the robots without them.

Regardless of these drawbacks, some opportunities lie within the solutions that may be proffered. These include:

- Safety – the developments of cobots and other peripheral devices for traditional industrial robots offer some safe working conditions with human presence [38]. Future developments hold more opportunities for providing even safer collaborative spaces.

- Perception – Some daily concerns that generally border about the general evolution of technology and the proliferation of robots/automation, is the reduction or total loss of human labour. It is feared that technologies, such as the cobots, destroy jobs [39].

Also, some crucial benefits include:

- Cost Efficiency – If effectively managed, the adoption of industrial robots ultimately reduces operating costs after a period [34].

● Productivity – A well planned operation with an industrial robot increases the productivity of the production floor [36].

● Learning and Research – As a rapidly growing, yet potentially viable field of study, it offers innovative ways to provide solutions [37]. Derivative and deductive analysis alongside iterative processes could offer some outstanding solutions to prevailing problems.

2.2 Cobots

Collaborative industrial robots, sometimes called collaborative robots or cobots are an improvement/advancement of traditional industrial robots [40]. They occupy less space, are safe and interactive with any human within their space as described by the IFR [41].

Although the concept of cobots were developed by J. Edward Colgate and Michael Paskin in 1996 [42,22], the first commercial cobot (UR5 model) was not sold until 2008 by Universal Robots, a Danish company [28].

As the current market requires a level of flexibility to achieve mass customization in reduced time through a multi-purpose assembly, Cobots provide a solution [43].

2.2.1 Applications

Collaborative industrial robots have been applied to multiple actions that normally should be performed by a human arm [44]. These actions include picking, palletizing, welding, painting, etc. In contrast to the traditional industrial robots which could also perform some of these tasks but without the physical presence of a human within the workspace, collaborative industrial robots can perform these tasks with the physical presence of a human within the workspace. On collision with (in some events, prior to collision), the collaborative industrial robot stops operation, to allow the action of the human to precede its action, creating a safe environment for collaborative interaction [38]. Some benefits of these collaborative interactions include a Quality inspection for an operation (machining, additive etc.) [44].

Applications of cobots may be summarized as proposed by Muller et al. [45]:

- Coexistence – considers a workspace where the human operator and cobot both exist but there is no interaction with each other.
- Synchronized – considers a workspace where the human operator and cobot both exist but perform their tasks at alternate times.

- Cooperation – considers a workspace where the human operator and cobot both exist and perform their tasks at the same time, but each party focuses on its separate tasks.
- Collaboration – considers a workspace where the human operator and the cobot ought to perform a task together thus, the action of one party has a direct or immediate consequence on the other party.

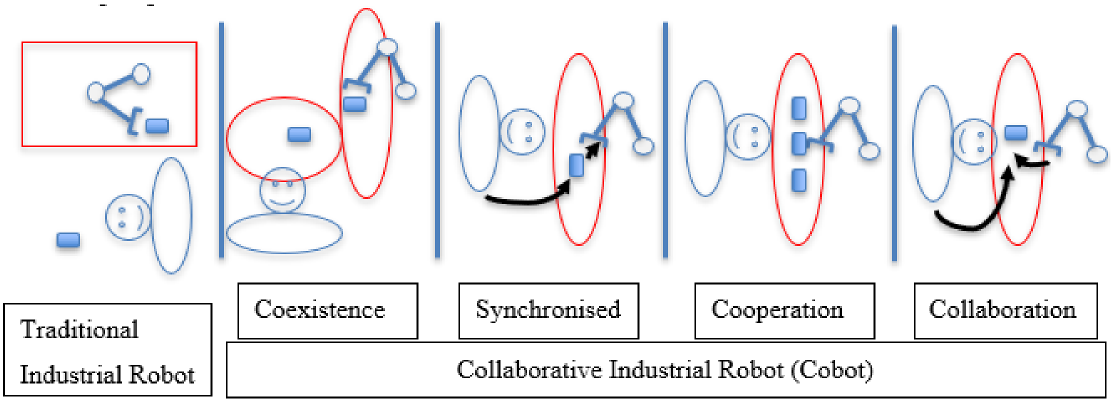


Figure 2.2 Cobot application arrangements (Source: Matheson et al, 2019 [34])

An improvement in a cobot today is “The Plug and Play” feature purported by [46] as a rendition of the “plug and produce” idea of Arai et al [39]. This framework considers the IT concept, “plug and play” which provides the ease of (un)plugging at a quick pace, components that need to be connected, with the barest or no reprogramming and reconfiguration of the whole or part of the system.

2.2.2 Future outlook

As the concept of Industry 5.0 considers the superposition of human considerations and ease to the performance of the machines, some outlook for collaborative robots include:

- High Sales – By 2025, it is believed the cobot market will grow to 12,303 million units sold and installed, from the 710 million units recorded in 2018 [47,48]. The IFR [31] estimates some dip in installations between 2022 and 2023 but is unfazed towards achieving the 2025 target.
- Improved Safety – There is a misconception that cobots are entirely safe [49]. This is not the case as it could be dangerous due to the tool being mounted [50]. Further research into improved safety is a possibility.
- Efficiency – More research will be carried out to improve the efficiency of current cobot models [34].

- Remote collaboration – An ongoing endeavor to remotely control and collaborate with cobots from any location with access to the internet [24].
- Artificial Intelligence – As the technological space approaches an Artificial Intelligent Ecosystem, the cobot is not excluded from this space [51].
- Green Solutions – Reduction of waste and green ways of manufacturing using cobots are being researched [52]

2.3 SMEs

Small and Medium Enterprises (SMEs) are characterized by their staff size, service or production delivery quantity and unique beginning. Globally, SMEs constitute 70% of manufacturers and job creation simultaneously [53].

Today, SMEs proffer some opportunities in the following regards;

- Product Customization
- Innovation
- Research & Design (R&D)

The EU white paper [51] in February 2020 stipulates the plan towards achieving an "Ecosystem of Excellence" by focusing on SMEs development, adoption and execution of Artificial Intelligence (AI). It indicates that 100 million Euros will be made available for the support of SMEs within the area of study from the first quarter of 2021. It also considers an innovation hub in each member state to provide support to the SMEs.

In Norway, the government supports the proliferation of SMEs via programmes such as Innovation Norway [53] to assist in providing innovative technological and business solutions. In 2021, 32% of SMEs in Norway received support from the government [55].

It is without doubt that across the globe, some crucial technological and business disruptive solutions/ideas were birth by SMEs [56] (sometimes before they are purchased by big corporations).

2.3.1 Composition

SMEs differ from each other and generally from big corporations by the size of staff employed in operations, the amount of turnover realized per Annum, the specialty of service rendered, amongst other measurable differences [53]. With regards to staff size, an SME typically has 1-250 staff employed [57].

Considering the applications of the cobot could help filter the types of SMEs interested or relevant to a particular operation. A survey performed by Nergård et al [58] in the northern regions of Finland, Norway and Sweden which obtained a 10% response rate from the respondents, informed that:

- the highest SME players interested in cobot application were in the Mechanical industry. The second highest were undefined industries lumped together, with the Electronics industry following in order.
- However, per respondents within the Norway economical area, the highest SME players interested in cobot application were in the undefined industries lumped together. The second highest respondents were in the Mechanical industry, with the Oil & Gas industry following in order.
- A relatively little number of SMEs outsourced their production, which presumes the notion that the application of the cobots to their operations could be crucial. However other factors such as the expected production units and turnover and among other considerations.

2.3.2 Challenges

Generally, most companies are concerned about how the adoption of the collaboration would affect the professional skills employed, and their organizational structure [39].

Existing literature (mostly theoretical) identifies the challenges of adoption for SMEs as Safety, Strategy for adoption, and Training of staff [2]. In minimal contrast, interviews conducted with stakeholders at some companies indicated replacing "the Training of staff" with two key points; Performance of the collaboration and the Involvement of the stakeholders [59].

Additional literature proposes that the limitations to understanding of Smart technology also creates some challenges for SMEs to adopt [60]. The need to purchase a recent technology because the company needs a "new toy" should not be paramount to the functionality of the technology, but rather because the specifications of work needed to be done demands it, thus the right supplier and after sales services are provided and necessary setup assessments are carried out [61].

Concise of all these challenges is the estimation/forecast mistake by companies to apply cobots in a low-production mix but expecting a high cost-effectiveness [34].

Involvement of Stakeholders requires the staff to be involved in every stage of the adoption process to better understand the requirements and demand expected [2]. This gives the staff a sense of belonging to the process and the relevant contributions based on existing work mode can be suggested [62].

Ultimately, an appropriate mix of the work to be done by the cobot, the collaborator or both parties need to be meticulously planned [36]. Excess burden should not be placed on the cobot such as an expectation of precise quality inspection required from a human eye. Also, the cobot (in itself) should not be a burden to the human collaborator [2].

2.4 Technology Transfer

The physiological principle that "no man is an island", also affects the introduction of new technological ideas and opportunities. When a new innovative or disruptive technology is developed, there may be some reluctance towards its adoption [63]. A creative way to ease how the industry understands the technology and the benefits it presents, as envisaged by the producer, can be termed "Technology Transfer". This is in thought with Sudha et al [64], which suggests Technology Transfer as, the use laid-out process to transfer elements of technology from a group or individual to another group or individual as a solution to needs.

Various classifications can be made on Technology Transfer. It may be classified by:

- The transfer mode of which most common technology transfers occur between [65]:
    a. Academic Institutions and companies that wish to buy an innovative idea
    b. A manufacturer and the client
    c. An individual and an entity that wishes to purchase his/her intellectual property
- The regional boundary of the transfer, as Rani et al outlined [64]:
    a. International – The transfer between a country (usually an industrialized country) and another (mostly a developing country) to solve a problem in the later or support a cause
    b. Regional – The transfer is made within the same country, but between regions, usually to share a solution to a problem

c. Cross-sector or -industry – This transfer occurs between one industrial sector and another to solve a problem in the later or share a solution for example between the military and a private
d. Inter firm - The transfer between a company and another company within the same industry space
e. Intra firm - The transfer between departments of the same company, or between subsidiaries to share best practices and transfer solutions

- The Technology Transfer Office (TTO) overseeing the process, such as Laundry et al stipulated [66]:
  a. Community Technology Transfer Office – This office considers single client entities and thrives to provide customized solutions for targets of companies with 10 employees or less.
  b. Non-Profit Technology Transfer Office – This office focuses on providing legal or financial solutions
  c. Public Research Organizations – This office considers the interests of the entire populace and specifically, the government.
  d. University Technology Transfer Office – This office considers research of novel solutions, scalability and commercialization of innovation.

2.4.1 Adoption

Generally, the adoption of a technology may be carried out in five (5) basic stages as described by Sudha et al [64]:

- The initial stage normally deals with the sale of an innovative technology and its accompanying licensing agreements that should cover all legal and ethical documentation such as the patent rights, trademarks and names etc. [67]. This process's duration is characterized by negotiations and product trials and may not be straightforward.
- The Second stage focuses on the arrangement of training schedules, training resources and hands-on product training. Some studies are done to weigh the reception of the new product by staff, and this informs some feedback to management towards the activation [68].
- The Third stage considers how the installation of the product would be carried out and the plans of operations [69]. The Fourth stage considers acquisition of peripheral

components of the product. These may be initially negotiated as part of the technology transfer.

- The final stage embodies any agreements on industrial or technical collaboration, plans for turn-key and the management of the product.

Technology transfer, however, is a continuous process and not a one-time activity [64]. Hence periodic and routine activities, laden with feedback to improve the process, are necessary as unsupported technology swiftly becomes obsolete [70].

2.4.2 Challenges

Adopting a new and innovative technological product does not occur without some setbacks [71]. Some of these may include [64]:

Technology acquisition – The need for the product presents a challenge. Management needs to perform several analyses on cost and operational capacity to make the decision of a purchase.

Choice of Technology – Obtaining the right solution to solve a problem can seldom be a herculean task due to the nature of the problem, available solutions and the knowledge on the available solutions. Due to the timeframe to solve the problem, a limited general understanding of the technology may have dire influence on the decision.

Terms of conditions of technology transfers – In certain instances, the terms of conditions seem unilateral to wholly cover the provider of the product against litigation. This poses a challenge as the purchase may require some high level of assurance and guarantee.

Adaptability – Tailoring the product to your operation and overall structure is key to optimization and increasing efficiency. Unfortunately, some products may provide some rigidity to customization.

HR issues – With the usual concern of technology replacing humans in occupation [39], the challenge arises for the Human Resource department to effectively communicate with staff to allay fears, as well as prepare a new renumeration structure if necessary.

2.4.3 Possibilities

Considering general Cobot adoption by SMEs, some opportunities include:

- A right fit – Depending on the operations of the company, the cobot can be employed to tailored needs [72]. This could greatly improve productivity while providing solutions.
- Versatility – The multipurpose nature of the cobot makes it versatile to customize to the operation. Also, the plug and play [47] nature makes it easy to reuse promptly for multiple tasks.
- Environment friendly – As a budding technology towards a green sustainable manufacturing, there are limitless opportunities to research on saving energy and reduce waste in production [52].
- Increase in local production which translates to better economic ratings for the economic space within which it is [9].

2.4.4 Framework for Technology Transfer

Since the introduction of the Cobot as an improvement to the traditional industrial robots, various frameworks have been proffered. There is almost no information on an all-round Technology Transfer framework. It is, however, prudent to consider some existing Technology Transfer frameworks available.

Efstathiades et al [74] outlines the structure for technology transfer in manufacturing industry:

- Drafting of the Technology transfer document – For an innovation that is yet to be commercially produced, this stage focuses on the initial transfer of technology idea to the purchaser. However, in a scale-up, a draft of the plan of action is prepared.
- Infrastructure preparation – Before, during and after the product's installation, there may be some considerable changes in the operations to cater for the adoption which are necessary towards utilization.
- Human resource policies – The relevant policies and guiding documents are considered as the wellbeing of the operator is relevant to operation.
- Training provision for the operators – Necessary training on activities related to the new technology is carried out periodically to get the operators up to task.

Various models are built on this structure with differing features based on the Technology Transfer Office preparing it. A crucial feature of these models is that there is some complementing factor by the supply towards the demand, to provide a tailored solution. However, some shortfalls of these models included [64]:

- Intermediaries outsourced to provide services to ease the technology transfer focus more on other avenues of engaging the receiver on other products.
- Improper or no analysis and evaluation framework of the technology.
- Unilateral advantages which does not provide mutual benefits
- Misunderstanding of the capabilitites of the technology and limitations towards the application it was purchased for.
- Some Ethical concerns within the technology transfer process.
- Lack of plan for the end of life disposal of components of the new technology.

3 METHODOLOGY

This chapter aims to outline the methodology employed to achieve the work. As the cobot focused on, through this work is the UR10e, much closely related terminologies and nomenclature were employed.

3.1 Scope

The scope of the development process involved:

i. To understand how the UR10e works
ii. Decide on the framework tool to be developed and its existing counterparts
iii. Perform a risk analysis
iv. Design the ease of knowledge transfer tool.
v. Test and evaluate the tool developed.
vi. Document the development process

3.2 How the UR10e works

Collaborative industrial robots built by the Universal Robots group are marketed and sold under the "UR" brand with the model differentiated by a number that signifies an estimate of the maximum allowable payload. This work focuses on the UR10e which possesses the following specifications:

Table 3.1 UR10e specifications

Specification	**Values**
Joints	6
Joint rotation	360 º
Longest reach	1300 mm
Payload	12.5 kg
Weight (actual arm)	28.9 kg
Weight (control box)	17 kg
Weight (teach pendant)	1.5 kg
Typical tool speed	1 m/sec
Power supply to tool from tool output	12 V/24 V with 600 mA
Available Power supply from control box output	24 V with 2 A

Installation	On a fixed platform or on a movable but stable platform
Maximum Joint Speed	180º/sec
Working Temperature	0 – 50 ℃
Communication	TCP/IP 1000 Mbit: IEEE 802.3ab, 1000BASE-T Ethernet socket, MODBUS TCP & Ethernet/IP adapter, Profinet
Input/Output (I/O)	16 digital inputs, 16 analog outputs, 2 analog inputs, 2 analog outputs, 2 analog inputs for tool, 2 digital inputs for tool, 2 digital outputs for tool
Material	Aluminum
Teach cable length	4.5 m
Teach pendent size	12-inch touchscreen
Teach pendant software	Polyscope

Some notable marketable features of the UR10e may be surmised as:

- Safety – Boasting an inbuilt safety feature that stops the cobot on sensing a considerable amount of resistance, makes it a unique option to work around humans. However, caution needs to be highly considered, depending on the tool fixed to the cobot or the part of the human body that could possibly be trapped by the cobot.
- Cost effective – At an estimated cost $35,000, the cobot is a considerable investment which when well-planned should generate a considerable significant positive Return on Investment (ROI)
- Detailed Output – It manages low speed production and this can be used to medium-level detailed work.
- Ergonomic Design – Rounded edges at each joint, tubular sleeves, and a sleek teach pendant are some of the ergonomically-considered designs of the UR10e.
- Compact Design – The design makes for it to be easily moved or mounted on a movable device.
- Adaptability – It possesses the ability to easily be connected to other devices with little or no additional programming needed. It boasts the proliferation of "plug and play"

capabilities hence peripheral device manufacturers are advised to adhere to that requirement.

3.3 Framework Tool Developed

To produce a tool that eases the technological transfer of a cobot to a SME, some considerations were made. These considerations included:

- What would a first-time adopter of the UR10e cobot be interested in?
- How easily can they obtain knowledge on the use of the UR10e?
- How can the basic expectations of achieving their routine/mundane tasks be met by the purchase and installation of a UR10e?
- What is the layout of the production facility?
- How can the UR10e be manipulated with the least technical skill?

Based of these considerations, the tool needed to be an easy means for even the least technically skilled staff of an SME to interact with the UR10e cobot, from any location of the production facility. It also needed to be able to meet the basic expectations of performing the required tasks of the SME, so that a return on the investment made on the UR10e is achieved.

It was thus considered that an intently user-friendly Graphical User Interface (GUI) would be designed and tested for the manipulation of the cobot as depicted in Figure 3.1.

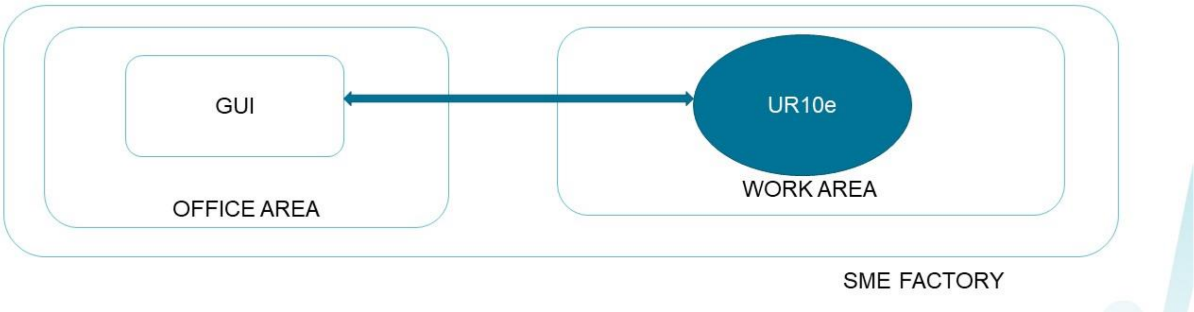


Figure 3.1 Framework considered

Some thoughts that had to be taken into consideration, involved the communication between the robot and a computer on a local network. Also, the ease of design, setup, launch and rework of the GUI were considered as well. The functions that the cobot would be tasked to do was subsequently considered.

The considered framework was inspired by the work of Shu and Solvang in 2021 [75] as can be seen in Fig 3.2 which suggests the use of an Open Platform Communications Unified Architecture (OPCUA) for socket communication. OPCUA is an open-source tool that provides a communication platform between machines connected to it, with some level of security in transmitting data between these machines.

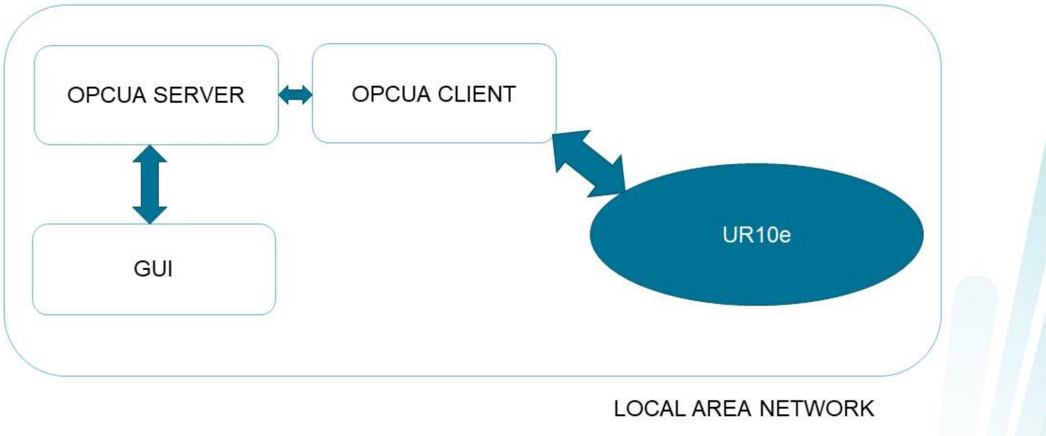


Figure 3.2 Communication architecture Source (Shu & Solvang, 2021 [75])

3.4 Existing interfaces

The UR10e has some interfaces and interfacing platforms for easy manipulation of the cobot. Key platforms provided by the manufacturer includes the Polyscope and URCaps. However, there are several interfaces built by various independent developers to obtain some desired outcome.

3.4.1 Polyscope

Polyscope which could also be referred to as URSim, is the GUI that is produced by the cobot for the easy controls of the UR. Each model’s teach pendant has this GUI preinstalled. It differs for the variants of the UR cobots and may slightly differ for cobots of a particular variant. This could be due to the different builds which are released to tackle a bug or simply an improvement, which need to be periodically updated.

3.4.2 URCaps

This platform enables developers to design an add-on or plug-in program which can be installed on the Polyscope. It provides the opportunity to develop a more concise program to work in a particular way with either a particular tool or a particular section of the cobot to produce a tailored type of work output.

This improves its adaptability feature as the manufacturers of the UR have outlined the prerequisites a URCaps enabled tool or plug-in. It requires:

- To use at least one interface (electrical, mechanical or software) of the UR cobot.
- To have a graphical user interface that can be installed within Polyscope. A development kit (URCaps SDK) is available to design and develop these applications.
- To be a plug and play component for easy setup and quick launch.
- To be easily programmable.
- Reliability in operation.
- Flexibility to adapt to various working conditions.
- To be collaborative during operation.
- To be safe for humans.

3.5 Risks Considered

A risk analysis was performed to understand the risks associated with the development and adoption of the suggested tool. Also, measures to mitigate these risks were outlined, monitored and employed, during the development process. See Appendix C.

Verbal low-level engagement with some stakeholders, revealed that the risks associated with the SMEs adoption of technology transfer solutions included:

- Complex design of previous solutions offered to them which cost more money to purchase and maintain.
- Poor maintenance of previous solutions offered, especially when it is on a subscription-based purchase.
- Low interest levels of SMEs towards the solutions offered because it does satisfy the functionality requirements to adequately perform the tasks they are required for.

Some considerations of risks expected during the development of this work involved:

- Loss of data during development
- Hardware malfunction
- Damage to the physical UR10e in the Lab
- Software challenges
- General laboratory hazards

4 DESIGN

The GUI is designed to be a simple interface for easy understanding, manipulation and redevelopment. It has four (4) different pages (Joint control, TCP control, Settings, Program) and is opened to upgrades.

4.1 Design Considerations

The Design of the GUI factored several considerations to make it user-friendly (for basic user and developer alike).

As a GUI could be compared to a frontline staff of a company, the program to develop the aesthetic feature and the connections to communication, was keenly relevant. Two softwares/platforms (NodeRed and Flask) were considered for building the GUI.

Some key comparisons are captured in Table 4.1:

Table 4.1 Differences between Flask and NodeRed

Element	**Flask**	**NodeRed**
Brief description	Web-based design platform	Flow-based design platform
Initial setup	Easy	Complicated
Dominating program	Python & HTML	Javascript
Complexity	Requires prior programming experience	Requires basic programming skills
Functionality	More functional	Moderately functional
End Product Design	Malleable to developer's imagination	Slightly rigid to design constraints
Developer User Friendly	Less	More
Support Resources	Limited	Slightly more available

Due to the time constraint on the project, a more developer user-friendly platform with basic programming skills was chosen as the design platform to engage.

4.2 Resources employed

The resources that were employed in the design and development of the design include PyCharm IDE, NodeRed, Visual Components, Polyscope, VM VirtualBox and UA Expert.

Also worth noting is the capacity/capabilities of the computer used during the project. This computer possessed a level of required capacity to run the selected softwares. These are captured in Figure 4.1.

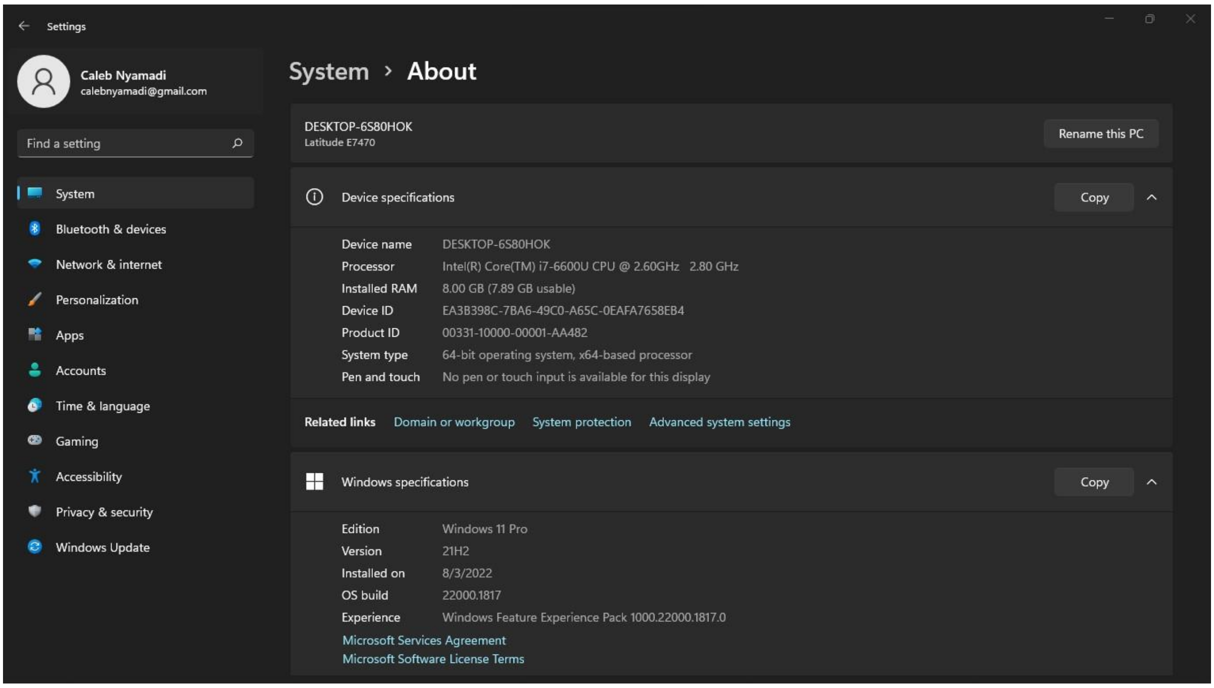


Figure 4.1 Computing capability of the PC used to develop the GUI (See Appendix C.1)

4.2.1 PyCharm IDE

PyCharm is a python Integrated Development Environment (IDE) that enables the writing of a python program, debugging and testing of programs within the environment. The version used was 2022.3.1 (Community Edition).

4.2.2 Polyscope

The Universal Robots provides a virtual option of their products' teach pendant for developers to explore and for the simulation of test programs. This platform is called Polyscope and it is run as a LINUX virtual machine. It contains all models of the UR brand and it is periodically updated. The version used was

4.2.3 NodeRed

NodeRed is a Java script-based platform for designing interfaces and connections for communication-based devices. It helps to create links between hardwares, interfaces and online resources. It is a widely used tool by contributors and enthusiasts of the Internet of Things (IoT). The version used was 3.0.2.

4.2.4 Visual Components

Design, simulation and testing of activities of an industry related environment such as layout consideration, process flow, optimization and product testing could be performed through the Visual Components software. It contains renditions of over thousands of industrial equipment as designed by the brand and model. These renditions can be connected to other peripheral components and programmed, just as it can be done with the physical counterparts. Thus, it makes a great tool for in-development testing. The version used was

4.2.5 Oracle VM VirtualBox

Oracle VM VirtualBox is a platform that enables the creation and running of a virtual machine with attributes similar to a physical computer. However, it obtains its computing attributes off the attributes of the physical computer it runs on. It can be used to provide some level of security in testing computer programs from unrecognized sources because any mishap presented would affect only the virtual machine and not the physical computer it runs on. It can also be used to run virtual renditions of device interfaces such as the Polyscope. The version used was 7.0.4 r154605 (Qt5.15.2).

4.2.6 UA Expert

UA Expert is an interface that enables the viewing of components within an OPCUA server. The version used was 1.6.3 448.

4.3 Joint Control Page

This page consists of four major demarcations/sections (Current position, visual representation of current position, target position and the visual representation of the target position). The action buttons on this page include the Move, Stop, Add Position and Home Position.

Upon connection to the cobot, readings of the positions of each of the six joints are populated under the “current position” banner and the visual representation of these values displayed. These values are obtained from the cobot.

Values which need to be communicated to the cobot are entered under each of the parameters listed under the “Wanted Position” banner and the visual representation of these values are automatically displayed. Once the values are certain to be sent, the “Move” button may be used to send the values to the cobot. Also, there are twelve buttons that are situated under the “Wanted Position” banner. Two of these buttons are linked to each of the Joints for increasing or reducing the individual joint angle.

Some predefined position values are attributed to the "Home" button to send these predefined values to the cobot. These values can be adjusted or changed in the settings page.

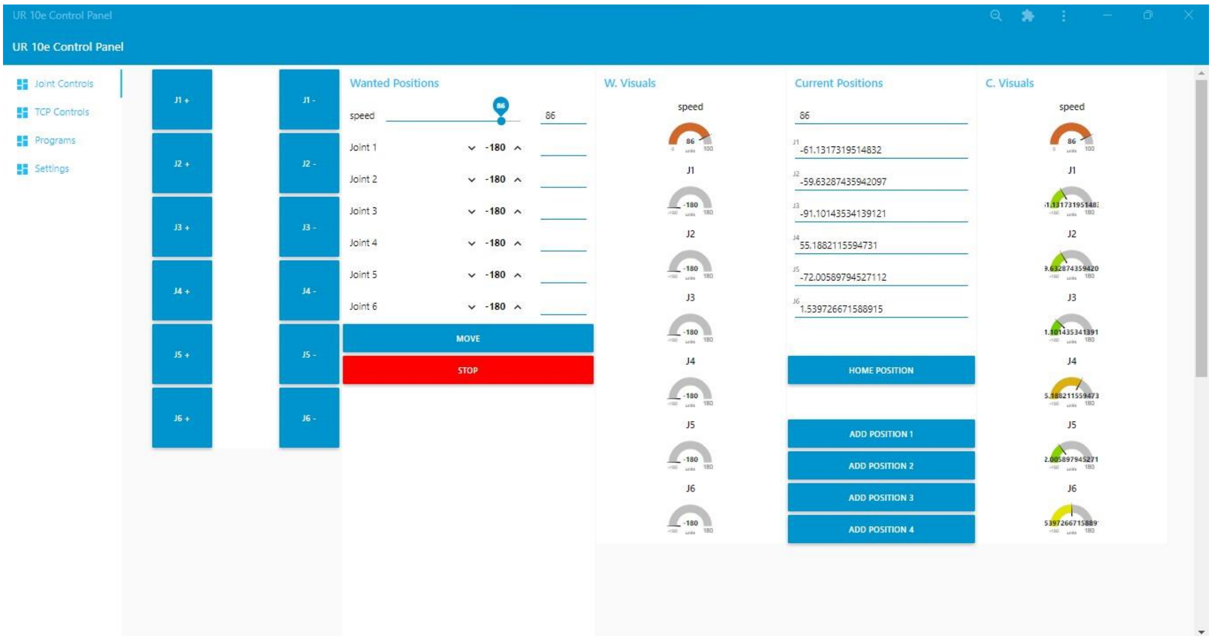


Figure 4.2 Screenshot of GUI design showing the 'Joint Control' page (See Appendix C.2)

To compile a program for the cobot to run automatically, the "Add Position …" buttons can be used to add the current position to a list on the "Programs" page and run as a collection of commands to derive a desired work outcome.

4.4 TCP Control Page

This page also consists of four major demarcations/sections (Current position, visual representation of current position, target position and the visual representation of the target position). The action buttons on this page include the Move, Add Position, Home Position and Stop.

Upon connection to the cobot, readings of the physical geometric positions of the Tool Center Point (TCP) of the cobot with respect to the base, are populated under the "current position" banner and the visual representation of these values displayed. These values are obtained from the cobot.

Values which need to be communicated to the cobot are entered under each of the parameters listed under the "wanted position" banner and the visual representation of these values are automatically displayed. Once the values are certain to be sent, the "Move" button may be used to send the values. Also, there are twelve buttons that are situated under the "Wanted Position" banner. Two of these buttons are linked to each of the TCP vector representation (x, y and z are linear representation while rx, ry, and rz are rotational representation) for increasing or reducing the value of each individual.

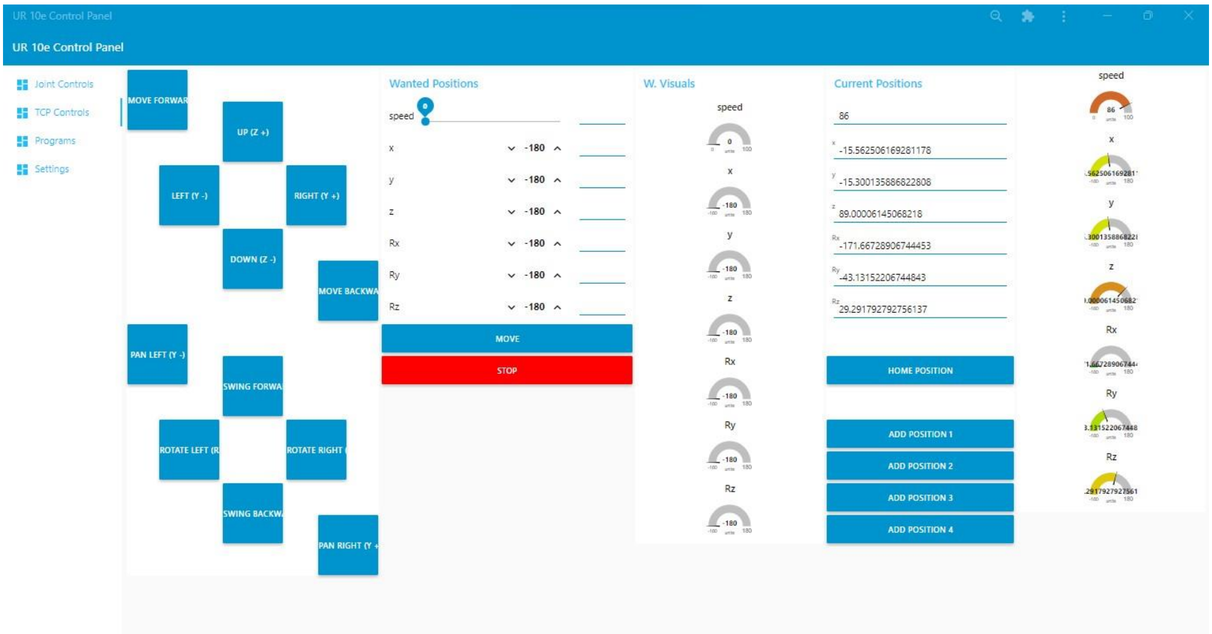


Figure 4.3 Screenshot of GUI design showing the 'TCP Control' page (See Appendix C.3)

Some predefined position values are attributed to the "Home Position" button to send these predefined values to the cobot. These values can be adjusted or changed in the "Settings" page.

To compile a program for the cobot to run automatically, the "Add Position" button can be used to add the current position to the program list. These added positions may be rearranged to suit the work operation on the "Programs" page.

The "Stop" button may be engaged if the "Wanted positions" activated were found to be in accurate and needs to be reviewed.

4.5 Program

The ability to communicate a set of commands for the cobot to chronologically perform, is derived from this page. The "Program" page enables the saving of positions so that the cobot can make use of them at a later period.

This page consists of six sections (Current Position, Commands, Waypoint 1, Waypoint 2, Waypoint 3 and Waypoint 4). It consists of seven (7) action buttons.

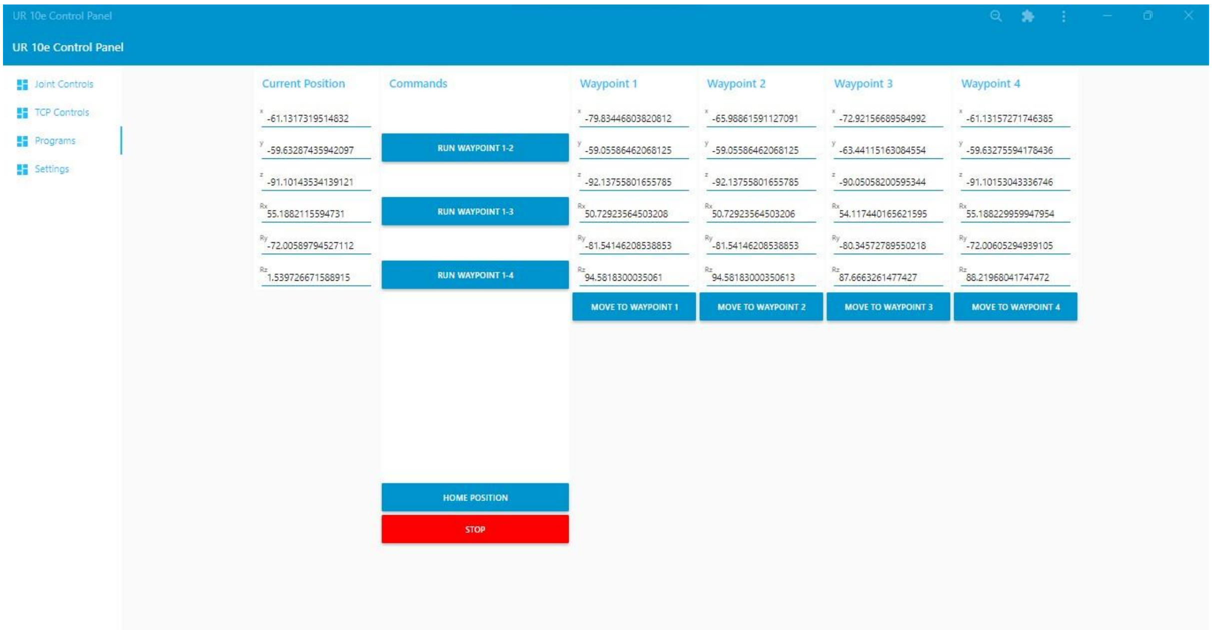


Figure 4.4 Screenshot of GUI design showing the 'Program' page (See Appendix C.4)

Upon connection to the cobot, readings of the physical geometric positions of the TCP of the cobot with respect to the base, are populated under the "Current Position" banner. Values which need to be communicated to the cobot are entered into the parameters of each section by triggering the "Add Position …" which are available on the. Depending on the number identified on the button, the corresponding section is populated by the "current position" at the instant of button trigger. Each section possesses a "Move to Position …" button to allow for the individual pose the section corresponds to. However, a section contains a list of action buttons (Run Waypoint 1-2, Run Waypoint 1-3 and Run Waypoint 1-4). These buttons command the cobot to move through some saved positions or through all the saved positions available.

4.6 Settings

To manage a neat workspace, the crucial parameters that need to be changed frequently based on the nature of the task to be achieved are populated on the "Joint Control" and "TCP Control" pages. However, other parameters which would sparingly be changed are incorporated to the "Settings" page. These include the Joint speed, Joint acceleration, TCP acceleration, TCP Speed. This page contains three (3) sections (Wanted Values, Current values and Home Position).

Upon connection to the cobot, readings of the parameters available to the cobot are displayed under the "current values" banner and the visual representation of these values displayed.

Values which need to be communicated to the cobot are entered under each of the parameters listed under the “wanted values” banner and the visual representation of these values are automatically displayed. Each parameter possesses an “Update” button to allow for individual manipulation of the parameters.

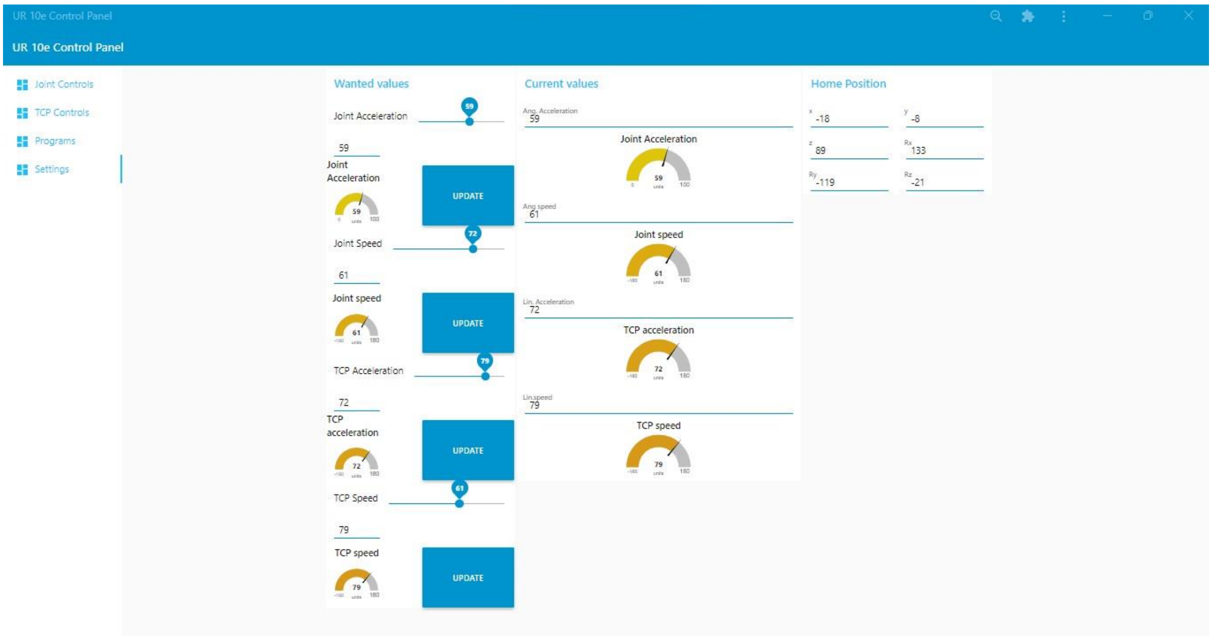


Figure 4.5 Screenshot of GUI design showing the ‘Settings’ page (See Appendix C.5)

A predefined list of values of which can be sent to the cobot for a movement action to a desired position, are displayed under the “Home Position”. “Home position” buttons on the “Joint Control” and “TCP Control” pages are triggered to communicate these set of values to the cobot. These values can be edited.

4.7 Layout

The Layout of each page is achieved by signifying the size the section and the size of the object. Sizing is achieved with the use of some patterned square boxes. Most of the sections used were 8 boxes. If the object has a size less than the section size for example 6x1), it can be dragged along the length of the section to the desired spot. Regardless of the size of the object (either same or less than the section size), it can be dragged along the height of the section to the desired spot. This allows for spacing between objects also. Thus, there is no limit to dragging towards the bottom of the section height. The size of the object can be edited in the properties of the object.

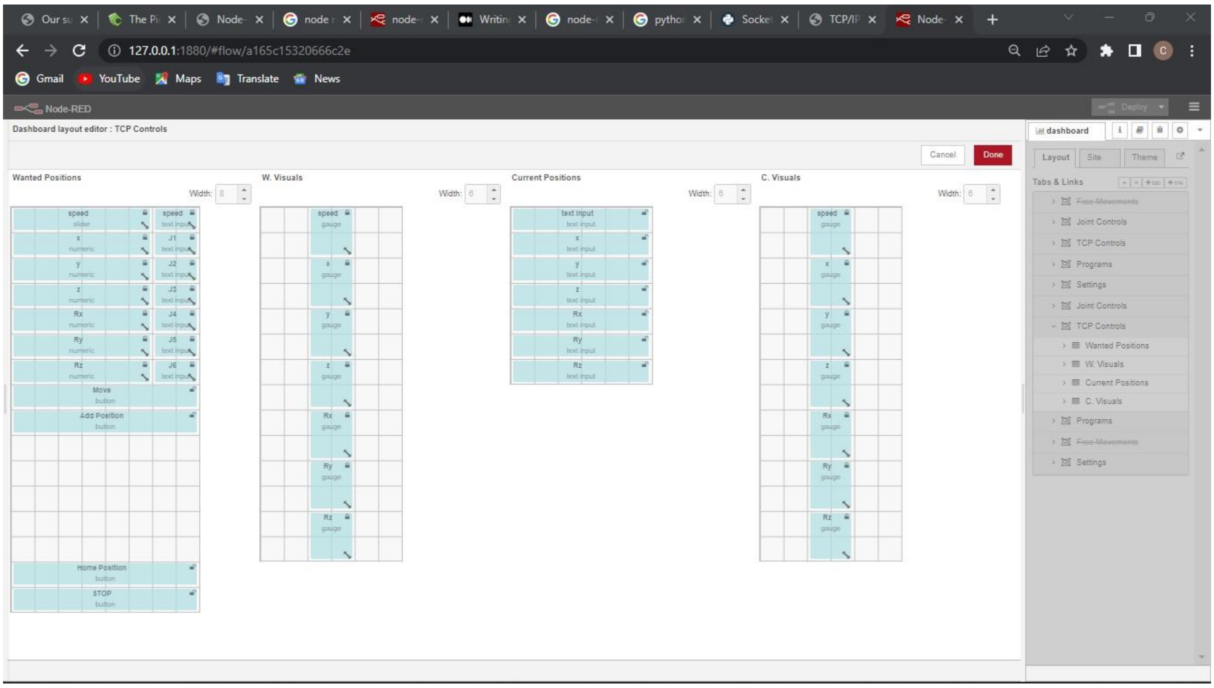


Figure 4.6 Screenshot of 'TCP Controls' Page Layout in NodeRed backend (See Appendix C.6)

5 OPERATION

There are two major parts to this GUI. The aesthetic part (graphical design) that is designed with NodeRed and could be run as an executable program or in a web browser, and the communication to the cobot from the visually aesthetic part through the OPCUA client and server programmed and run as a python program in PyCharm or any python IDE (functionality).

In order for the communication from our aesthetic part of the GUI to have an effect on the UR10e, we need to understand the nomenclature and linguistics of the UR10e. An extensive library of the variable containers is made available on the resource page of the UR website. Communication to these containers effect the desired action on the cobot. Some containers that were employed in this work include as depicted in Table 5.1.

Table 5.1 Some UR10e cobot recognised variables (Source: UR Real-Time Data Exchange (RTDE) Guide [76])

Name	**Type**	**Explanation**
target_q	VECTOR6D	The target joint positions depicted as a 6 digit vector (J1,J2,J3,J4,J5,J6)
actual_q	VECTOR6D	The actual joint positions depicted as a 6 digit vector (J1,J2,J3,J4,J5,J6)
actual_TCP_pose	VECTOR6D	A actual 6 digit vector with cartesian coordinates of the tool: (x,y,z,rx,ry,rz), where x, y and z are linear representation while rx, ry and rz are a rotational representation of the tool orientation
target_TCP_pose	VECTOR6D	The target 6 digit vector with cartesian coordinates of the tool: (x,y,z,rx,ry,rz), where x, y and z are linear representation while rx, ry and rz are a rotational representation of the tool orientation
tool_analog_input0	DOUBLE	Sends current [mA]or voltage [V] to tool analog input 0
tool_digital_output0_mode	UINT8	What the state of the digital output 0 is

The UR10e is booted and placed in the remote mode. Then the OPCUA server is initially run and the OPCUA client is also run when the UR10e network IP is known and entered into the client python script. Without this, the real time communication can not be established with the cobot and no values can be read or written. Upon a successful launch of the OPCUA server and client, NodeRed is run via a command (cmd) dialog box. Once it is fully running, the developer backend of the NodeRed could be accessed for use through a web browser using the address outlined in the cmd dialog box (usually a default of http://127.0.0.1:1880/). In the backend, it is imperative to check that the IP address and the port of the OPCUA server matches the information on the NodeRed interface. If this is not accurately established, there cannot be values retrieved to the GUI nor any manipulation of the cobot through the GUI.

Once these premises are accurately established, values can be read under the "current position" of both the "Joint Control" and "TCP Control" pages. This is obtained by reading the … value of the OPCUA client. These are some read-only predefined parameters created on the OPCUA server that constantly obtains its values from the cobot through the use of the real time data exchange python module employed.

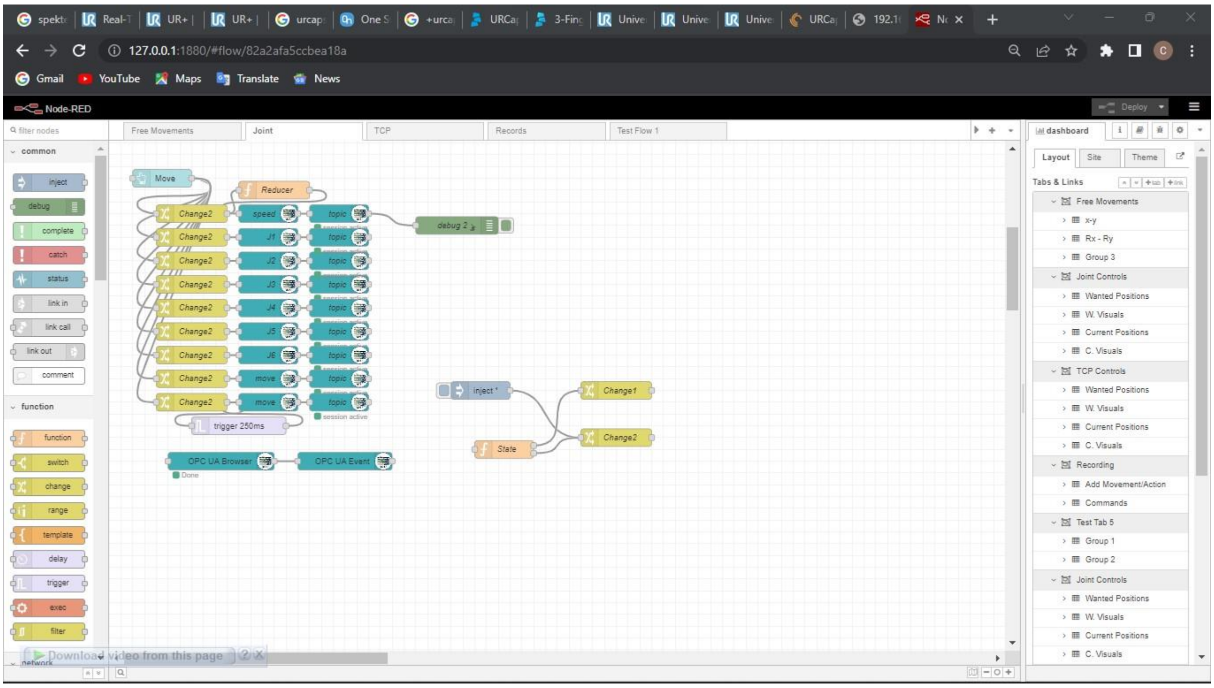


Figure 5.1 Screenshot of NodeRed backend showing the links for the wanted Joint values button activation (See Appendix C.7)

To manipulate the cobot, the "wanted position" values entered on any part of the GUI are written to the "wanted position" value of the OPCUA client. These are some writeable predefined parameters created on the OPCUA server that sends values to the cobot based on how the command request is set. This communication also employs the real time data exchange python module.

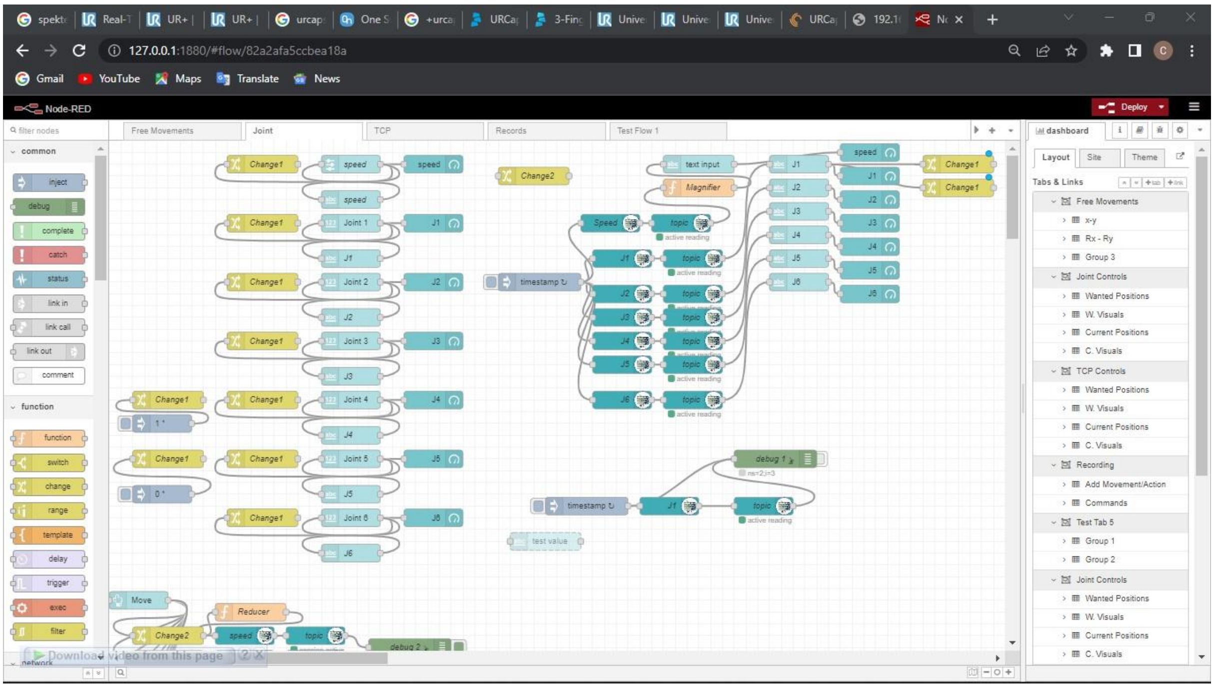


Figure 5.2 Screenshot of NodeRed backend showing the links for joint control 'wanted position' communication (See Appendix C.8)

These values to be written on the "Joint Control" page may be a number between 0 and 100 for the speed and a number between -180 and 180 for each of the Joint values. The activation is achieved by writing a value of numerical 1 to the respective variable of the OPCUA client that corresponds to the "move_flag" of the robot while simultaneously sending a value of numerical 0 to the respective variable of the OPCUA client that corresponds to the "movement_format" of the robot is simultaneously sent to dictate a forward kinetics joint movement command with the joint values.

The values to be written on the "TCP Control" page may be a number between 0 and 100 for the speed, a number between -130 and 130 for each of the translational vectors (x, y and z), and a number between -360 and 360 for each of the rotational vectors (Rx, Ry and Rz). The activation is achieved by writing a value of numerical 1 to the respective variable of the OPCUA client that corresponds to the "move_flag" of the robot while simultaneously sending a value of numerical 1 to the respective variable of the OPCUA client that corresponds to the "movement_format" of the robot is simultaneously sent to dictate a linear movement command with the TCP values.

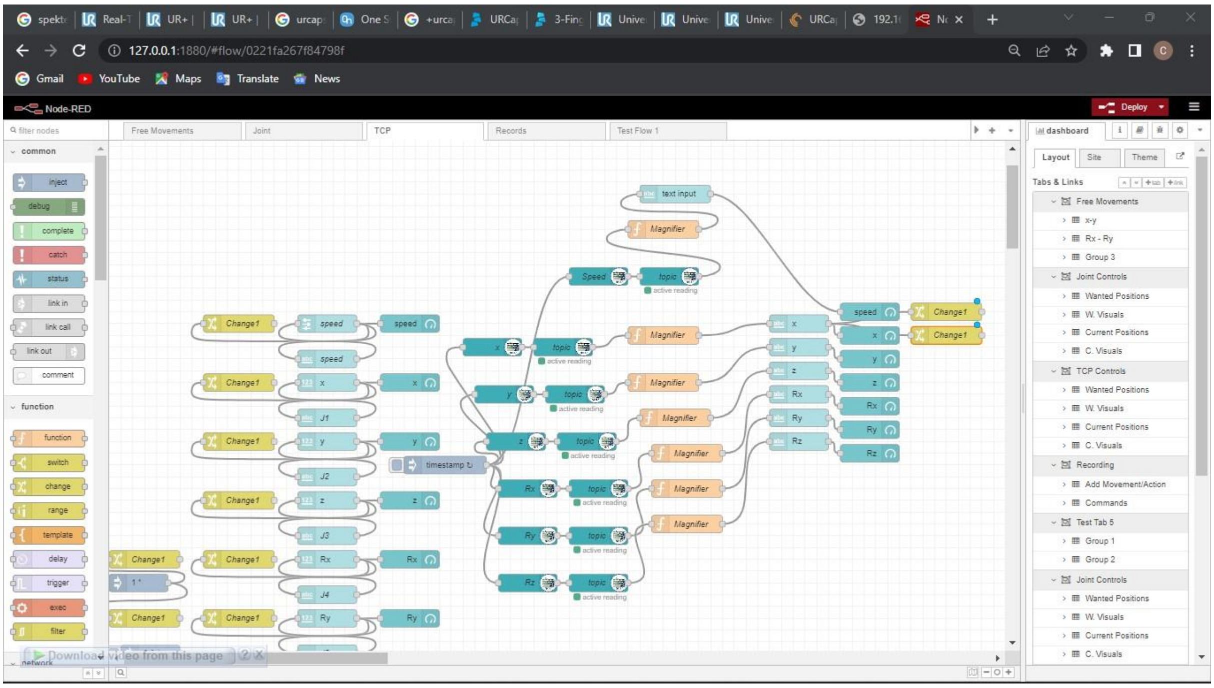


Figure 5.3 Screenshot of NodeRed backend showing the links for TCP control 'current position' communication (See Appendix C.9)

In a similar regard, the action of the "Home Position" button (regardless of the page on the GUI) triggers the communication of writing some predefined values to the respective translational vectors (x, y and z) and the rotational vectors (Rx, Ry and Rz). The activation is achieved by writing a value of numerical 1 to the respective variable of the OPCUA client that corresponds to the "move_flag" of the robot while simultaneously sending a value of numerical 3 to the respective variable of the OPCUA client that corresponds to the "movement_format" of the robot simultaneously sent to dictate an inverse kinetics joint movement command with the TCP values.

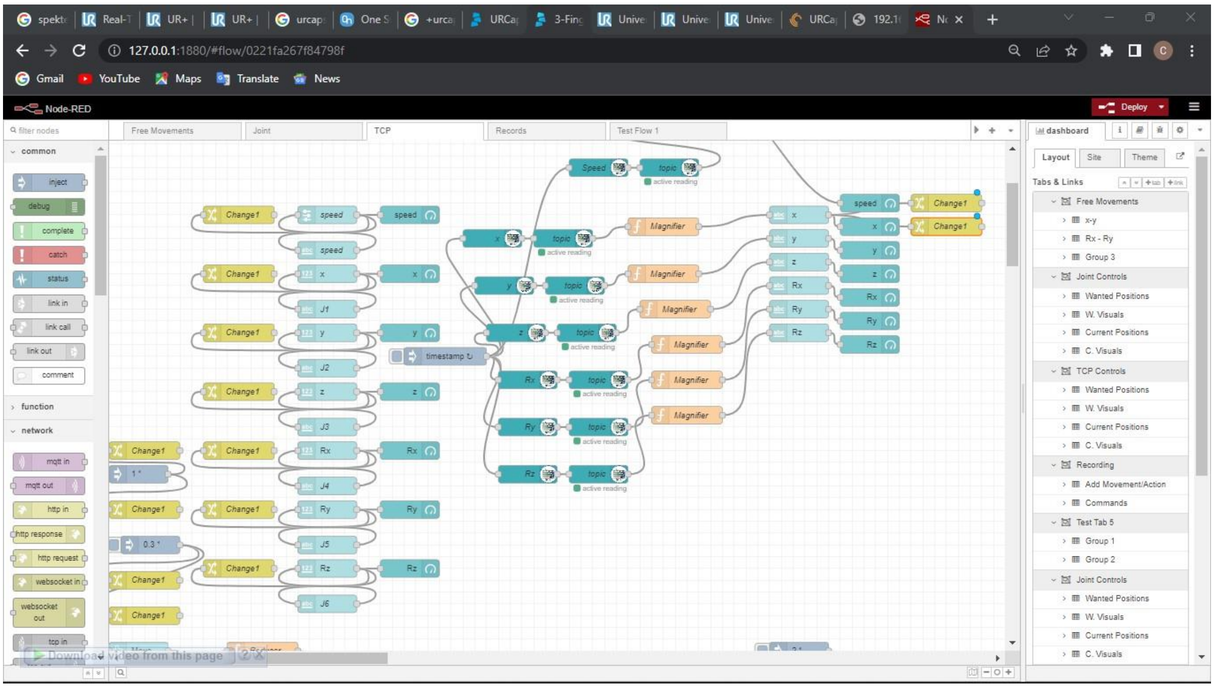


Figure 5.4 Screenshot of NodeRed backend showing the links for the wanted TCP values communication (See Appendix C.10)

The buttons triggered for saving positions (Add to Position 1, Add to Position 2, Add to Position 3 and Add to Position 4) are available on the “Joint Control” and “TCP Control” pages. However, activations of any of these buttons triggers the communication to the corresponding parameters in the OPCUA server to store for call-up at a needed time. Upon need of these saved values, writing the appropriate numerical value to the respective variable of the OPCUA client that corresponds to the “path_move” of the robot. These numerical values with corresponding outcome are 1 – Move to Position 1, 2 – Move to Position 2, 3 – Move to Position 3, 4 – Move to Position 4, 1.2 – Run Waypoint 1-2, 1.2 – Run Waypoint 1-3 and 1.4 – Run Waypoint 1-4.

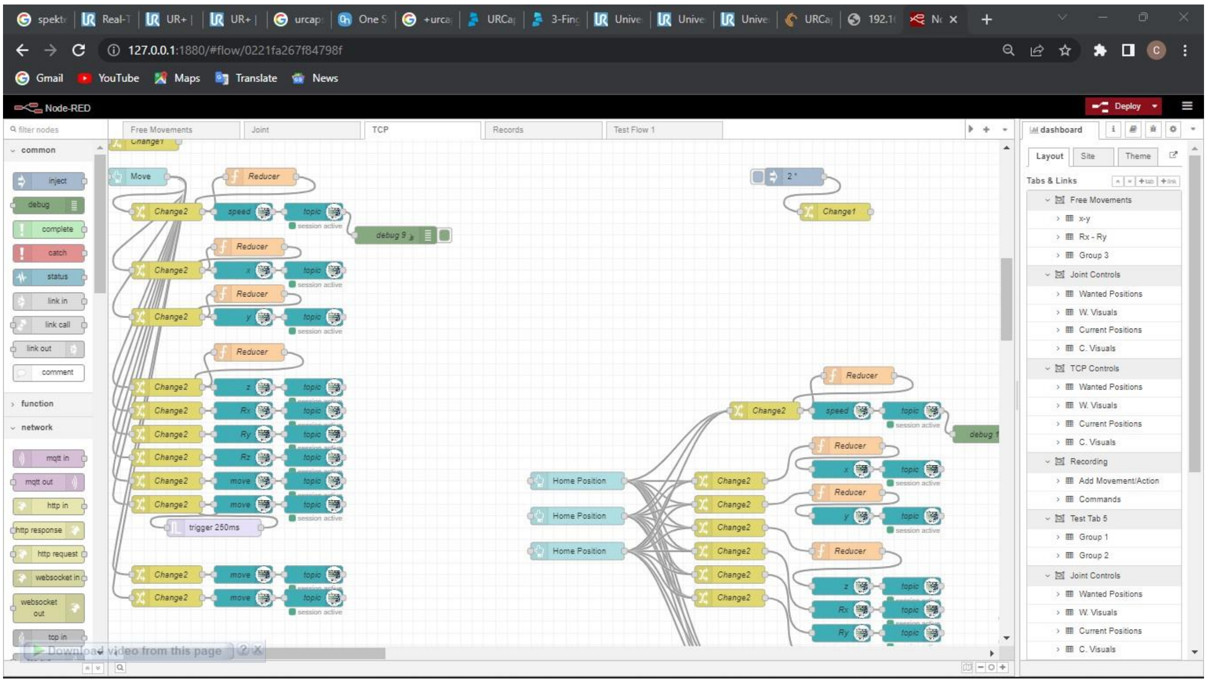


Figure 5.5 Screenshot of NodeRed backend showing the links for the current TCP values button activation (See Appendix C.11)

The values of the translational vectors (x, y and z) the robot receives through the python script ought to be in the range of 0.0 to 1.3. Thus, at the back-end of the GUI, any value entered by the user is reduced by 100. Likewise, the speed value (regardless of the page of the GUI) the robot receives through the python script ought to be in the range of 0.0 to 1.0. Thus, at the back-end of the GUI, any value entered by the user is reduced by 100.

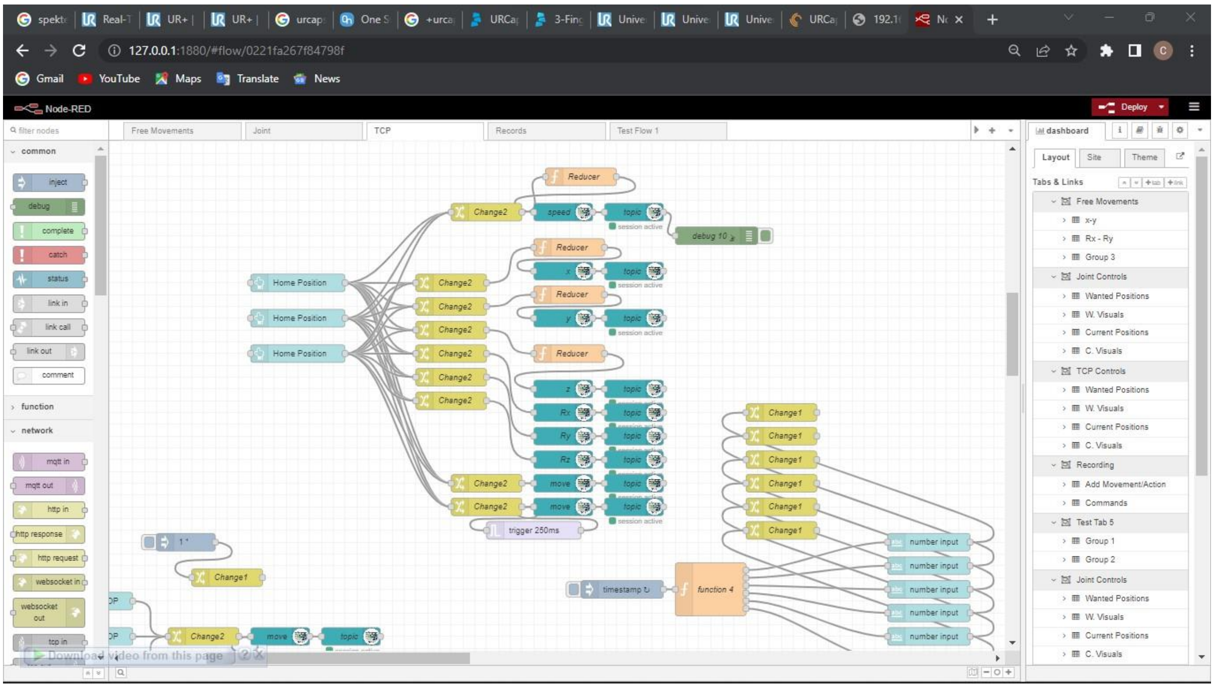


Figure 5.6 Screenshot of NodeRed backend showing the links for the 'Home Position' activation (See Appendix C.12)

To manipulate the cobot using the incremental buttons on the "Joint Control" page, each click triggers an output to be sent to the parameter "Increment". Based on the value that is sent, an increment or decrement of 10 ⁰ is made to the corresponding Joint angle element of the current position vector and a movement command is triggered simultaneously.

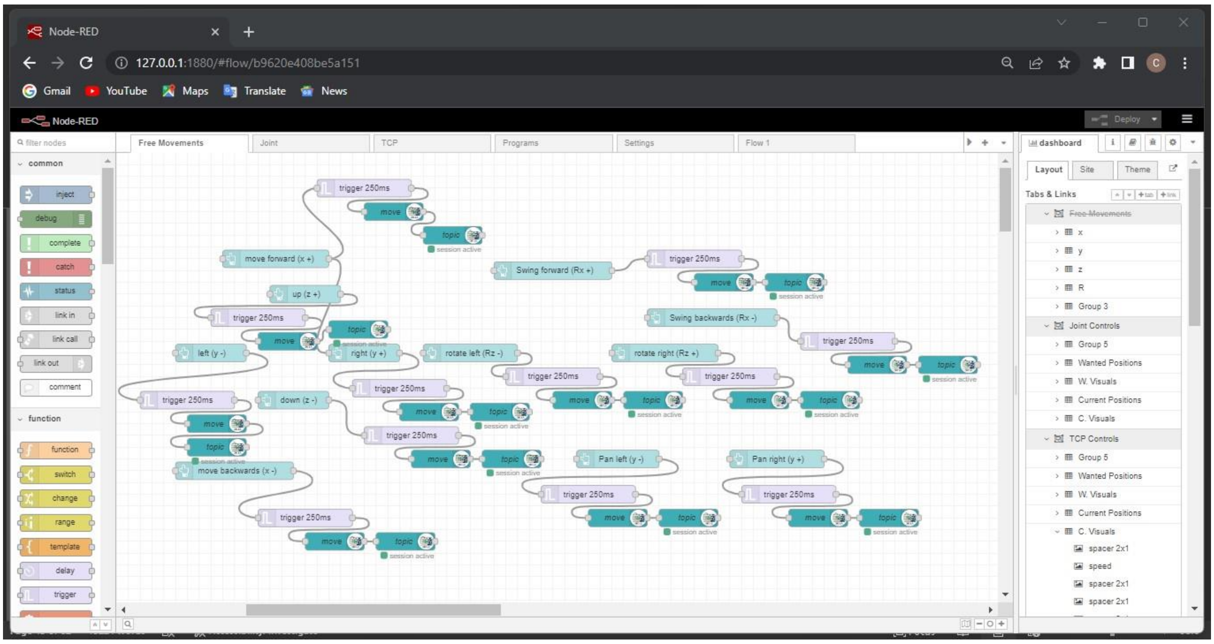


Figure 5.7Screenshot of NodeRed backend showing the links for the TCP pose increment activation (See Appendix C.13)

To manipulate the cobot using the incremental buttons on the “TCP Control” page, each click triggers an output to be sent to the parameter “Increment”. Based on the value that is sent, an increment or decrement of 10 (reduced to 0.1 for the robot) is made to the corresponding translational element (x, y, z) of the current TCP pose vector and a movement command triggered simultaneously. Also, depending on the value that is sent, an increment or decrement of 10 ° is made to the corresponding rotational element (rx, ry, rz) of the current TCP pose vector and a movement command triggered simultaneously.

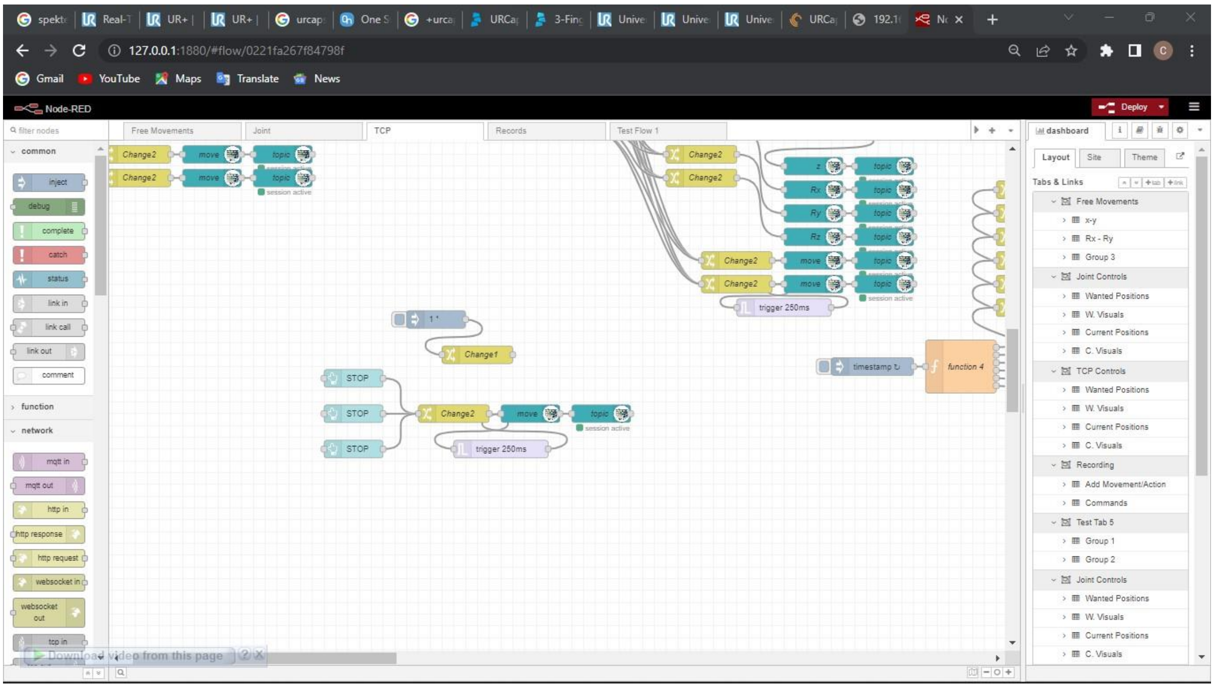


Figure 5.8 Screenshot of NodeRed backend showing the links for the ‘Stop’ activation (See Appendix C.14)

The action of the “Stop” button (regardless of the page on the GUI) triggers the communication of writing a value of numerical 1 to the respective variable of the OPCUA client that corresponds to the “servoStop” command of the robot.

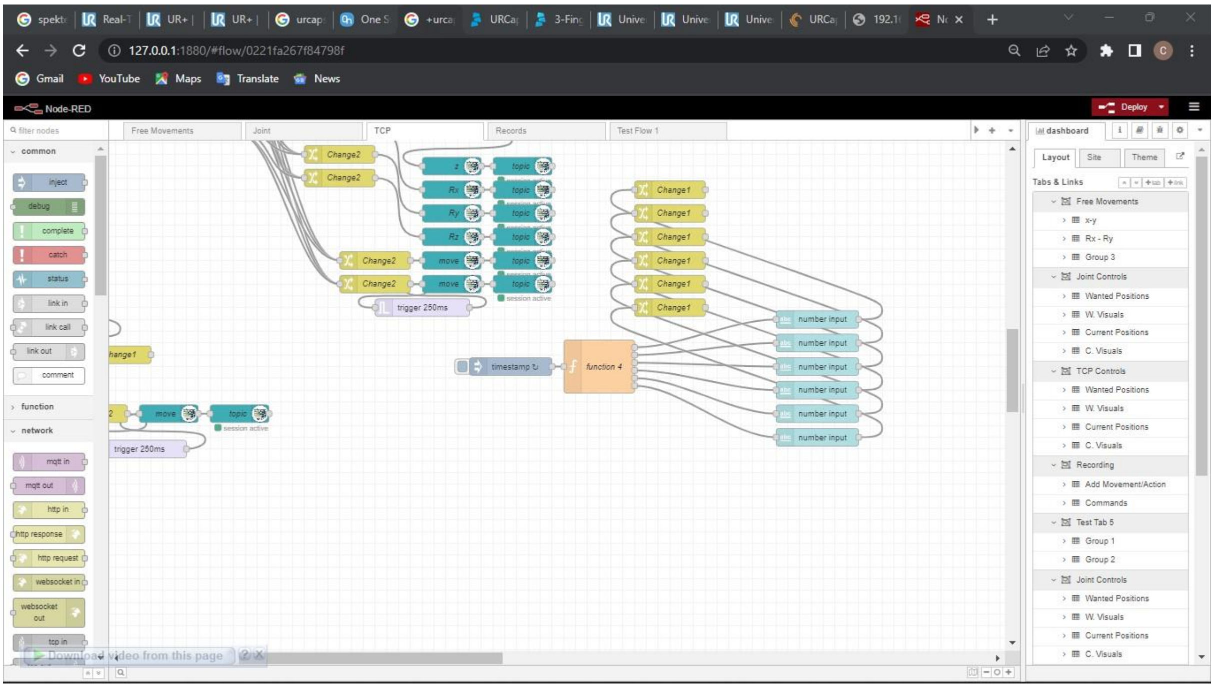


Figure 5.9 Screenshot of NodeRed backend showing the links for the 'Home Position' data communication (See Appendix C.15)

The action of the "Tool" button (regardless of the page on the GUI) triggers the communication of writing a value of numerical 3 to the respective variable of the OPCUA client that corresponds to the "movement_format" of the cobot.

5.1 NodeRed communication links

To receive data from OPCUA server:

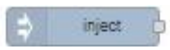
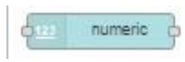
1. Connect the output of an "Inject" to the input of the "OPCUA Item".
2. Connect the output of an "OPCUA Item" to the input of an "OPCUA Client".
3. Connect the output of the "OPCUA Client" to the input of a "Text".
4. Insert a Function in between the "OPCUA Client" and the "Text" if necessary for conversion purposes (increments, decrements, multiplier etc).
5. Make the "Inject" a timestamp that sends a time log after every second. This enables a refresh of the data every second (or whatever duration is chosen).
6. Enter the OPCUA server address in the "OPCUA Client".
7. Enter the attribute of the parameter to be read from the OPCUA server, in the "OPCUA Item".
8. If "Function" is used, write the Json script to achieve the desired action.
9. Deploy after crosscheck.

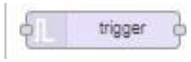
To send data to OPCUA server

1. Connect the output of a "Slider", "Numerical Input" or "Text Input" to the input of a "Change" (let's call this the ***encoder***).

2. Connect the output of a “Button” to the input of another “Change” (let’s call this the ***decoder***)
3. Connect the output of the **decoder** to the input of an “OPCUA Item”.
4. Connect the output of the “OPCUA Item” to the input of an “OPCUA Client”.
5. Insert a Function in between the “OPCUA Item” and the “Change” if necessary for conversion purposes (increments, decrements, multiplier etc).
6. Set *flow*.(a unique name e.g. ‘MyInputLeft’) to *msg.payload* in the properties of the encoder
7. Set *msg.payload* to *flow*.(the same unique name i.e. ‘MyInputLeft’) in the properties of the decoder.
8. Enter the attribute of the parameter of the OPCUA server to be written onto, in the “OPCUA Item”.
9. Enter the OPCUA server address in the “OPCUA Client”.
10. If “Function” is used, write the Json script to achieve the desired action.
11. Deploy after crosscheck.

Table 5.2 NodeRed Components and Application

Image	**Name**	**Description**	**GUI Pages Employed on**			
			Joint Ctrl	TCP Ctrl	Program	Settings
	Inject	Introduces a new message into a flow either send in intervals or one time.	X	X	X	X
	Slider	Offers an incrementatal input	X	X	X	X
	Text Input	Provides field for text input	X	X	X	X
	Numerical Input	Provides field for text input	X	X		
	Function	Dictates the line of action through a JavaScript program.	X	X	X	X

	Change	Converts(set, change, delete or move) the identity of an information passing through the flow.	X	X	X	X
	Gauge	Visually displays the numerical output of a component	X	X		X
	Text	Displays text				X
	Trigger	When triggered, can send a message, and then optionally a second message, unless extended or reset.	X	X	X	
	Button	One touch triggers to activate an action	X	X	X	X
	OPCUA Client	Connect to an endpoint using the OPCUA server address	X	X	X	X
	OPCUA Item	Defines OPCUA item type value. The attribute of the OPCUA parameter is entered	X	X	X	X

	Debug	Returns the output of a component it is connected to. It can be used to identify the signal, payload or message passing through that component	X	X	X	X

Some functions used in the backend included:

- Reduction – This program is used to reduce an input value by division to the required output.

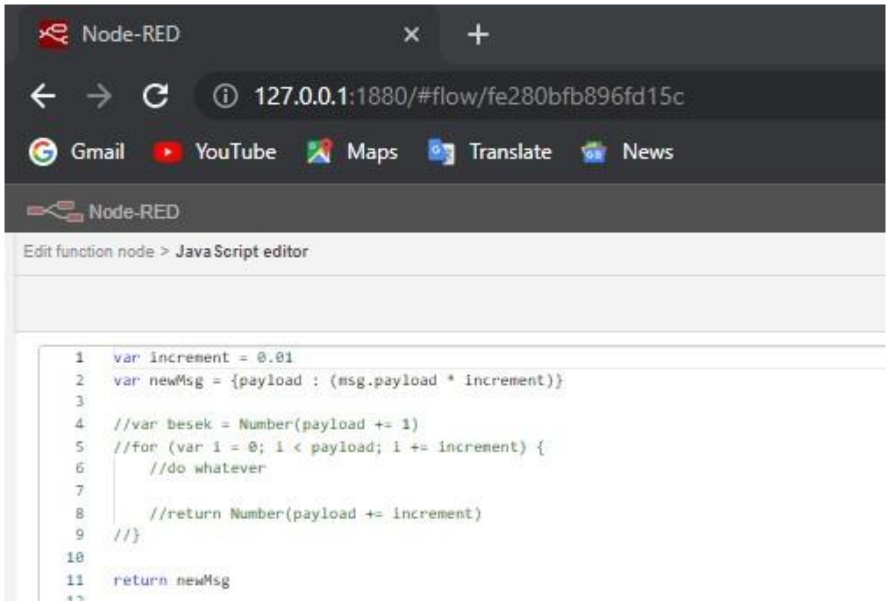


Figure 5.10 Screenshot showing the Javascript code of the reduction function in NodeRed backend

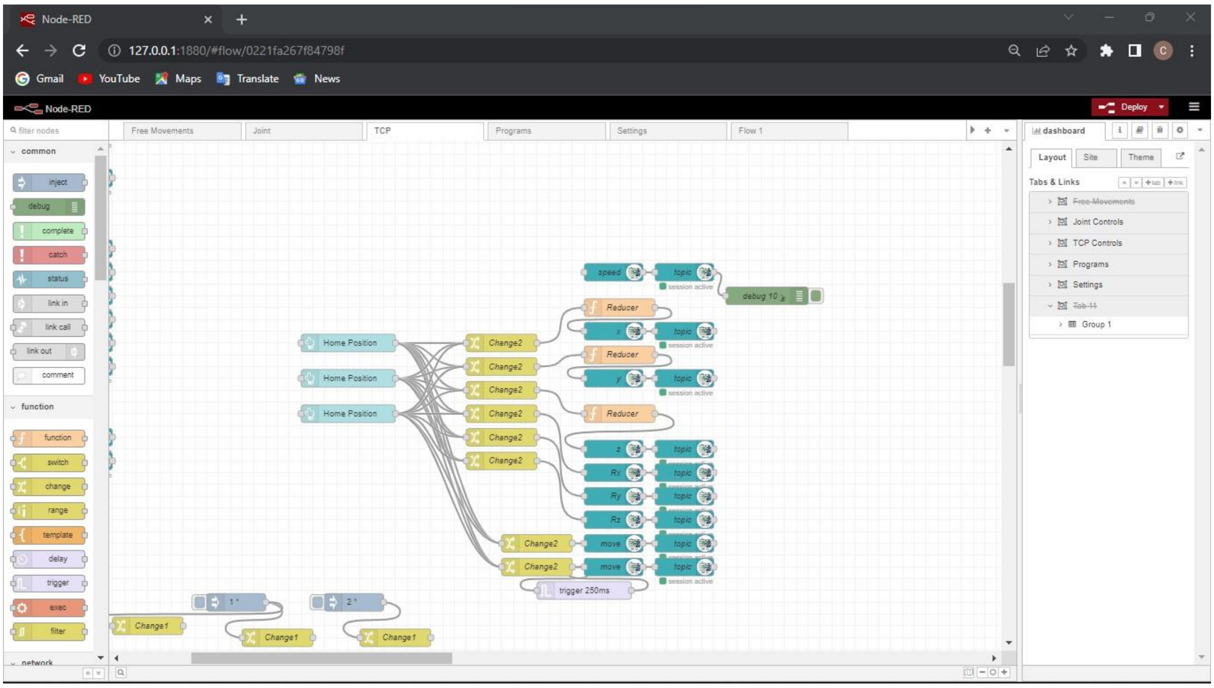


Figure 5.11 Screenshot showing the application of the reduction function in NodeRed backend (See Appendix C.16)

- Magnification – This program is used to increase an input value by division to the required output.

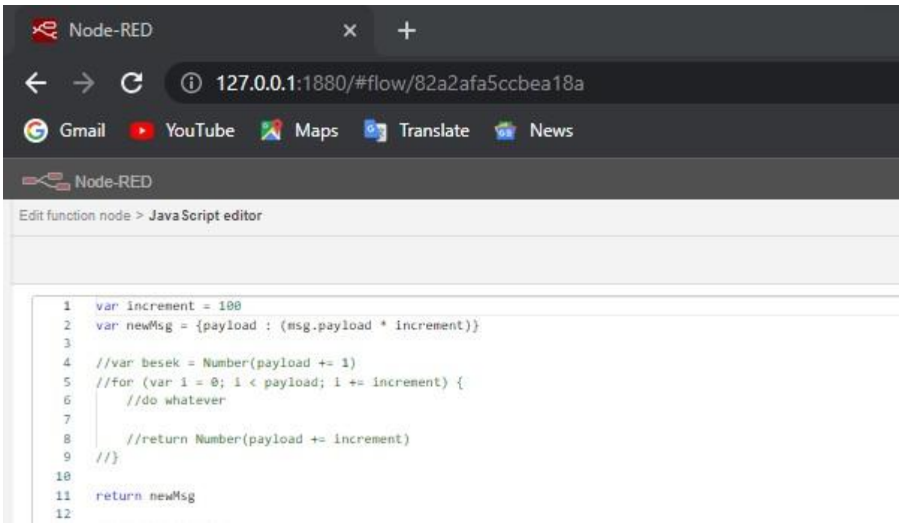


Figure 5.12 Screenshot showing the Javascript code of the magnification function in NodeRed backend

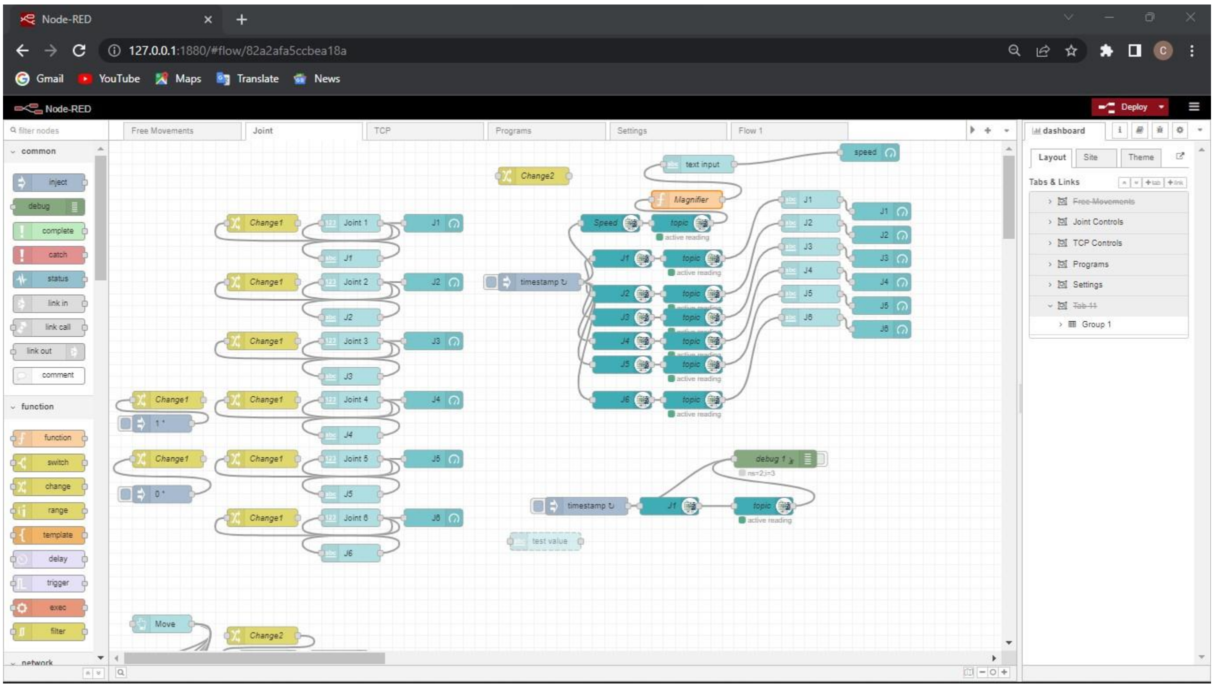


Figure 5.13 Screenshot showing the application of the magnification function in NodeRed backend (See Appendix C.17)

- Multiple output – This program is used to send out multiple output silmutaneously based on an input.

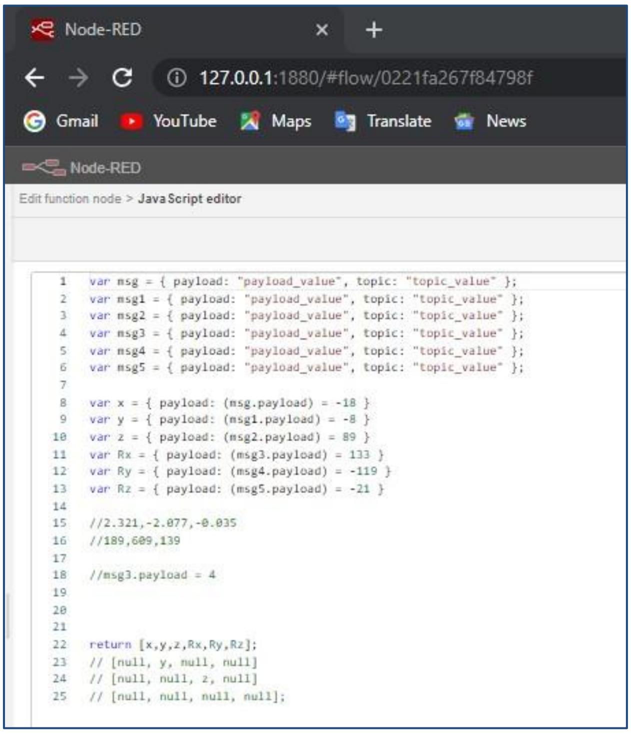


Figure 5.14 Screenshot showing the Javascript code of the multiple output function in NodeRed backend

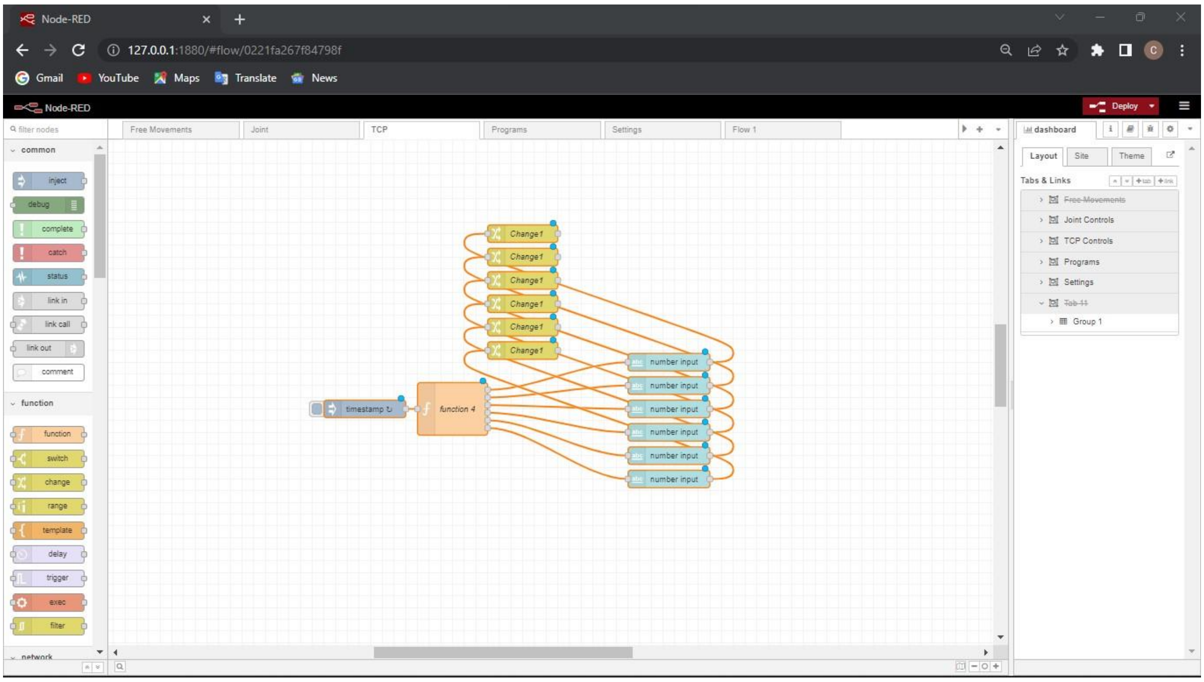
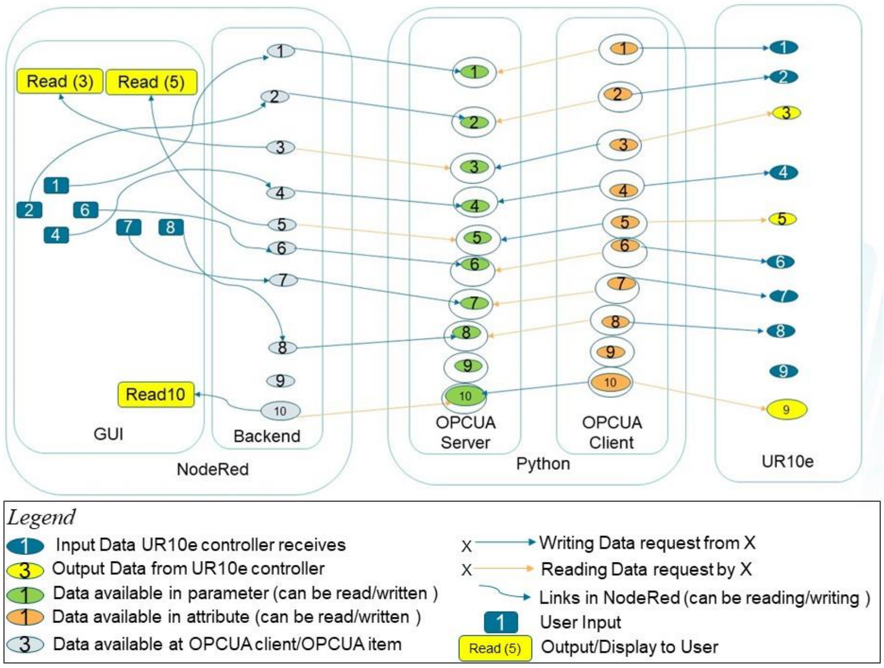


Figure 5.15 Screenshot showing the application of the multiple output function in NodeRed backend (See Appendix C.18)

5.2 Python Programming

The OPCUA Server and Client were built as python scripts using the PyCharm IDE. Some packages were installed to aid the scripts run and communicate as expected. Crucial of these packages is the “ur-rtde” package. This “ur-rtde” package contains some predefined classes, definitions, functions, lists, variables and requirements to communicate with the controller of the UR cobot.

A “UR10e-parameters” script was built to contain all parameters required in the OPCUA server. This script is called by the server upon launch, and populated onto the server. When the client is launched, it has to search for the parameters on the server with its corresponding attributes. A successful connection of client to a server enables the client to request to write the value of its attribute to the server’s parameter or request to read the value of server’s parameter to its attribute.



Also, the client ought to connect to the controller of the UR cobot through some or all three connection options:

- Input/Output (I/O) – Sends signals from the controller of the UR cobot to the OPCUA client and vice versa.
- Receive – Sends data on the current state of the robot, from the controller of the UR cobot to the OPCUA client to read.
- Control – Sends data on the wanted state from the OPCUA client to the controller of the UR cobot to act.

Upon a successful connection, the attributes of the OPCUA Client are linked to the variables that the controller of the UR cobot reads and understands. Thus, any manipulation of the attribute in the OPCUA client would be communicated to the controller of the UR cobot for the consequential reaction from the UR cobot.

6 TESTING AND EVALUATION

This GUI was vigorously tested during the development and also at post-development.

6.1 Testing

During development, the safety of the cobot and its purchase cost, birthed the consideration to build and test the GUI with a virtual rendition of the UR10e cobot. This was actualized as the Polyscope which is run as a program in a LINUX virtual machine platform performs exactly like the teach pendant of a physically functioning UR10e.

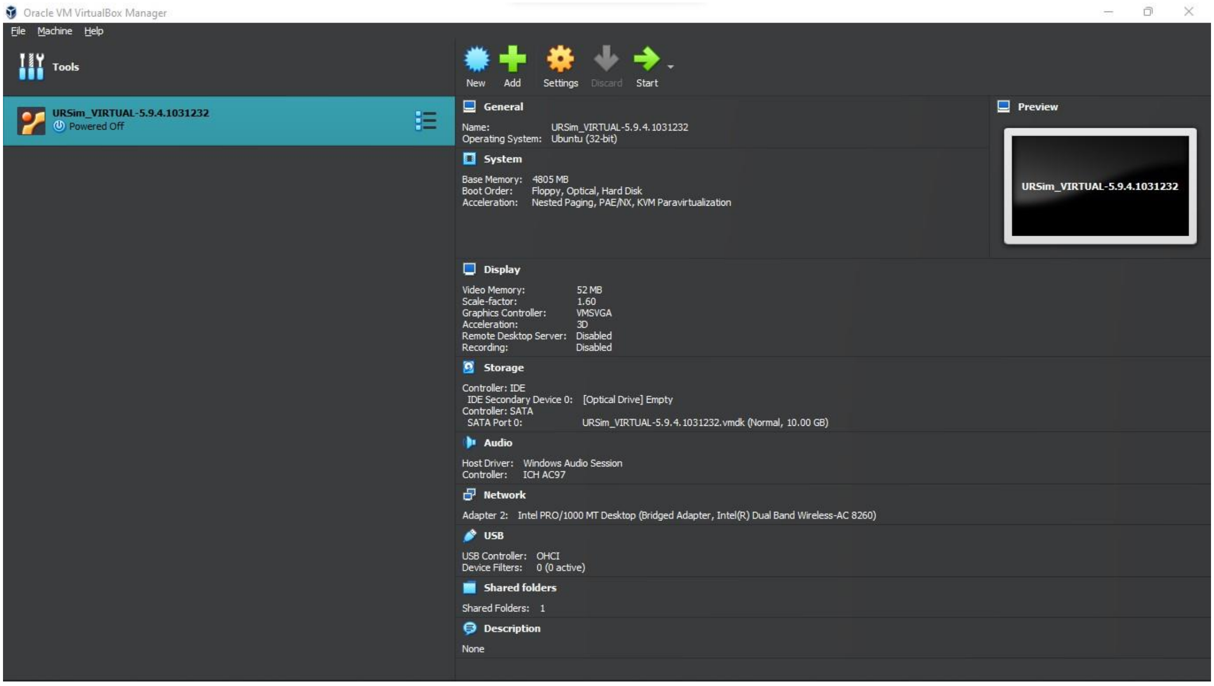


Figure 6.1 Screenshot of VM VirtualBox showing the computing of the virtual machine containing Polyscope (See Appendix C.19)

However, to visualize the motion actions of the cobot, the UR10e virtual rendition of the Visual Components software was employed. This provides a digital twin solution as depicted in Figure 6.2. The connectivity plug-in of Visual Components offers various remote connection options of which two were optimum. These were:

- UR-RTDE – It offers an easy solution to mimic an existing UR product by communicating to the products interface.
- OPCUA – It offers a robust solution to link parameters as desired by communicating to an OPCUA server.

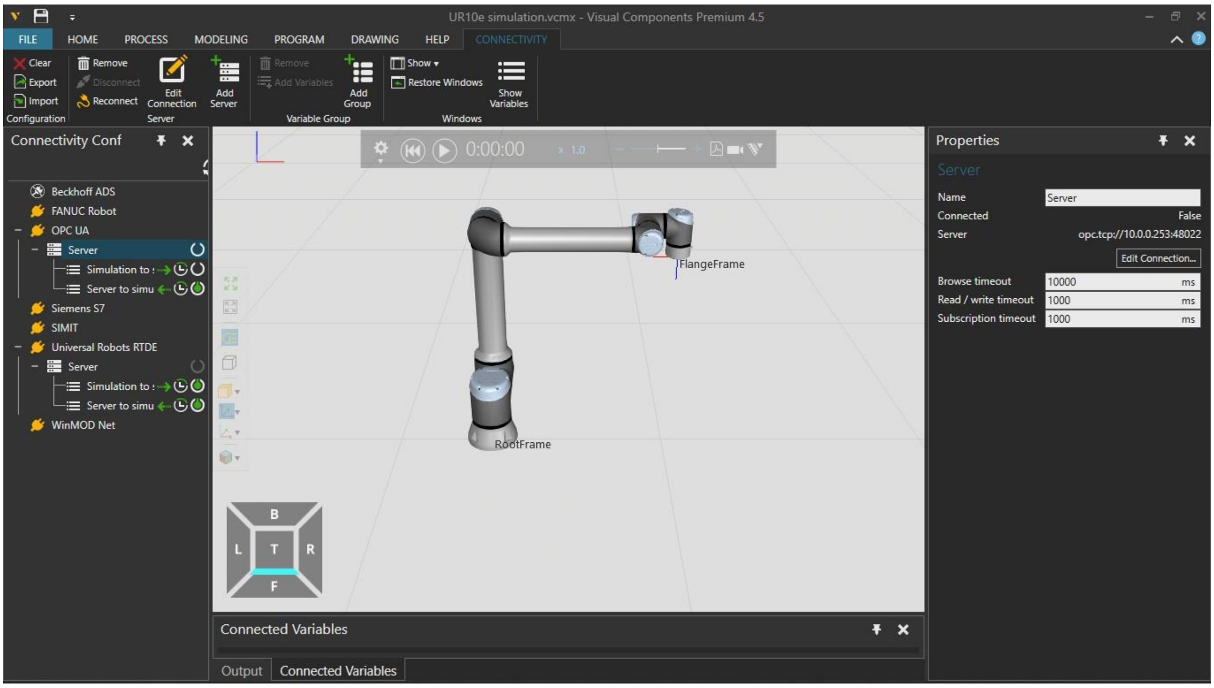


Figure 6.2 UR10e Digital twin on Visual Components

Table 6.1 Comparison of connectivity options for digital twin testing of the GUI

Element	**UR-RTDE**	**OPCUA**
Connects to	Address of robot or Polyscope	Address of OPCUA server
Joint connection	Uses the collective variables	Can use individual variables
Manipulation of digital twin	From robot	From OPCUA server input (e.g., directly, GUI, etc.)
Developer control	Limited	Robust opportunities

From Table 6.1, it can be established that the OPCUA connectivity offers more flexibility and detailed results towards the target of this work, thus this option was largely used.

To provide a monitor to read the components of the OPCUA server and its corresponding attributes, the UA Expert was indulged. This was extremely useful during the development stage to identify the attribute of a parameter to be used and also correct wrong pairings between NodeRed backend components and parameters created on the OPCUA server.

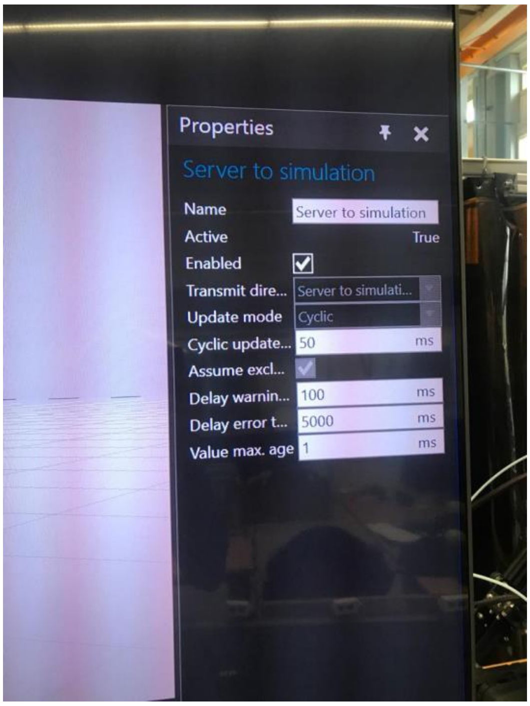


Figure 6.3 Established communication with OPCUA server

Once the connection is established as shown in Figure 6.3, several differing commands were sent through the GUI as would be expected to be operated by the SMEs. The reaction of the robot in the Visual Components' environment were as expected on a live UR10e cobot.

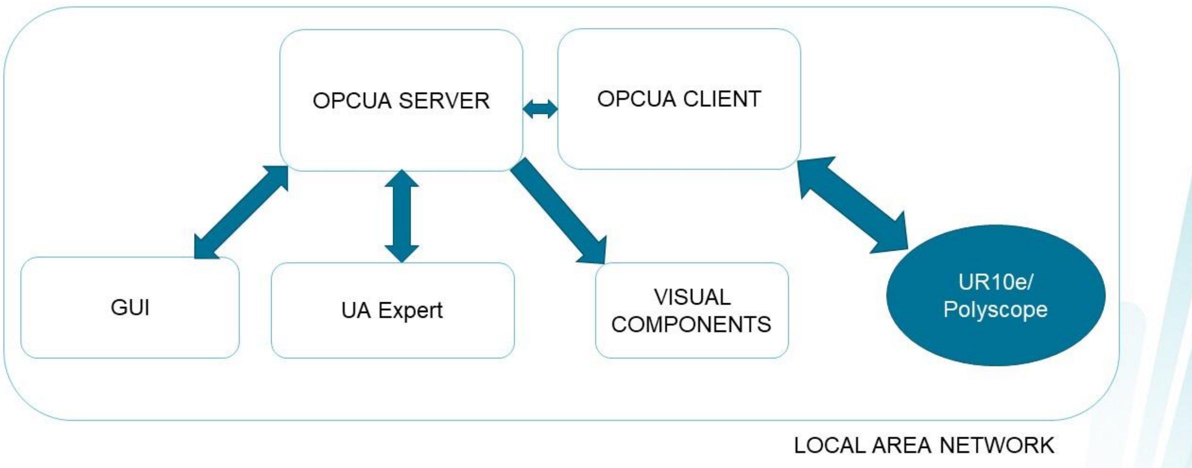


Figure 6.4 Framework for post development testing

Upon several testing and appreciation of the performance of the virtual rendition, testing with the physical UR10e in the lab was carried out.

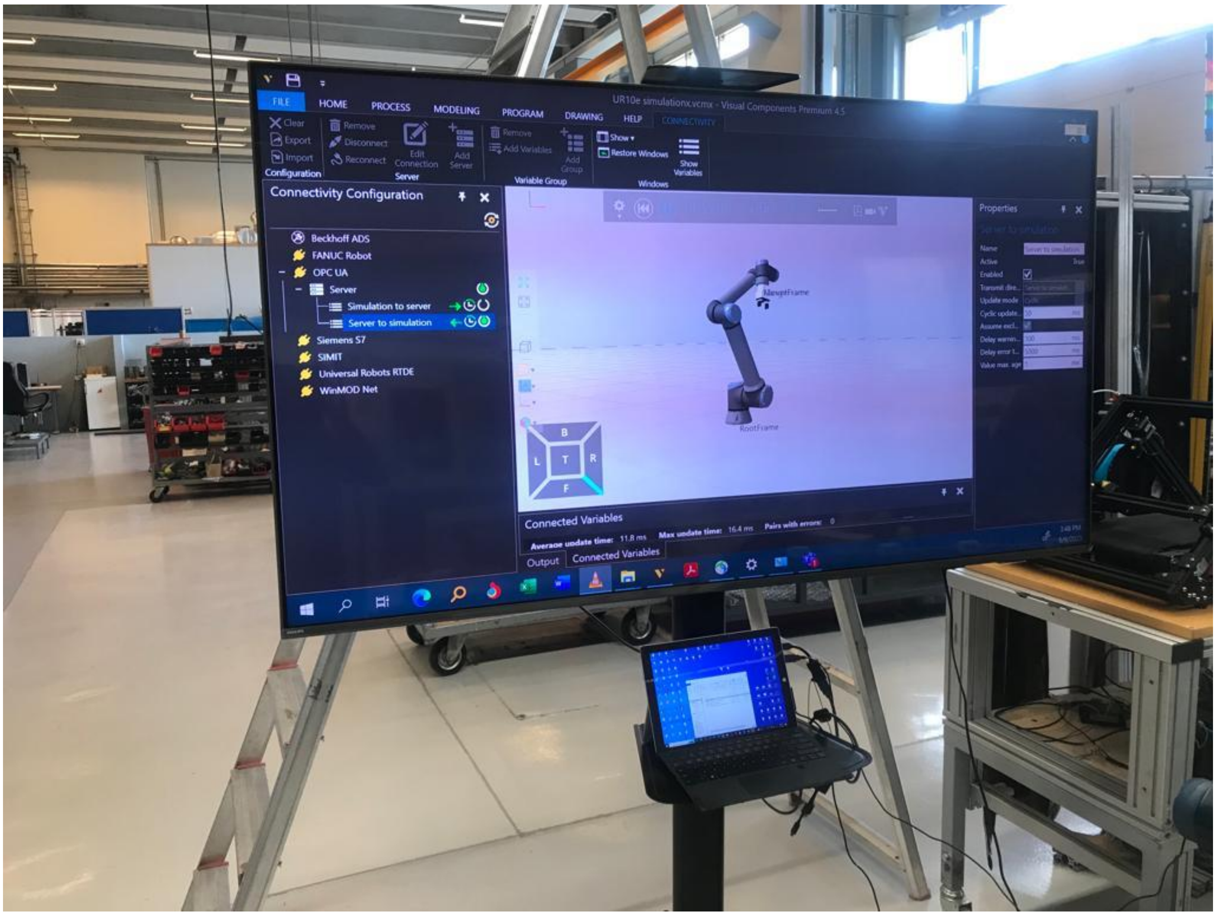


Figure 6.5 Testing the GUI with the virtual rendition in the department laboratory

The GUI was used over a period of five (5) days and twenty (22) hours for a total of one hundred and forty- two (142) hours and was engaged in movement actions. It performed amicably well. However, some challenges encountered involved:

- Network connectivity
- Safety triggers
- Tool activation

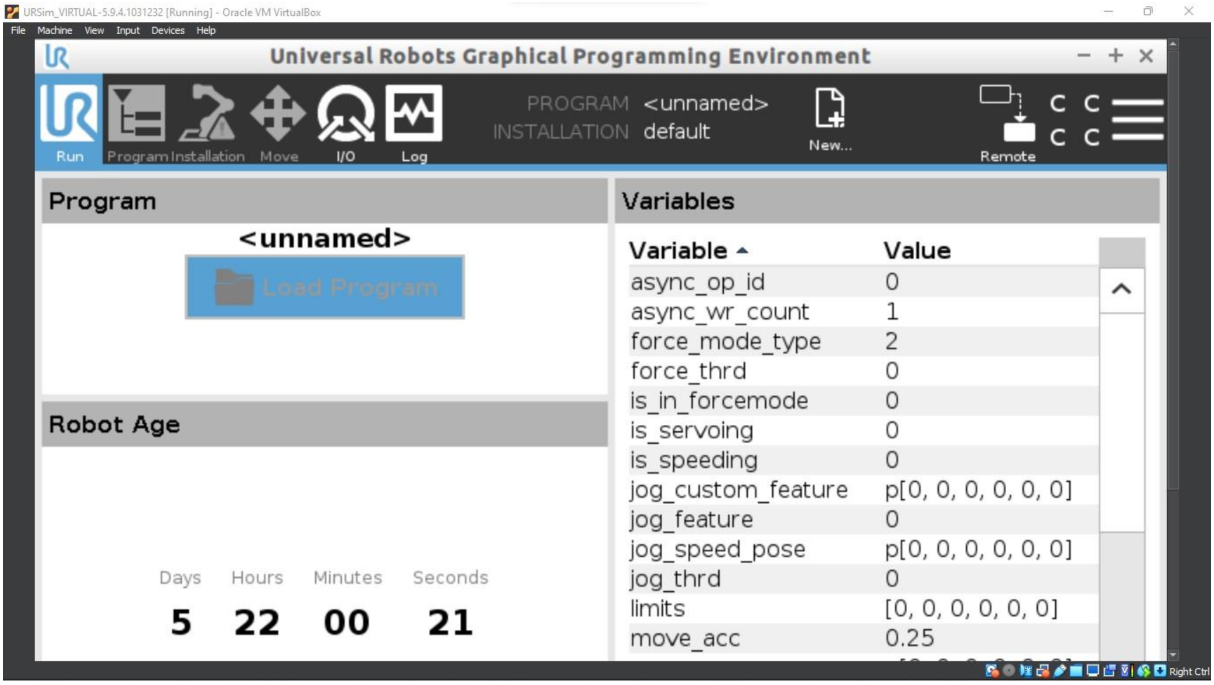


Figure 6.6 Screenshot displaying runtime of the virtual UR10e cobot environment

6.2 Evaluation

Despite the limitations towards aesthetic design by the NodeRed, the design and layout of the GUI offered an easy to understand tool to work with.

Also, the operation of the GUI by users with with little or no robot knowledge prior, offers the opportunity of easy adoption . However, some thoughts that need to be communicated with users with little or no prior robot knowledge has to be the selection of values in the “TCP Control” Page. These include:

- Right selection to prevent target point to be out of reach. For instance, a x,y,z,Rx,Ry,Rz position of (-30, 130, 15, 0, -180, -78) could be reached. However, a x,y,z,Rx,Ry,Rz position position of (-35, 130, 15, 0, -180, -78) could not be reached. This is due to maximum reach of the cobot arm.
- Right path choice to prevent the cobot from approaching singularity.
- Right path choice to prevent the cobot from triggering the ‘Preventive Stop’ after. sensing joints been too close or the possibility of tool flange being trapped in motion.

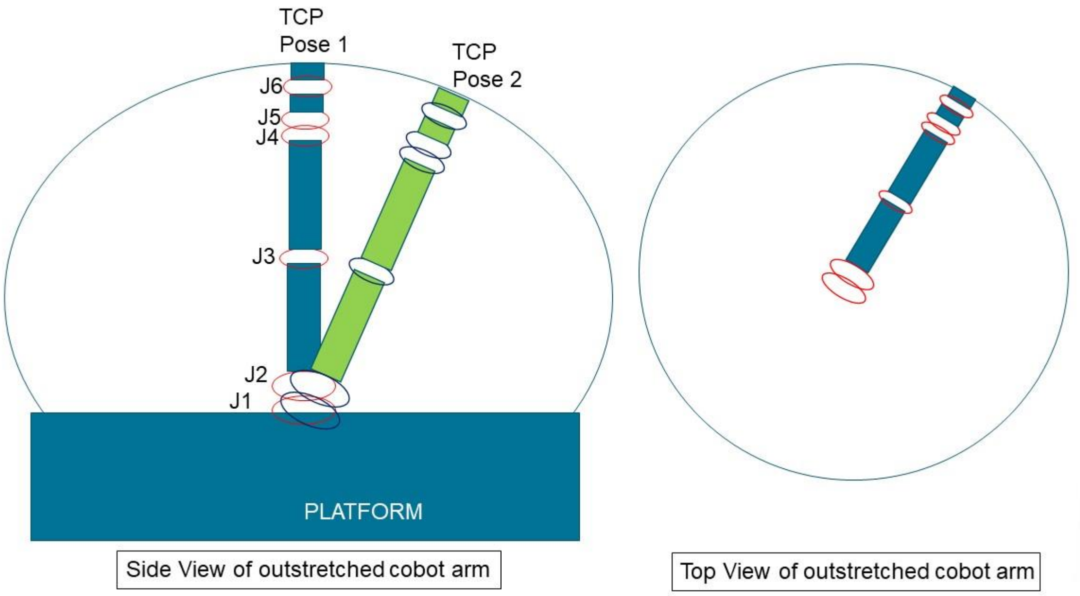


Figure 6.7 Depiction of maximum arm reach of the UR10e

Setup time of the GUI was also considered as it is neccesary to a production process flow. It was initially recorded at about fifteen (15) min but with use, it reduced to five (5) minutes.

Ease of first-time installation was also considered. Considering that the NodeRed setup is detailed. This could be a challenge with users of the barest minimum computing skills. However, an alternative approach is to pre-install the NodeRed and other required packages on a virtual machine and make the virtual machine available. This offers the opportunity to move the virtual machine between multiple physical computers will maintaining saved data and properties. This eases use of the GUI by users of the barest minimum computing skills.

The LAN connectivity offers any device connected to the network, access to the GUI. This enables use of the GUI by any computer, phone, or device that can call the host computer's address (https://***.***.***:1880/ui) in a browser. Although this provides some flexible adaptability, it also creates a security breach opportunity if the network is opened to the public or if the access oughts to be be only to authorized personel.

In mitigating the risks identified prior to the design and development of the GUI, measures that were earlier outlined were adequately employed, monitored and updated, during the process. For instance, during the development process, there was some challenge accessing the software via the university license. It was however resolved within about four (4) working days upon contact to the support team by the technical staff of the university.

6.3 Recommendations

Some recommendations to ensure a smooth use of the GUI include:

1. Ensure to follow the steps to launch the GUI to prevent errors
2. Ensure there are no empty variable container before clicking an action button to prevent the system crashing from receiving an improper variable.
3. Crosscheck the Settings page to ensure that the values of the default/updated parameters are the desired values.
4. Use of the Chrome web browser has the advantage to download a desktop widget which you can run like an executable application.
5. As an added safety feature, each page has its own speed slider. It is necessary to choose the speed needed to work in that condition else it may create an empty variable as explained in (2).

6.3.1 Troubleshooting

Some challenges were encountered during the development and testing of the GUI which were worth taking note of. Permanent solutions to these challenges were not readily found thus in Table 6.2 are some challenges with corresponding possible solutions to troubleshoot the tool. Given that this work is open for further development, the table is divided into two (2) sections to cater for normal operational use by anyone and also, during a developmental and testing period by a developer.

Table 6.2 Possible solutions to foreseeable downtimes

Challenge	**Possible Solution**
Normal Operation	
Values not appearing on the current position upon launch	1. Check Python IDE if OPCUA server is running. 2. Check Python IDE if client is still running.
Buttons not responding to clicks	1. Check page for empty fields. 2. Check settings for additional parameters. 3. Check NodeRed cmd and restart. 4. Check Python IDE if client is still running. 5. Check Cobot for warning prompt.
Testing and Development	

Values not appearing on the current position upon launch	1. Confirm OPCUA server address in NodeRed backend is correct. 2. Confirm the right mode of the OPCUA Client component is set to READ. 3. Confirm the right attribute of the OPCUA parameter is entered in the OPCUA Item component.
A new parameter added to the OPCUA returns errors when called in the client (e.g., UnboundLocalError)	1. Crosscheck the attribute name and build of the parameter in the Parameter script. 2. Crosscheck the attribute name and build of the parameter in the Client script.
Buttons not responding to clicks	1. Crosscheck the connectivity of the button to the desired trigger. 2. Confirm OPCUA server address in NodeRed backend is correct. 3. Confirm the right mode of the OPCUA Client component is set to WRITE. 4. Confirm the right attribute of the OPCUA parameter is entered in the OPCUA Item component. 5. Crosscheck action program/code in Python script.

7 CONCLUSION

This work provides some contribution towards an easy adoption of the UR10e cobot by SMEs. The result of this work is been used at the Laboratory of the Industrial Engineering department with the UR10e. It enables the control of the movement of the cobot through joint movements (individually and collectively) and linear movements with respect to the TCP. It also triggers the activation of commands to stop the robot and input to the tool port.

The current application of this GUI could be relevant to SMEs in the manufacturing industry that embody tasks such as sanding, polishing, spray painting, quality inspection and other tasks that require repetitive movement without a tool activation from the robot. An improvement of the GUI to engage tool would broaden the possibilities of use of the GUI.

This GUI embodies a solution for technology transfer to SMEs as it requires little to no programming skills. It also requires little knowledge on robot operation and as such, can be used by a layman. This solution should offer the opportunity for SMEs to retain current staff as they embrace the technology, increase their revenue and increase their production opportunities.

Although the initial installation stage may require some computer skills, a solution to further ease the technology transfer would be to pre-install all the required items (softwares, modules, packages and plug-ins) on a virtual machine and make this virtual machine available to the SME. This reduces the setup to only three chronological steps:

1. Virtual machine reader installation (e.g., VM VirtualBox)
2. Launching of virtual machine
3. Launching of GUI

In connection with the digital twin (virtual Polyscope and Visual Components rendition of UR10e cobot) as was employed during the development and testing stages, testing unverified production routines or tasks could be carried out. Also, the training of new staff, demonstration to customers and exhibition of the production processes of the SMEs could be achieved.

In fulfilment of the tasks assigned at the start and through-out the project period, the following were accomplished:

1. Preparation of an extensive review of literature around Industrial robots (and the evolution to collaborative robots), SMEs and Technology Transfer.
2. Engagement with some stakeholders was carried out.
3. Design and development of a Technology Transfer tool (GUI).
4. Testing and Evaluation of the tool.
5. Documentation of the accomplished work
6. Presentation and demonstration of the tool at the Laboratory of the Industrial Engineering department (Demonstration accessible online at: https://www.loom.com/share/632b043606e64d7b900680727c2a60d3)

7.1 Further Research

Some considerations for further work to be done in the future include:

1. To make the GUI an executable file which can be installed and run as a collection of files.
2. To build a URCaps counterpart for the GUI with characteristics spelt out by UR that can obtain it a special recognition (URCaps+).
3. To improve the Tool control features to enable the activations of tools such as grippers, screwdrivers, etc. for tasks such as fastening, stacking and other activity-related tasks.
4. To improve the Program list and “Run” capabilities to enable positions to be stored in a database and called when they are needed. This could make the number of saved positions limitless.
5. To engage more communication to the cobot to achieve some specialized tasks such as switches between move types after an action.
6. To design a web-based solution for off-site manipulation of the cobot.

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Appendix

A. PLANNED MASTERS THESIS ACTIVITY GANTT CHART

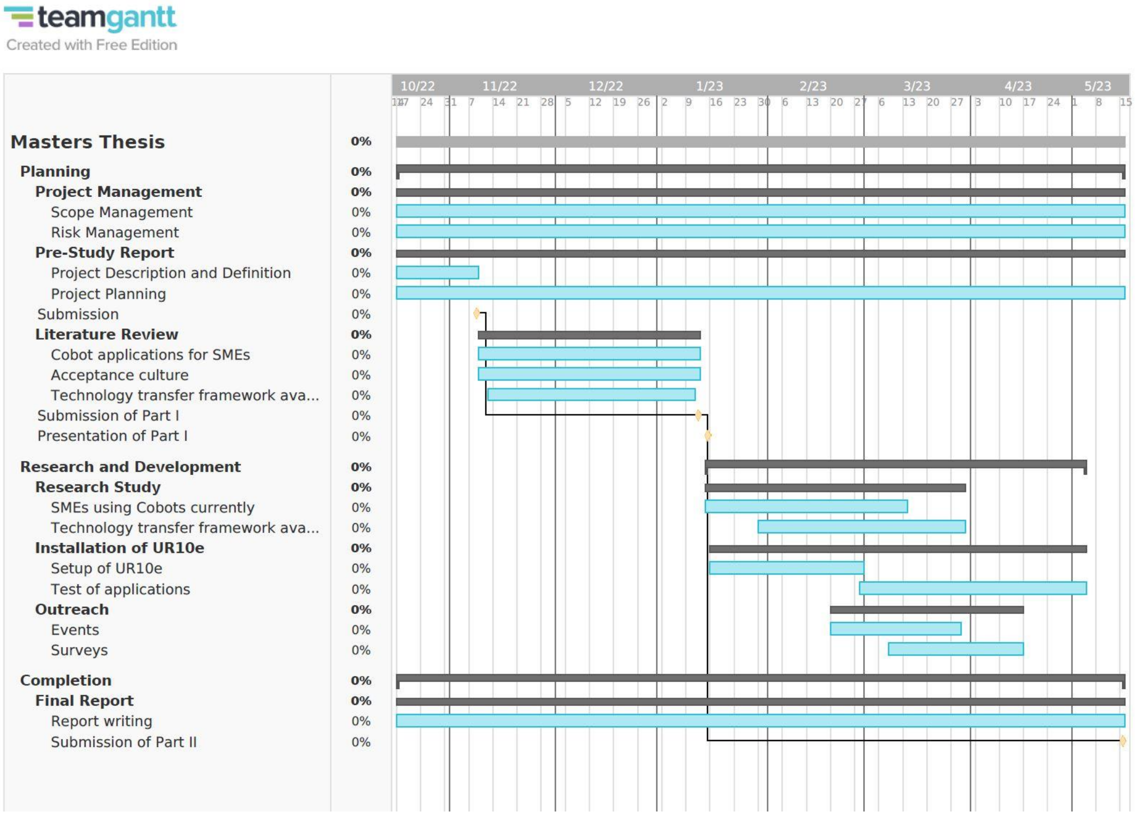
B. OPCUA COMPONENTS DEVELOPED

C. ENLARGEMENT OF SOME IN-TEXT FIGURES

D. RISK ANALYSIS

E. TASK DESCRIPTION, PRE-STUDY AND PROGRESS REPORTS

A. PLANNED MASTERS THESIS ACTIVITY GANTT CHART



B. OPCUA COMPONENTS DEVELOPED

	Folder	Object	Data Type	Send	Receive	Application	Joint Control Page	TCP Control page	Programs	Settings
		UR10e A1 Current	Double	UR10e	GUI	Receives Joint Value from Cobot	X		X	
		UR10e A2 Current	Double	UR10e	GUI	Receives Joint Value from Cobot	X		X	
		UR10e A3 Current	Double	UR10e	GUI	Receives Joint Value from Cobot	X		X	
		UR10e A4 Current	Double	UR10e	GUI	Receives Joint Value from Cobot	X		X	
		UR10e A5 Current	Double	UR10e	GUI	Receives Joint Value from Cobot	X		X	
	1 UR10e Current Joint	UR10e A6 Current	Double	UR10e	GUI	Receives Joint Value from Cobot	X		X	
		UR10e A1 Wanted	Double	GUI	UR10e	Sends Joint Value to Cobot	X			
		UR10e A2 Wanted	Double	GUI	UR10e	Sends Joint Value to Cobot	X			
		UR10e A3 Wanted	Double	GUI	UR10e	Sends Joint Value to Cobot	X			
		UR10e A4 Wanted	Double	GUI	UR10e	Sends Joint Value to Cobot	X			
		UR10e A5 Wanted	Double	GUI	UR10e	Sends Joint Value to Cobot	X			
	2 UR10e Wanted Joint	UR10e A6 Wanted	Double	GUI	UR10e	Sends Joint Value to Cobot	X			
		UR10e x Current	Double	UR10e	GUI	Receives Translational TCP Value from Cobot		X		
UR10e Platform	3 UR10e Current xyz	UR10e y Current	Double	UR10e	GUI	Receives Translational TCP Value from Cobot		X		

		UR10e z Current	Double	UR10e	GUI	Receives Translational TCP Value from Cobot		X		
		UR10e Rx Current	Double	UR10e	GUI	Receives Rotational vector TCP Value from Cobot		X		
		UR10e Ry Current	Double	UR10e	GUI	Receives Rotational vector TCP Value from Cobot		X		
		UR10e Rz Current	Double	UR10e	GUI	Receives Rotational vector TCP Value from Cobot		X		
		UR10e x Wanted	Double	GUI	UR10e	Sends Translational TCP Value to Cobot		X		
		UR10e y Wanted	Double	GUI	UR10e	Sends Translational TCP Value to Cobot		X		
		UR10e z Wanted	Double	GUI	UR10e	Sends Translational TCP Value to Cobot		X		
		UR10e Rx Wanted	Double	GUI	UR10e	Sends Rotational vector TCP Value to Cobot		X		
		UR10e Ry Wanted	Double	GUI	UR10e	Sends Rotational vector TCP Value to Cobot		X		
	4 UR10e Wanted xyz	UR10e Rz Wanted	Double	GUI	UR10e	Sends Rotational vector TCP Value to Cobot		X		
		UR10e Wanted Position Format	Double	GUI	UR10e	Sends a Value to Cobot to determine either a Joint or TCP movement	X	X		
		UR10e Home Position	Double	GUI	UR10e		X	X	X	X
		UR10e Joint Speed	Double	GUI	UR10e	Sends Angular Velocity Value to Cobot	X	X		X
		UR10e Joint Acceleration	Double	GUI	UR10e	Sends Angular Acceleration Value to Cobot	X	X		X
		UR10e TCP Speed	Double	GUI	UR10e	Sends Linear Velocity Value to Cobot	X	X		X
	5 UR10e Control	UR10e TCP Acceleration	Double	GUI	UR10e	Sends Linear Accelaration Value to Cobot	X	X		X

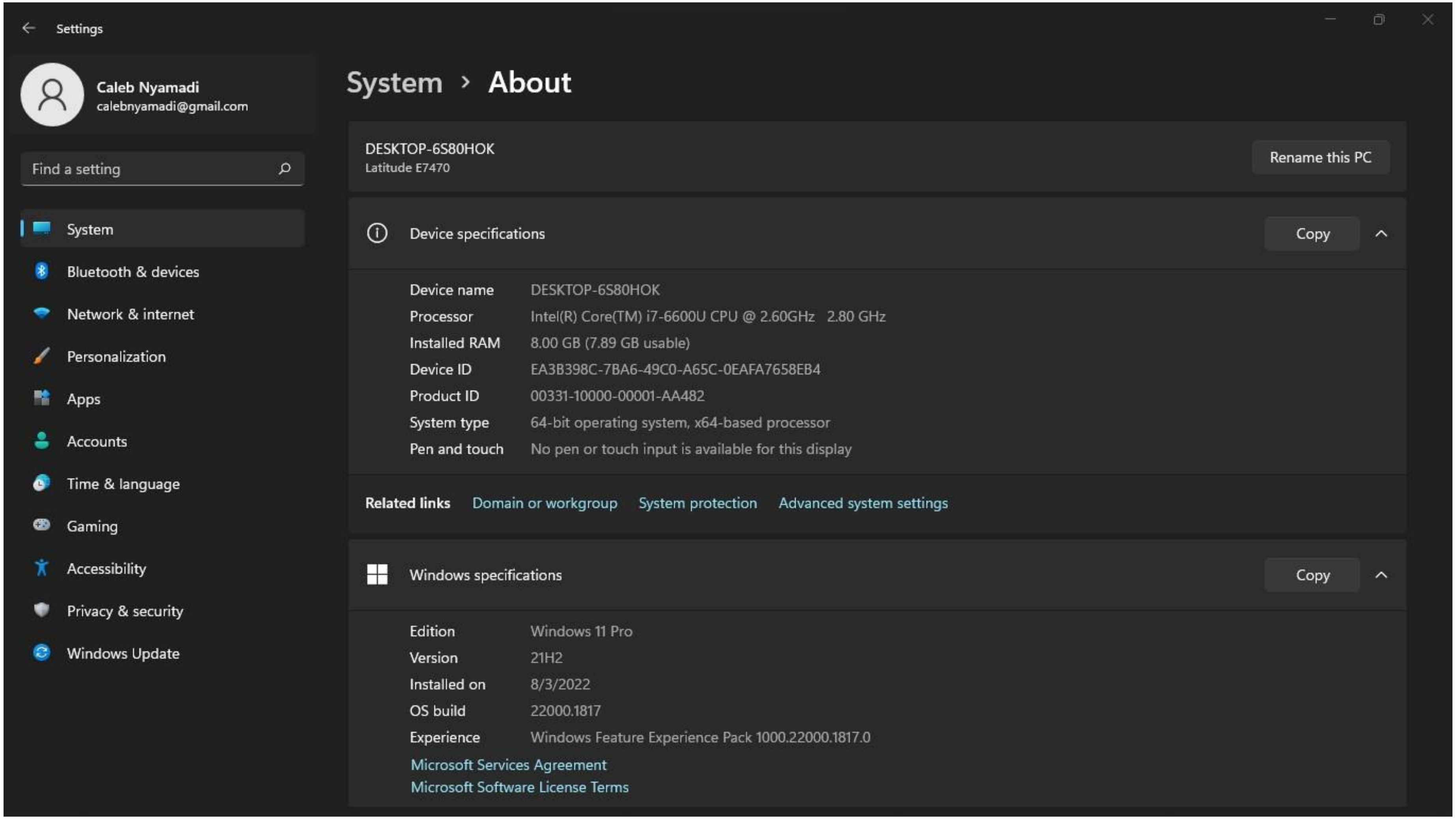
		UR10e Moving Flag	Double	GUI	UR10e	Sends a Value to Cobot to commence movement	X	X		
		UR10e Tool Input	Double	GUI	UR10e		X	X		
		UR10e Stop Input	Double	GUI	UR10e	Sends a Value to Cobot to halt movement	X	X	X	X
		UR10e Overall Speed	Double	GUI	UR10e	Sends an amplification speed Value to Cobot	X	X	X	
		UR10e Increment	Double	GUI	UR10e	Sends a Value to Cobot to increase or decrease a position element and by what extent	X	X		
		UR10e Run Path	Double	GUI	UR10e	Sends a Value to Cobot to determine how to move through multiple positions in one instance			X	
		UR10e input bit 0	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
		UR10e input bit 1	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
		UR10e input bit 2	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
		UR10e input bit 3	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
		UR10e input bit 4	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
		UR10e input bit 5	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
		UR10e input bit 6	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
	8 UR10e Digital Input bits	UR10e input bit 7	Boolean	GUI	UR10e	Sends a Value to Cobot to control input				
	8 UR10e Digital Output bits	UR10e output bit 0	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				

		UR10e output bit 1	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				
		UR10e output bit 2	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				
		UR10e output bit 3	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				
		UR10e output bit 4	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				
		UR10e output bit 5	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				
		UR10e output bit 6	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				
		UR10e output bit 7	Boolean	GUI	UR10e	Sends a Value to Cobot to control output				
		UR10e output 1	Boolean	GUI	UR10e	Sends a Value to Cobot to control tool output				
	9 UR10e Tool	UR10e output 2	Boolean	GUI	UR10e	Sends a Value to Cobot to control tool output				
		UR10e x 1 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e y 1 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e z 1 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e Rx 1 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Ry 1 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Rz 1 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e x 2 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
	10 UR10e Wanted Path xyz	UR10e y 2 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	

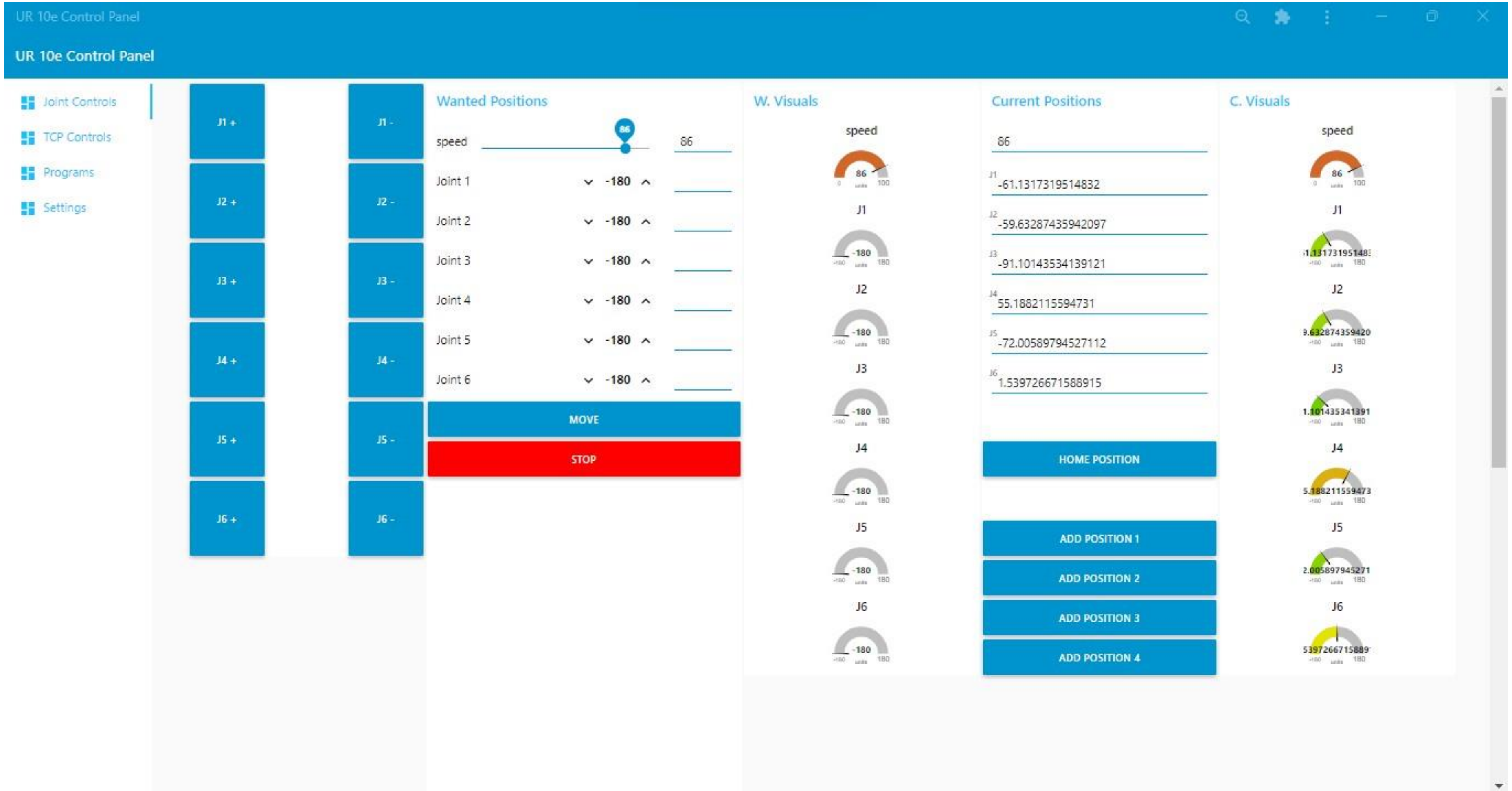
		UR10e z 2 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e Rx 2 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Ry 2 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Rz 2 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e x 3 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e y 3 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e z 3 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e Rx 3 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Ry 3 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Rz 3 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e x 4 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e y 4 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e z 4 Wanted	Double	GUI	UR10e	Holds Translational TCP Value to Cobot	X	X	X	
		UR10e Rx 4 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Ry 4 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	
		UR10e Rz 4 Wanted	Double	GUI	UR10e	Holds Rotational vector TCP Value to Cobot	X	X	X	

C. ENLARGEMENT OF SOME IN-TEXT FIGURES

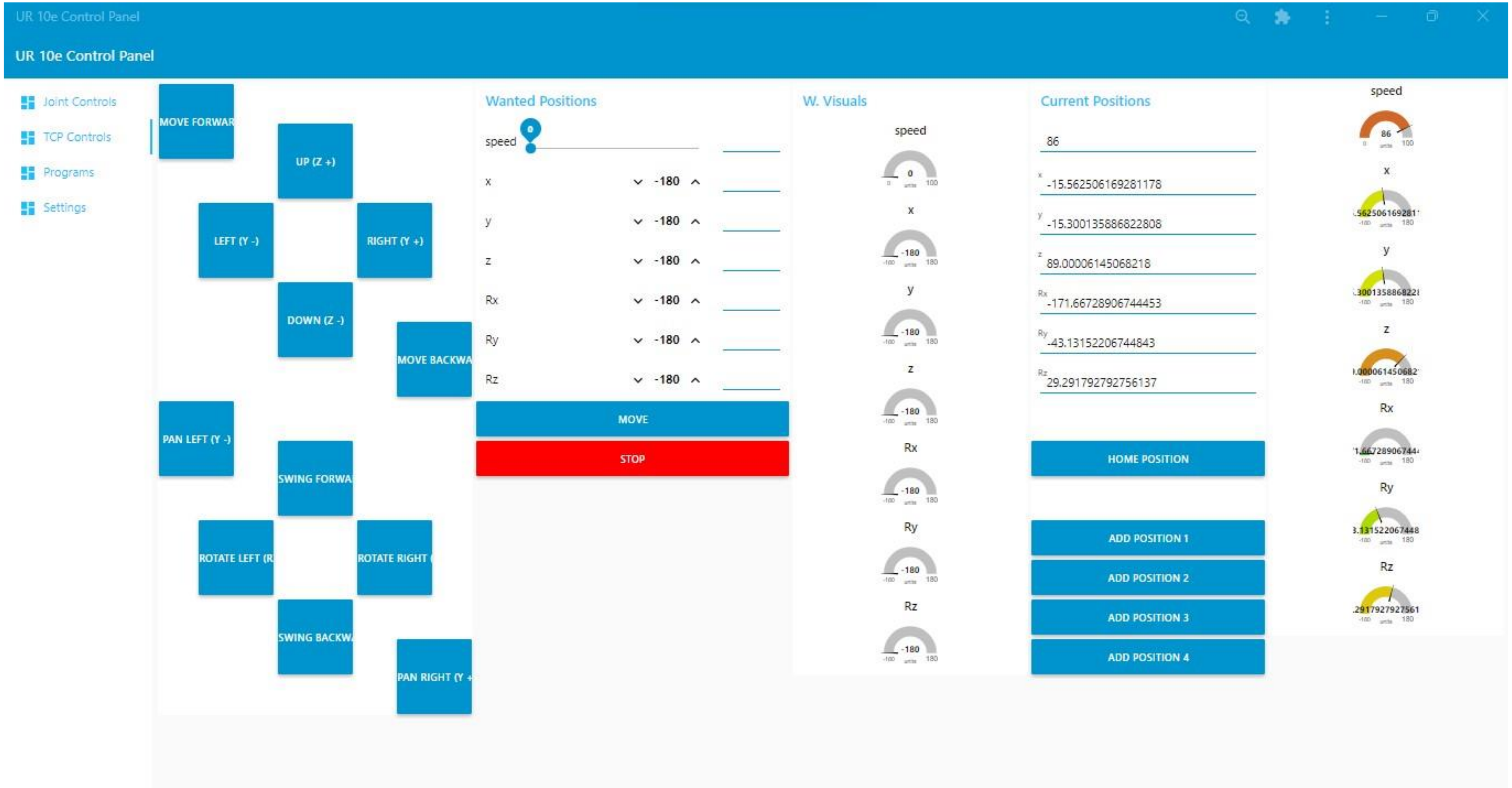
C.1. Computing capability of the PC used to develop the GUI



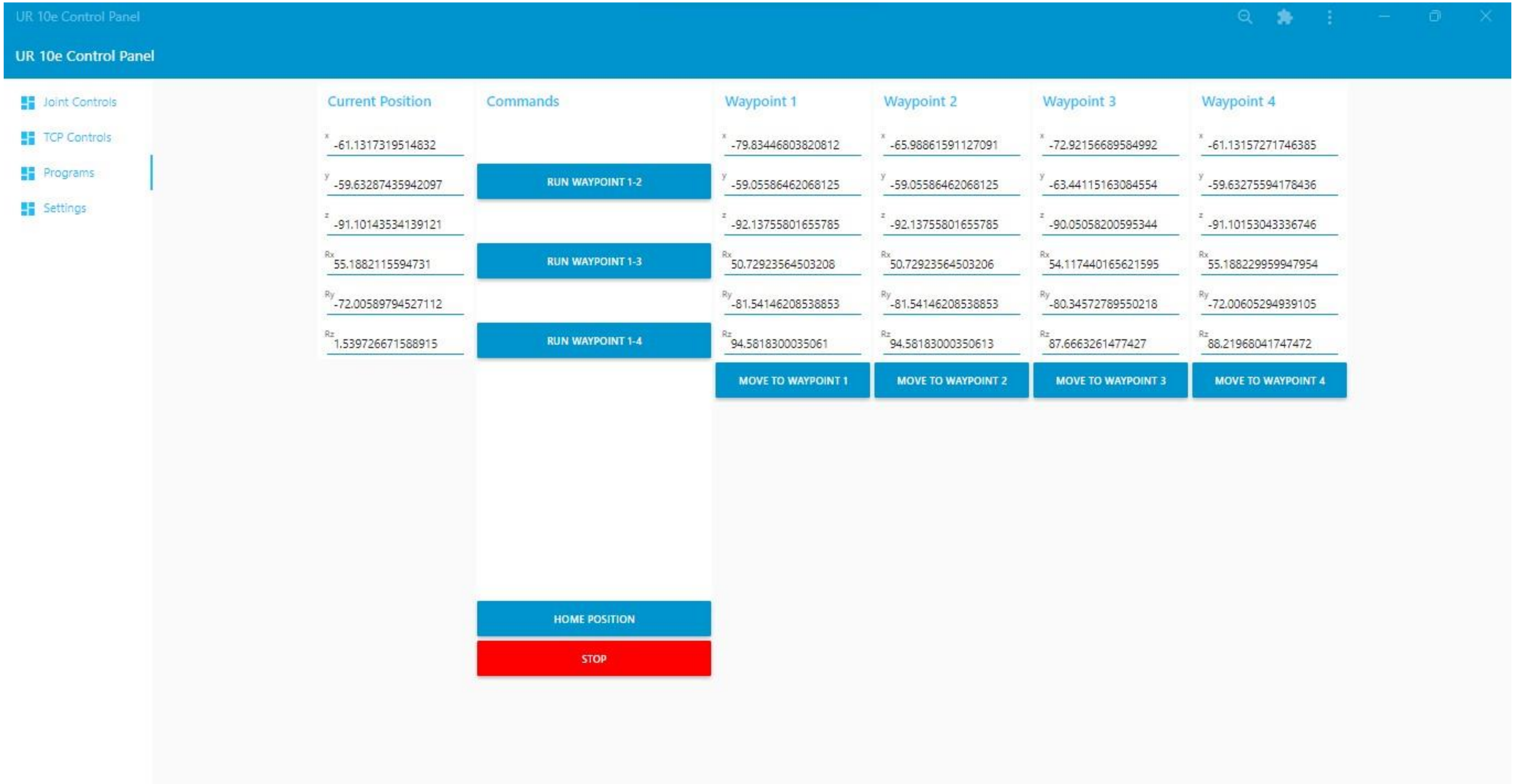
C.2. Screenshot of GUI design showing the 'Joint Control' page



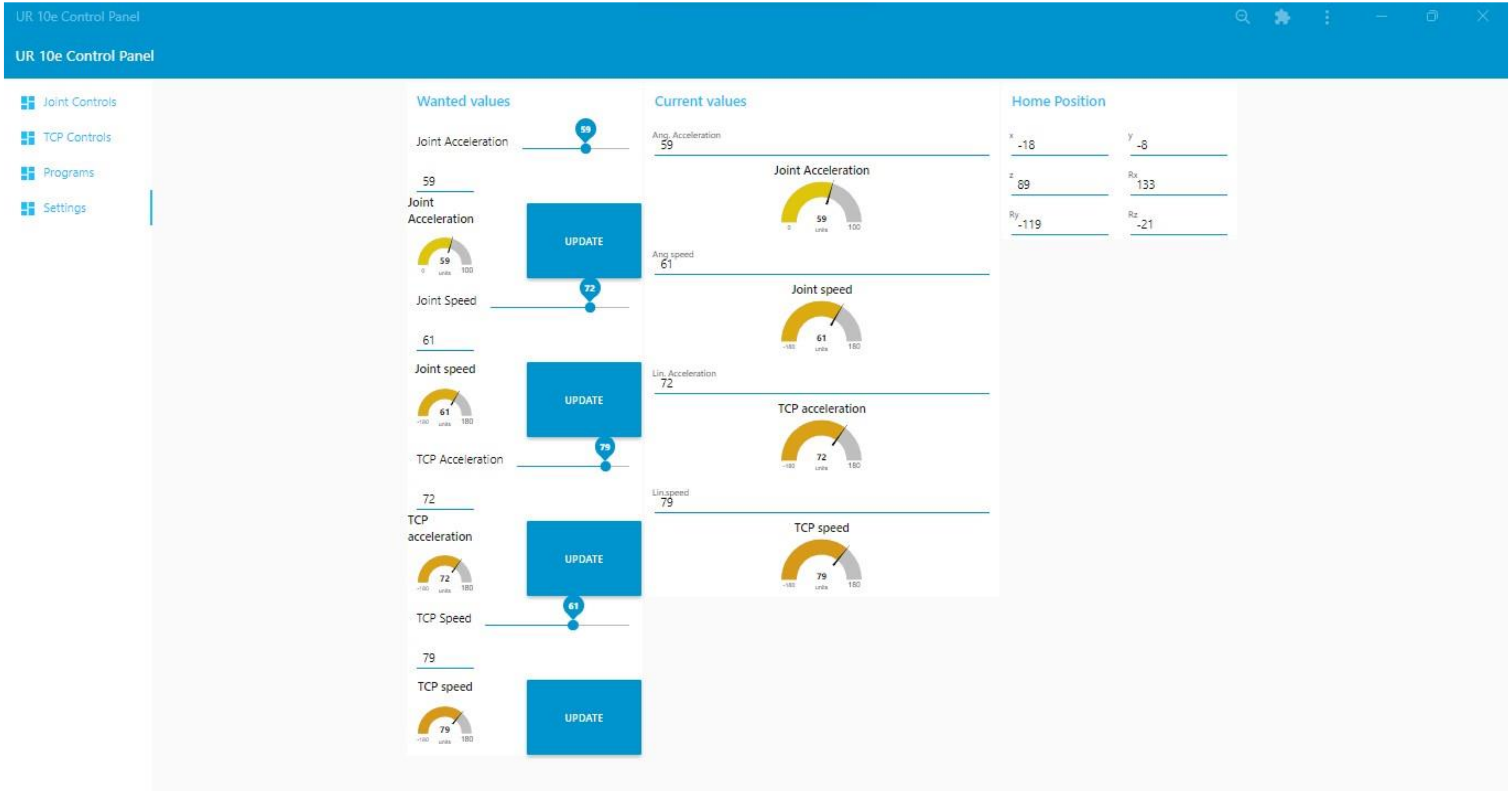
C.3. Screenshot of GUI design showing the 'TCP Control' page



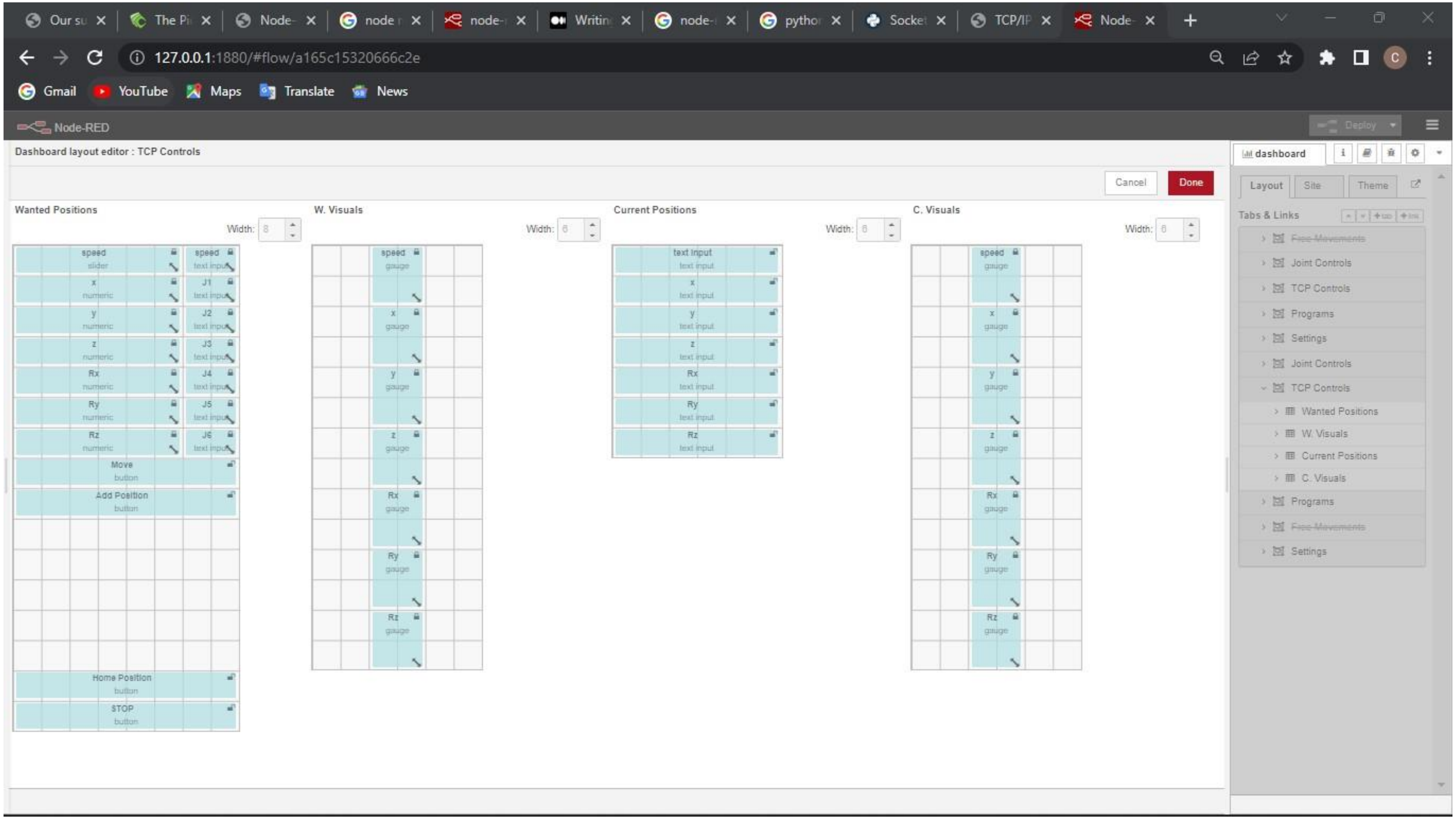
C.4. Screenshot of GUI design showing the ‘Program’ page



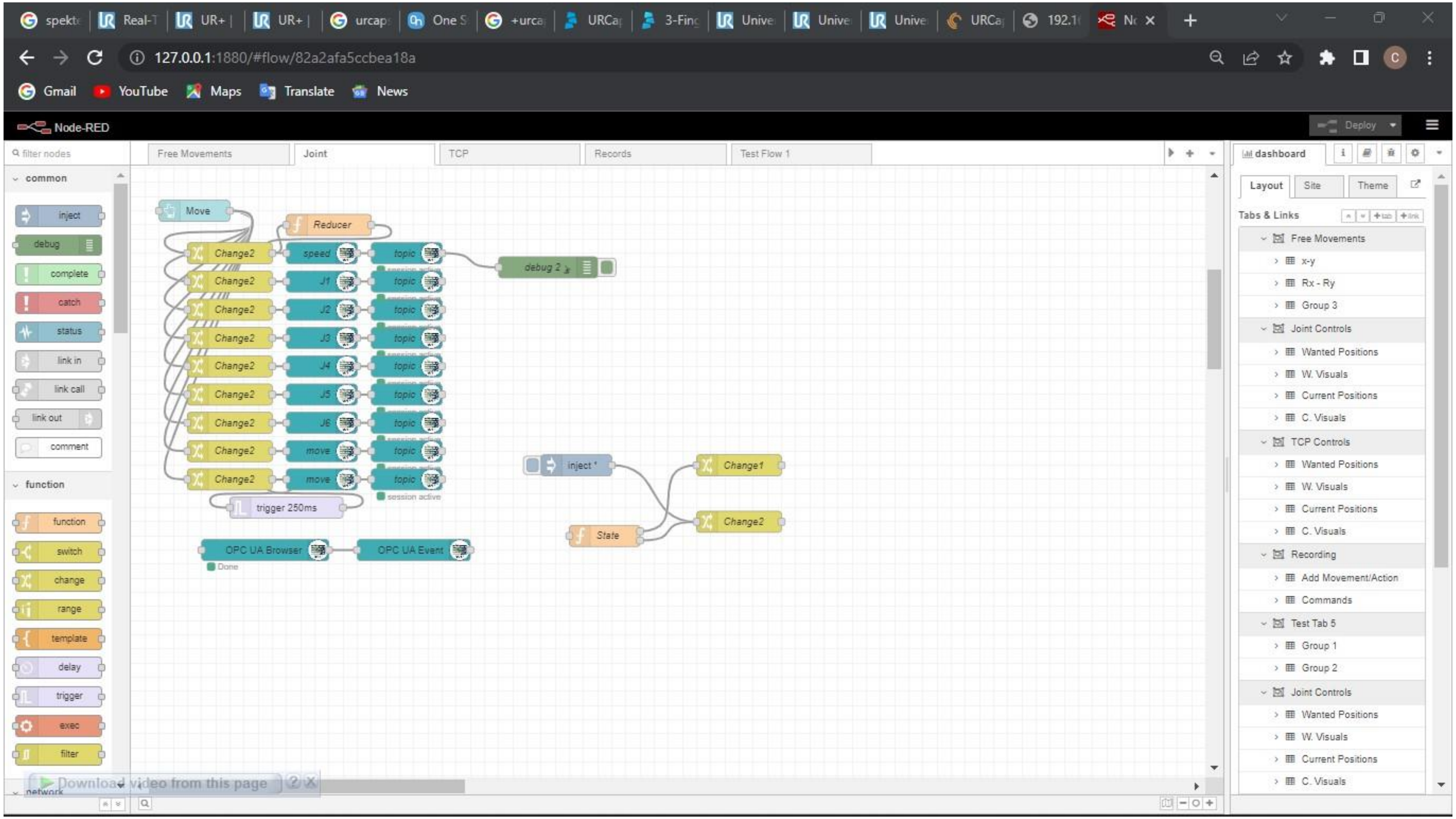
C.5. Screenshot of GUI design showing the 'Settings' page



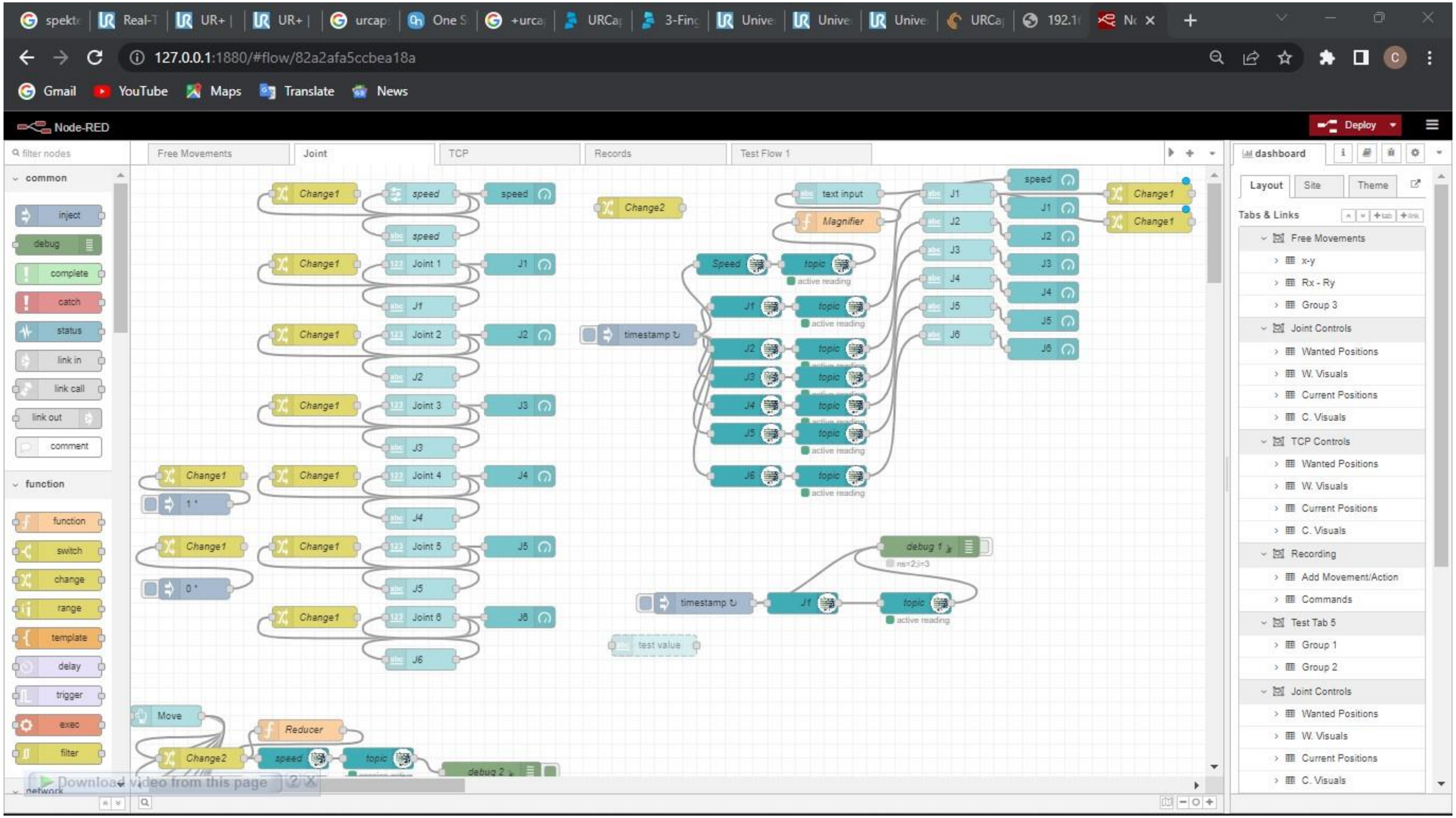
C.6. Screenshot of 'TCP Controls' Page Layout in NodeRed backend



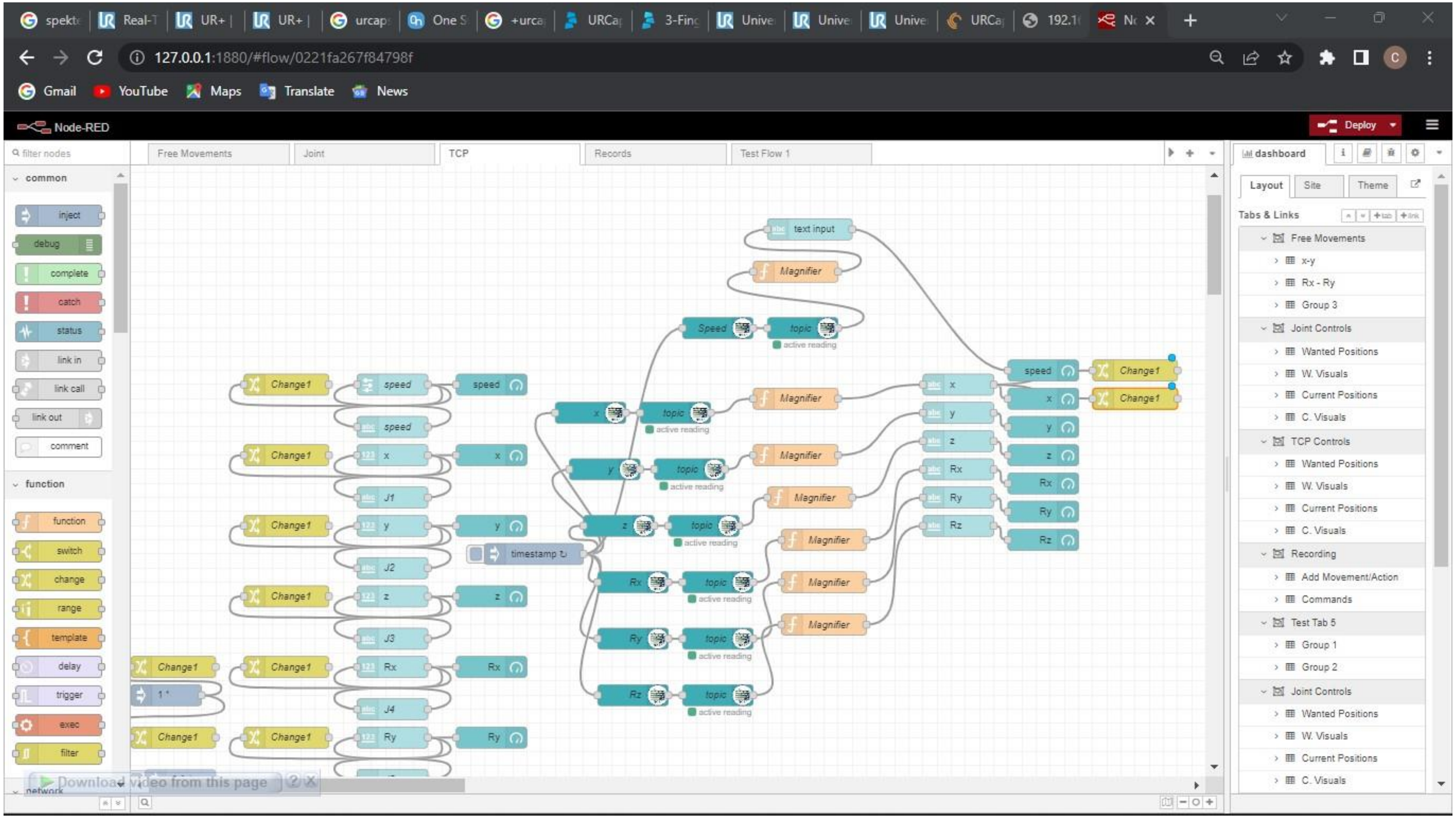
C.7. Screenshot of NodeRed backend showing the links for the wanted Joint values button activation



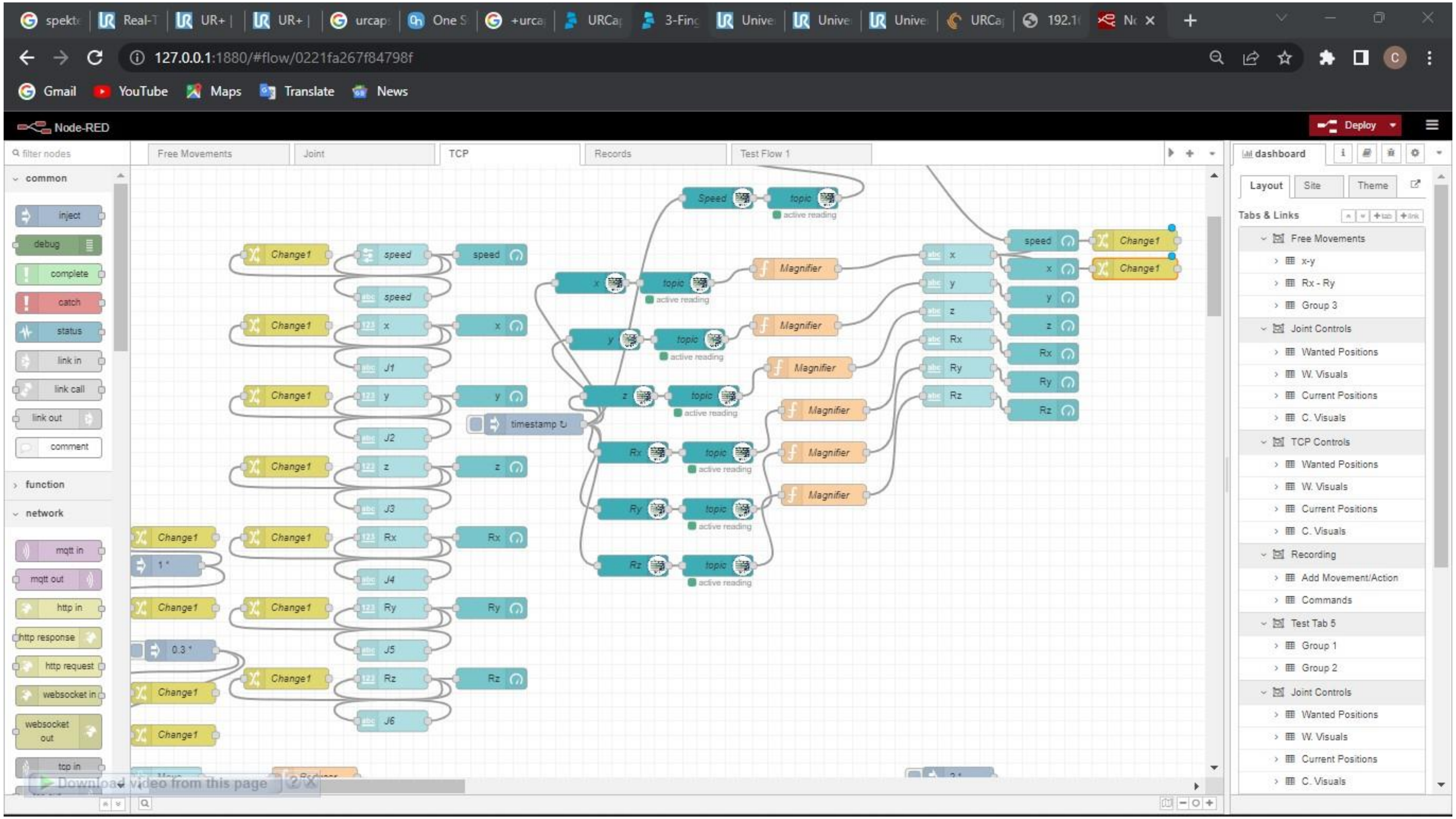
C.8. Screenshot of NodeRed backend showing the links for joint control 'wanted position' communication



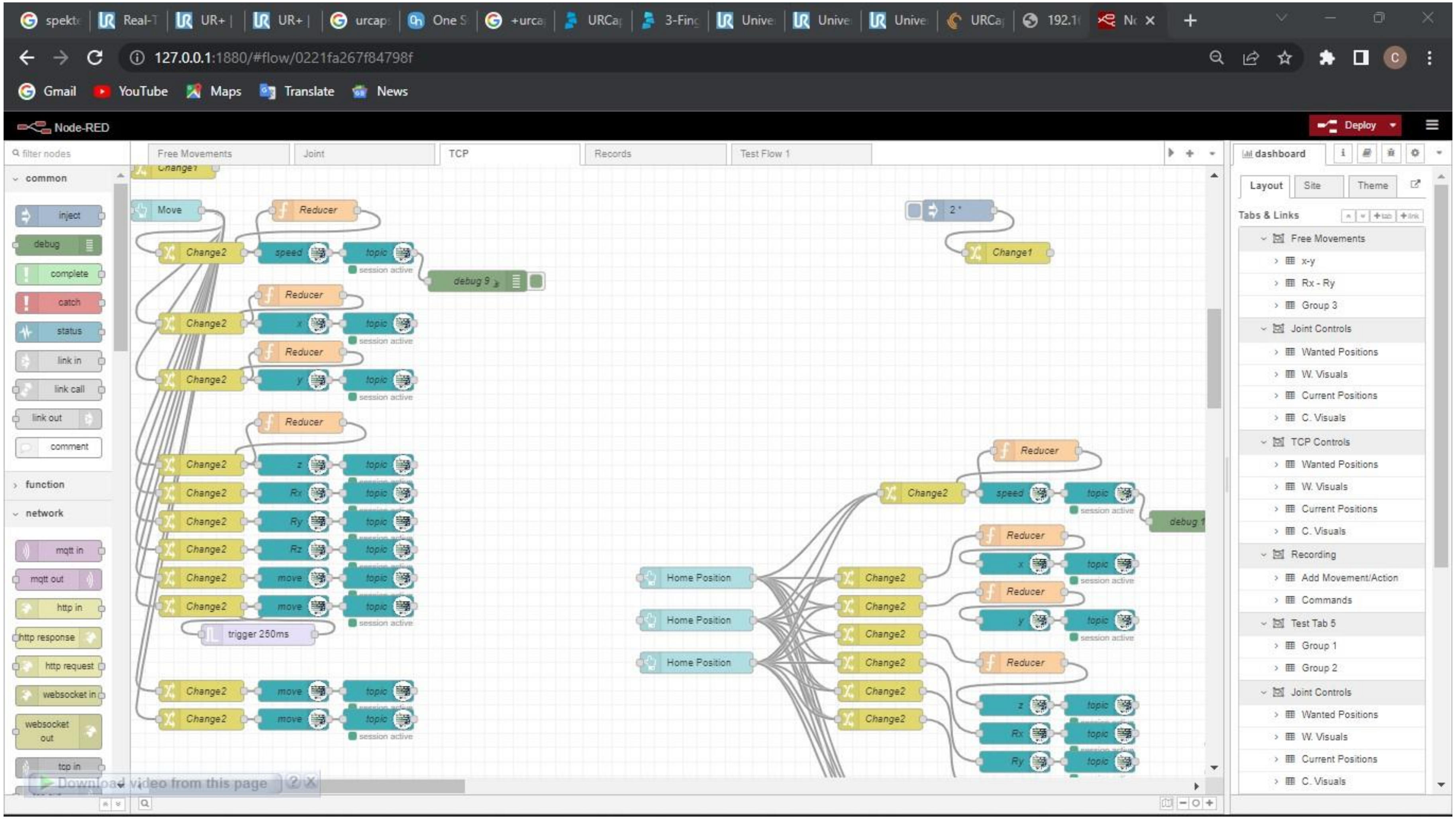
C.9. Screenshot of NodeRed backend showing the links for TCP control ‘current position’ communication



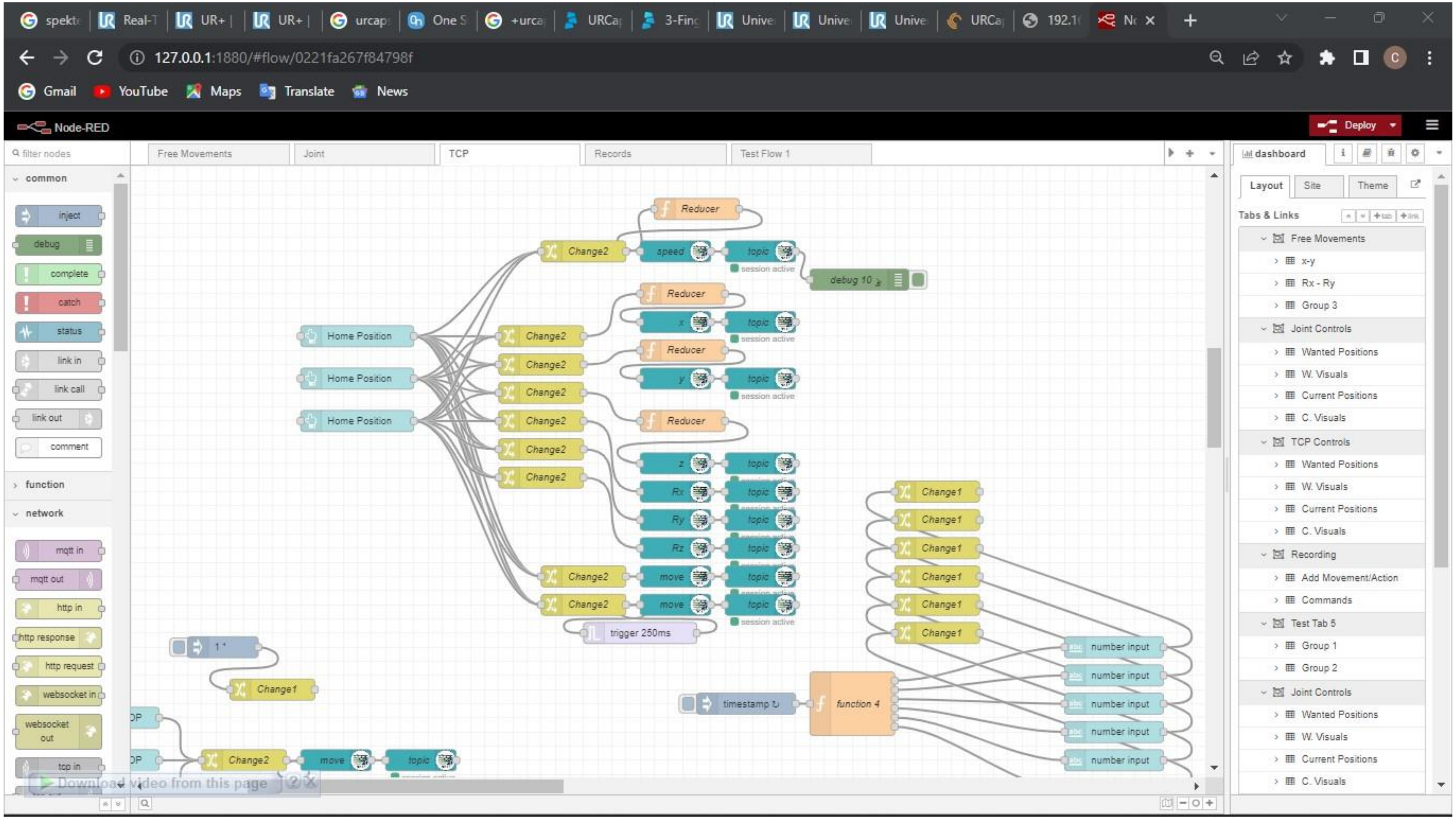
C.10. Screenshot of NodeRed backend showing the links for the wanted TCP values communication



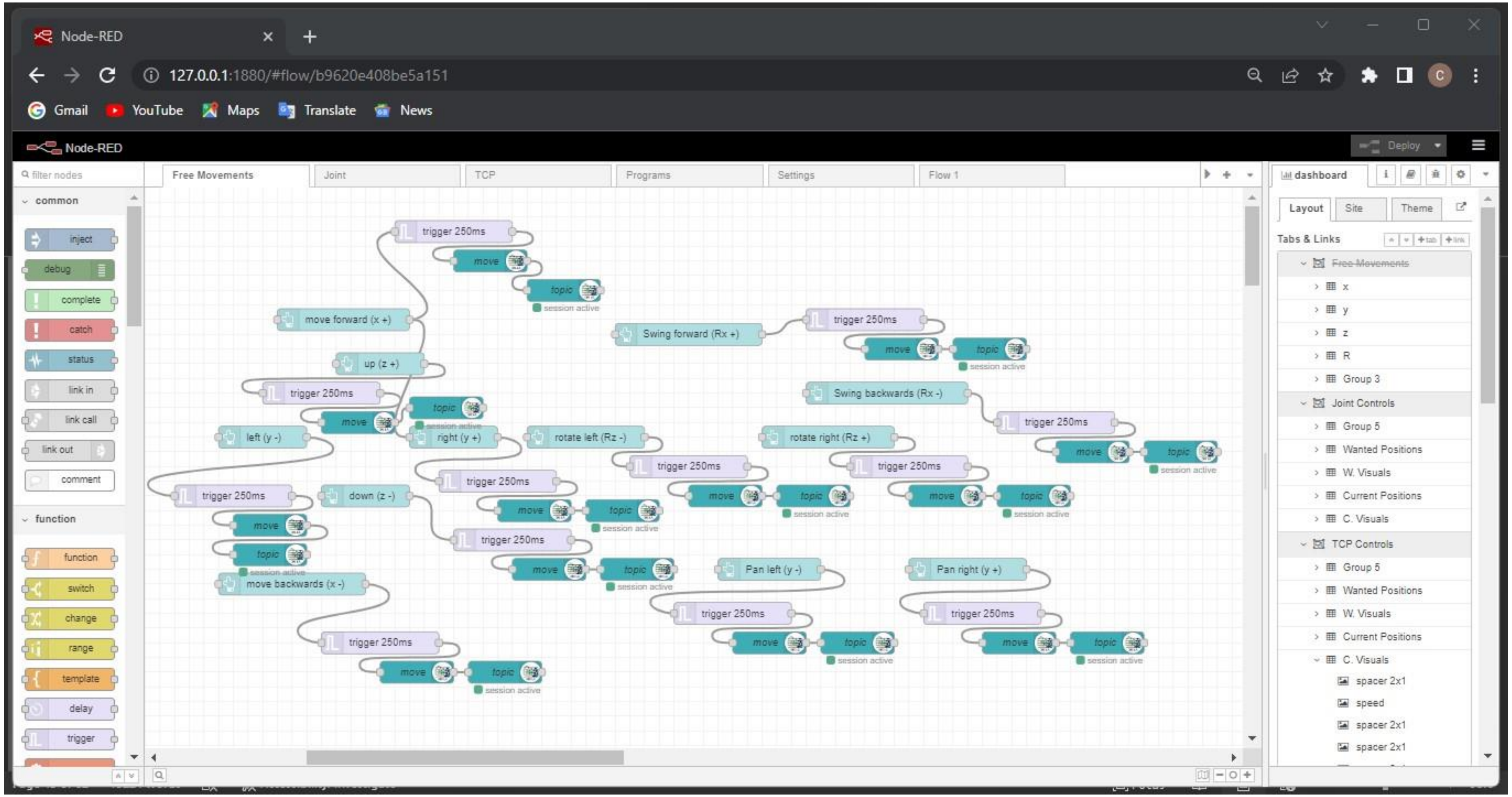
C.11. Screenshot of NodeRed backend showing the links for the current TCP values button activation



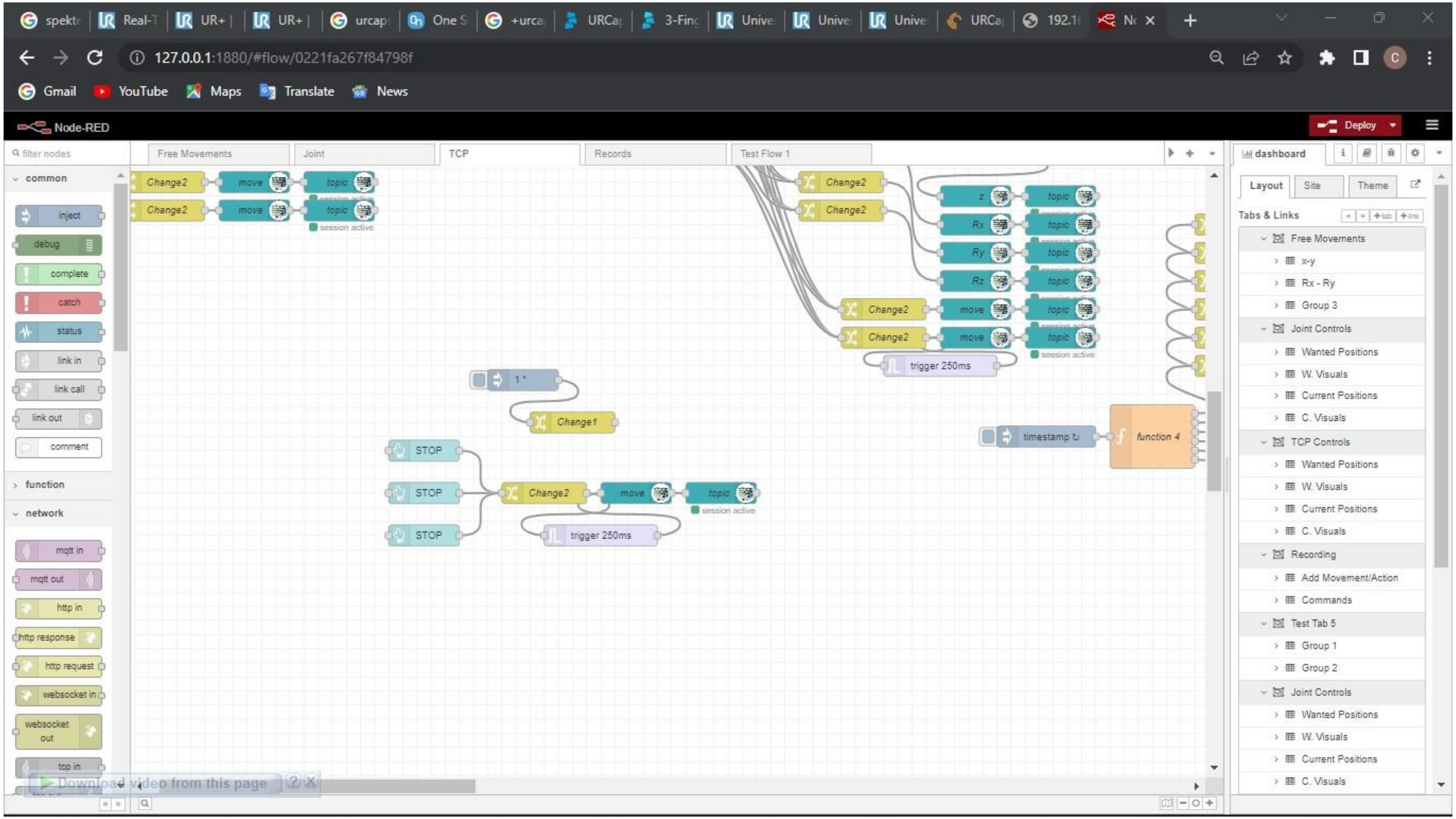
C.12. Screenshot of NodeRed backend showing the links for the 'Home Position' activation



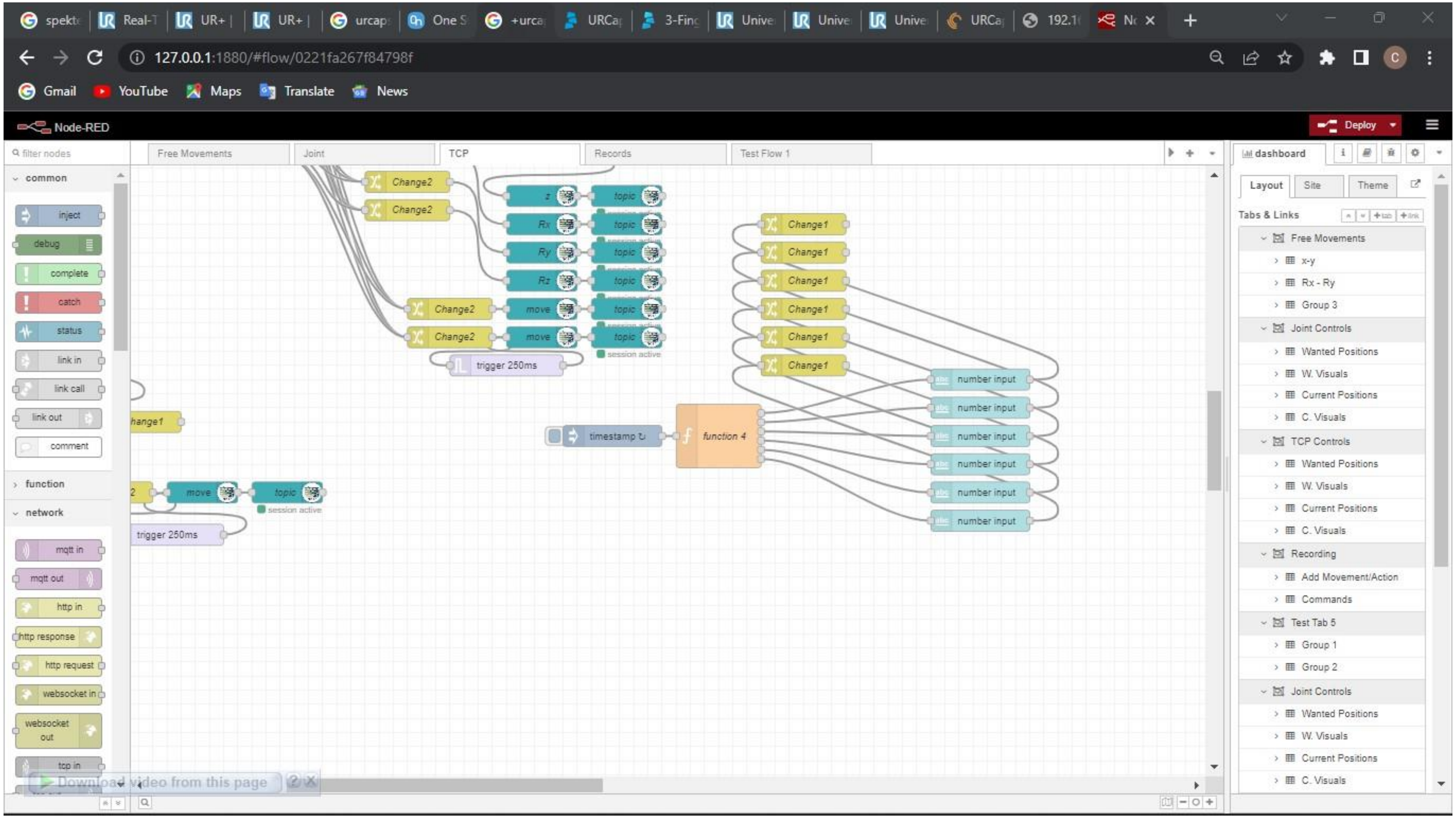
C.13. Screenshot of NodeRed backend showing the links for the TCP pose increment activation



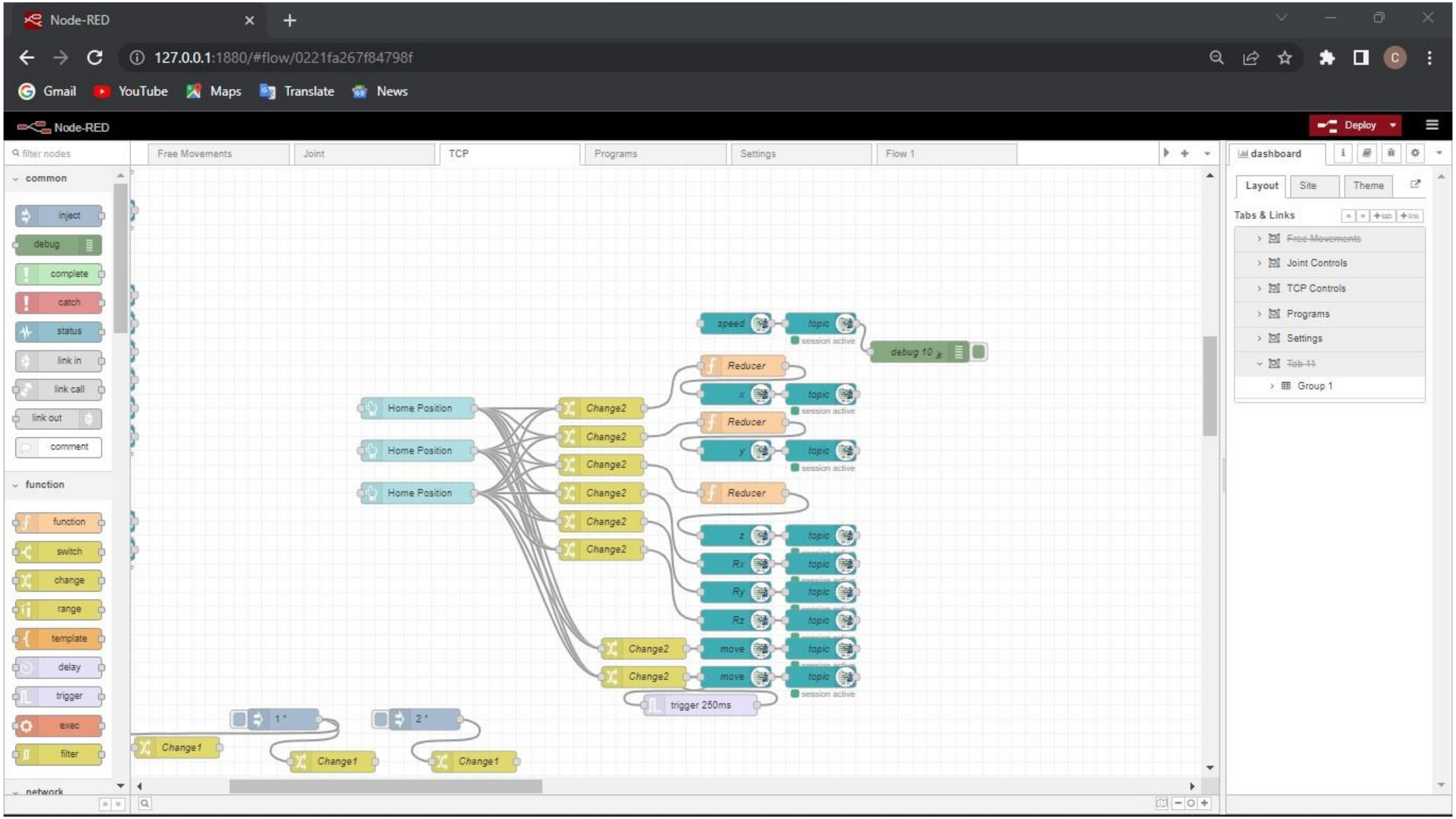
C.14. Screenshot of NodeRed backend showing the links for the 'Stop' activation



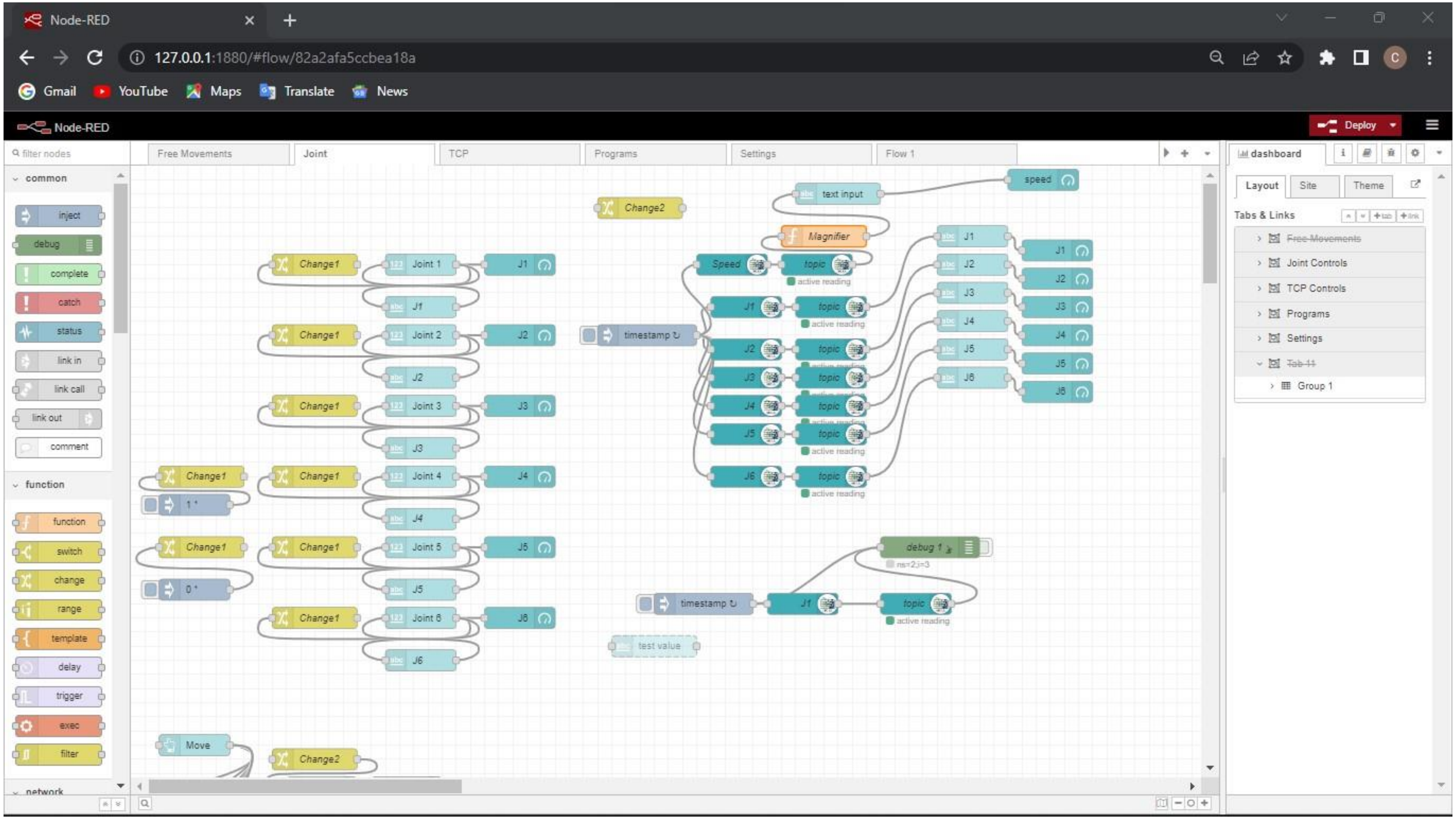
C.15. Screenshot of NodeRed backend showing the links for the ‘Home Position’ data communication



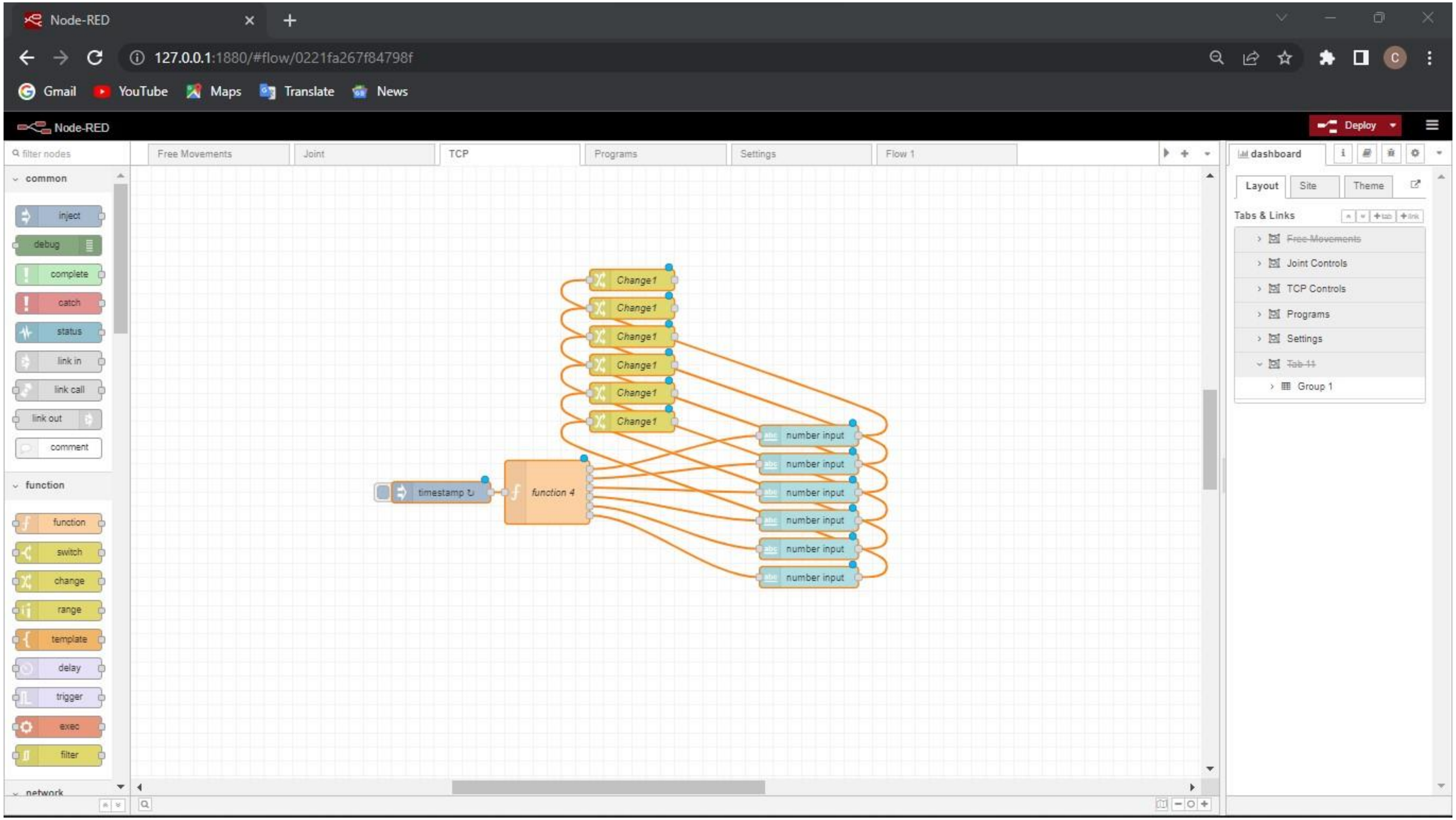
C.16. Screenshot showing the application of the reduction function in NodeRed backend



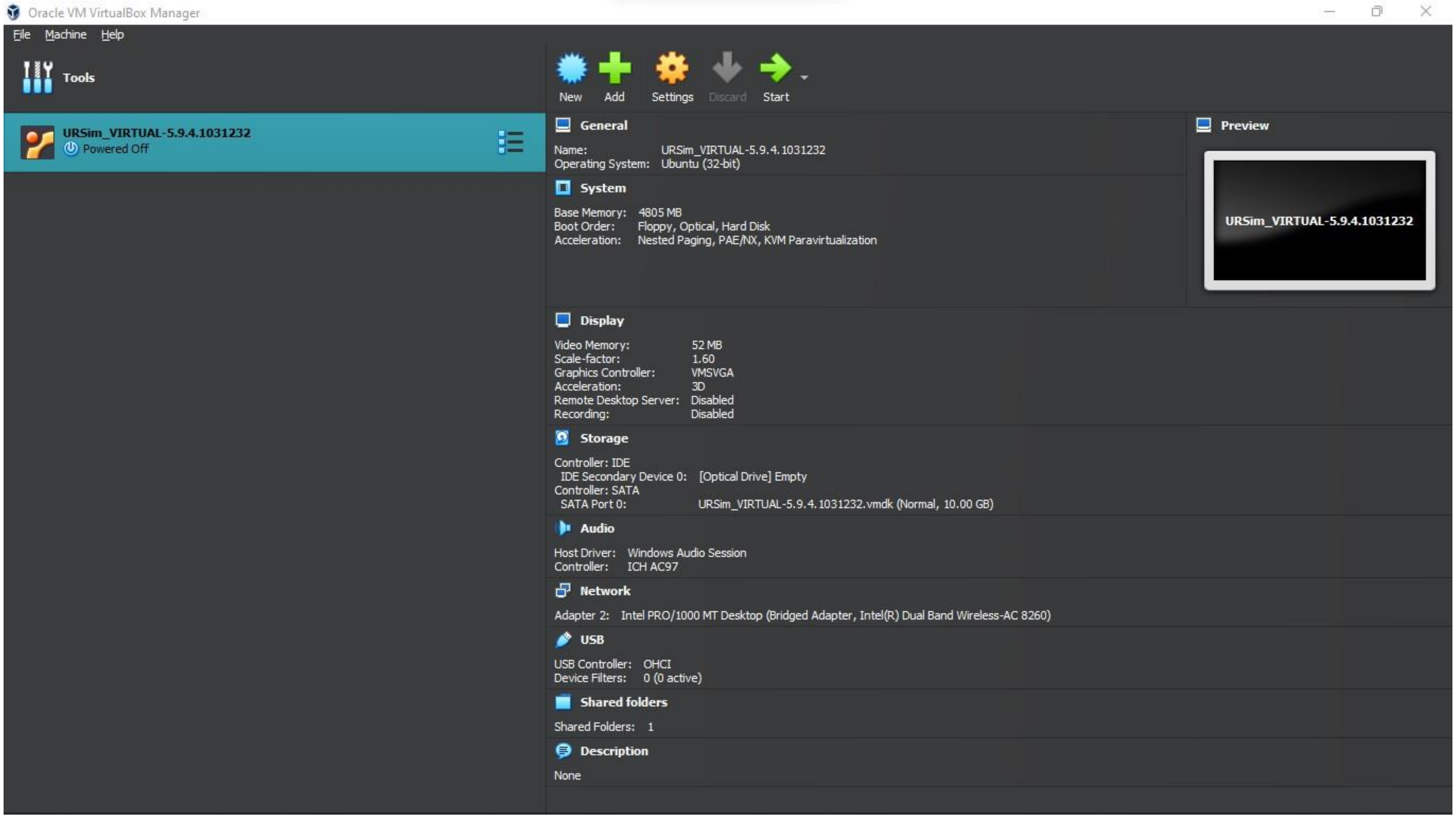
C.17. Screenshot showing the application of the magnification function in NodeRed backend



C.18. Screenshot showing the application of the multiple output function in NodeRed backend



C.19. Screenshot of VMBox showing the computing of the virtual machine containing Polyscope



D. RISK ANALYSIS

D.1. Risk Analysis Model Employed

Consequences			**Probability**		
Category Definition	Consequences	Rating	Category Definition	Probability	Rating
High (H)	Severe	3	High (H)	Probable	3
Medium (M)	Medium Severity	2	Medium (M)	Possible	2
Low (L)	Insignificant	1	Low (L)	Remote	1

Consequences	Rating(R)			
	H	3	6	9
	M	2	4	6
	L	1	2	3
		L	M	H
	Probability			

Result	
	High
	Medium
	Low

D.2. Identified Risks

ID	Risk factors	Impact description	Consequence	Probability	Probability description	Risk
R1	Project change	Decision to change the project would negatively affect motivation, final output quality and expected work period	High	Low	A change of the project is less likely. However, a focus on the tool considered to be develop could change.	Medium
R2	Lack of knowledge	Little or no sufficient knowledge of softwares, tools and regulations to be used	High	Medium	Depending on the selected tool, new knowledge may be required to succeed	High
R3	Lack of time	Constrained time limit without extensions	High	Medium	More time may be required for new knowledge acquisition before the tool development	High
R4	Activities will not be completed	Incomplete activities prevent a successful achievement of the goal	High	Medium	Deadlines may not be met for some tasks	High
	Illness	Health related downtime would negatively impact progress of project	High	High	The period of the project has likelihood of flu. Also, other ailments may arise from lifestyle habits.	High

R5	Lack of motivation	Unwillingness to perform tasks towards achieving the goal	High	High	The period of the project has likelihood of depression. Also, other factors may arise from work life inbalance.	High
R6	Loss of data during development	Computer virus, network breach, data deletion that would hinder access to gathered data	High	Medium	Vulnerability is imminent with internet-connected devices. An unplanned activity could also lead to loss of data	High
R7	Hardware malfunction	Short circuit, production error, etc., that could make the hardware not work as it should	High	Medium	Regardless of quality certified tests carry out on hardware before delivery to the laboratory, unforeseen occurrences are expected too.	High
R8	Damage to the physical UR10e in the laboratory	Short circuit, run-in accidents, etc that could damage the cobot	High	Medium	Working periods may be without a supervisor available.	High
R9	Software challenges	Inability to access, expiry of licence, etc that makes the project come to a halt	Medium	Medium	Validity of licence could elapse if not monitored. Also, bugs and attacks are expected.	Medium

R10	General laboratory hazards	Fire, chemical spill, hazardous fumes etc that could lead to a complete shutdown of the laboratory. Hinders project progress.	Medium	Medium	As an open laboratory, tight surveillance is almost impossible.	Medium
R11	Late delivery	Inability to complete the project in due time	High	Medium	An intensive project might not be achieved in a tight time period	High
R12	Technical failure	Improper results, unresponsive commands etc., of the tool that occur after the completion of the project.	High	High	Inability to adequately test the tool could lead to a failure	High
R13	Complex Design	Inability of a basic user to manipulate the tool without concise assistance	High	Medium	Unavailability or limited resources could lead to a complex design as the final product	High
R14	Low Interest from SMEs	Unwanted functionalities and irrelevant applications that may cause SMEs to not want to consider the adoption of the tool	High	High	Inability of the tool developed to perform required tasks would deepen the disinterest of SMEs	High

R15	Poor maintenance	Unavailability of maintenance support/information, high maintenance cost and high skill required to maintain the tool could lead to disinterest of the tool after a series of breakdown	High	Medium	Inability to understand or complete the project leaves a gap on preparing information	High

D.3. Mitigative measures

ID	Risk	Measures	Consequence after measures	Probability after measures	Remaining risk
R1	Medium	Perform a careful consideration process to prevent a change. However, adequate buffer in the scheduling to cater for lags would help in the eventuality.	Low	Low	Low
R2	High	Prompt learning of the required skills. However, adequate buffer in the scheduling to cater for lags would help in the eventuality.	Medium	Medium	Medium
R3	High	Regular meetings and presentation to monitor the process of the project	Medium	Medium	Medium
R4	High	Adequate buffer in the scheduling of tasks to cater for lags would help in the eventuality	Medium	Medium	Medium
	High	Adhere to relevant health practices to stay healthy. However, adequate buffer in the scheduling to cater for lags would help in the eventuality.	Medium	Medium	Medium

R5	High	Engage in activities to boost motivation. Also setting minor tasks to derive satisfaction from each milestone acconplished.	Medium	Medium	Medium
R6	High	Protect data and prepare backups periodically	Medium	Medium	Medium
R7	High	Promptly contact support team	Medium	Low	Low
R8	High	Carefully follow instruction manual, request adequate supervision and perform tests with alternate options like a virtual enviroment	Medium	Low	Low
R9	Medium	Promptly contact support team	Low	Low	Low
R10	Medium	Adhere to Safety & Working regulations governing the laboratory	Low	Low	Low

R11	High	Schedule the Project with tools that enable visual monitoring	Medium	Low	Low
R12	High	Perform adequate tests to access the quality, durability and reliability of the tool	Medium	Medium	Medium
R13	High	Simplify the design as much as the design and development process ethically allows	Medium	Medium	Medium
R14	High	Link the functionalities of the tools to relevant applications of the SMEs	Medium	Medium	Medium
R15	High	Prepare adequate maintenance information at the barest cost available.	Medium	Medium	Medium

UiT THE ARCTIC UNIVERSITY OF NORWAY

Faculty of Engineering Science and Technology
Department of Industrial Engineering
Date: 08.11.2022

Industrial Engineering, Master Thesis 2022/2023, part I INE-3900

Stud. Techn. Caleb Nyamadi

Title: Technology transfer framework review for easy Cobot adoption by SMEs

1. Introduction

Collaborative industrial Robots (Cobots) were introduced as an advancement to traditional industrial Robots. Some advantages that were incorporated in Cobots included the easy of human interaction, safety and the size [1].

However, many Small & Medium Enterprises (SMEs) are still not convinced of the merits of adopting Cobots into their operations. This could be due to challenges SMEs face in the adoption of new generation robots [2].

This study seeks to understand the marketable features of the Cobot systems, and link these features to the operations of some SMEs in northern Norway.

A literature review would be conducted to understand the evolution of industrial robots and the current applications of Cobots in various industries.

2. Scope

1. Conduct a literature review on the evolution of industrial Robots and the current applications of Cobots in various industries towards Industry 5.0.
2. Perform a study on how SMEs have employed Cobots in their operations
3. Prepare a Report on the findings.
4. Defiine clear scopes for Part II
5. Prepare a PowerPoint presentation and give an oral presentation of the performed work.

3. Some relevant links/references (if actual)

[1] IFR, *Demystifying Collaborative Industrial Robots, Positioning Paper*, 2020.
[2] M. Schnell and M. Holm, "Challenges for Manufacturing SMEs in the Introduction of Collaborative Robots", in *SPSS2022: Proceedings of the 10th Swedish Production Symposium,* pp. 173-181, 2022.

4. General

Master thesis at Industrial Engineering is divided into two parts where the total allocated time is limited to 27 weeks fulltime work, corresponding to 45 study points.

Part I

In general, this part is an introduction to the project and is often a literature review especially adapted to meet the challenges within the project as well as to strengthen the competence of the candidates in a given field or direction. Part I study counts for 1/3 of the total time allocated to the project. This part has to be finished with a PowerPoint presentation and a written report after approximately 9 weeks fulltime work. Any written documentation of the thesis part I has to be enclosed or integrated in the final thesis reporting.

Part II

This is the main part of the master thesis within the Industrial Engineering education, and is a R&D project. The part II study counts for 2/3 of the total time allocated to the project. The final report with all accompanying documentation has to be handed in after approximately 18 weeks full-time work.

Within three weeks (full-time work) after the start of Part I, a pre-study report shall be prepared. The report has to include the following (a pre-study report template exists):

- An analysis of the work task's content specifically emphasizing the areas where new knowledge has to be gained.
- A description of the work packages that have to be performed. This description shall lead to a clear definition of the scope and extent of the total task to be performed.

- A time schedule for the project. The plan shall comprise a Gantt chart with specification of each individual activity/work package, their scheduled start and end dates, and a specification of project milestones.

The pre-study report is a part of the total thesis reporting and has to be enclosed with the final report. This includes also all progress reports made during the working period as well as the original task description. (A progress report template also exists.)
The final report should be edited as a research report with a summary, table of contents, conclusion, list of references, list of literature etc. The text should be clear and concise, and include the necessary references to figures, tables, and diagrams. It is also very important that exact references are given to any external sources used in the text.
All documentation developed during the work, e.g. computing programs, measuring results, drawings and models are parts of the final report and have to be enclosed.
The final report will be evaluated and basis for the grade of the master thesis.

If the work is performed in cooperation with an external organization, the candidate has to comply with the actual organization's company regulations and possible other relevant orders from the company's management. The candidate has no opportunity to interfere with the organization's information systems, manufacturing equipment or the like. If this should be relevant in connection with the execution of the tasks, it has to be authorized by the organization's management.

Any travel, copying, phone or other expenditures have to be covered by the students themselves, unless other agreements have been established.

If the candidate encounters unforeseen difficulties during the work, and if these difficulties warrant a reformulation of the tasks, these problems should be addressed immediately to the supervisor at the faculty.

5. Deadlines and participants

Date of hand out part I:	8th November 2022
Date of progress report:	6th December 2022 at 12:15. Progress report to be submitted to the Principal supervisor before the deadline.
Date of hand in part I	11th January 2023.
Presentation in part I:	PowerPoint presentation and give an oral presentation of the work on 13th January 2023.
Date of hand-out part II:	After presentation and approval of part I.
Date of hand in part II (final report):	15th May 2023.
Student(s):	Stud. techn. Caleb Nyamadi, address: Selsbanesgate 41, 8514, Narvik, mobile phone: +47 40974544, E-mail: cny015@uit.no
Supervisor:	Professor Bjørn Solvang, Faculty of Engineering Science and Technology, office phone: +4776966227, mobile phone: 41200475, E-mail: bjorn.solvang@uit.no
Co.-supervisor:	Syed Abdur Rahman Tahir, Researcher Faculty of Engineering Science and Technology, mobile phone: +4776966268, E-mail: syed.a.tahir@uit.no
Company liaison:	

Obligations and acceptance:

By signing this task document I am/we are fully aware of the consequences of not following the respective delivery dates defined above. I also accept the obligations this task description implies.

I /we have received this task description:

Date: ……07 Nov. 2022…………………

Students' signatures:

………………………………  ……………………………

Faculty of Engineering Science and Technology

Bjørn Solvang

Professor

(sign.)

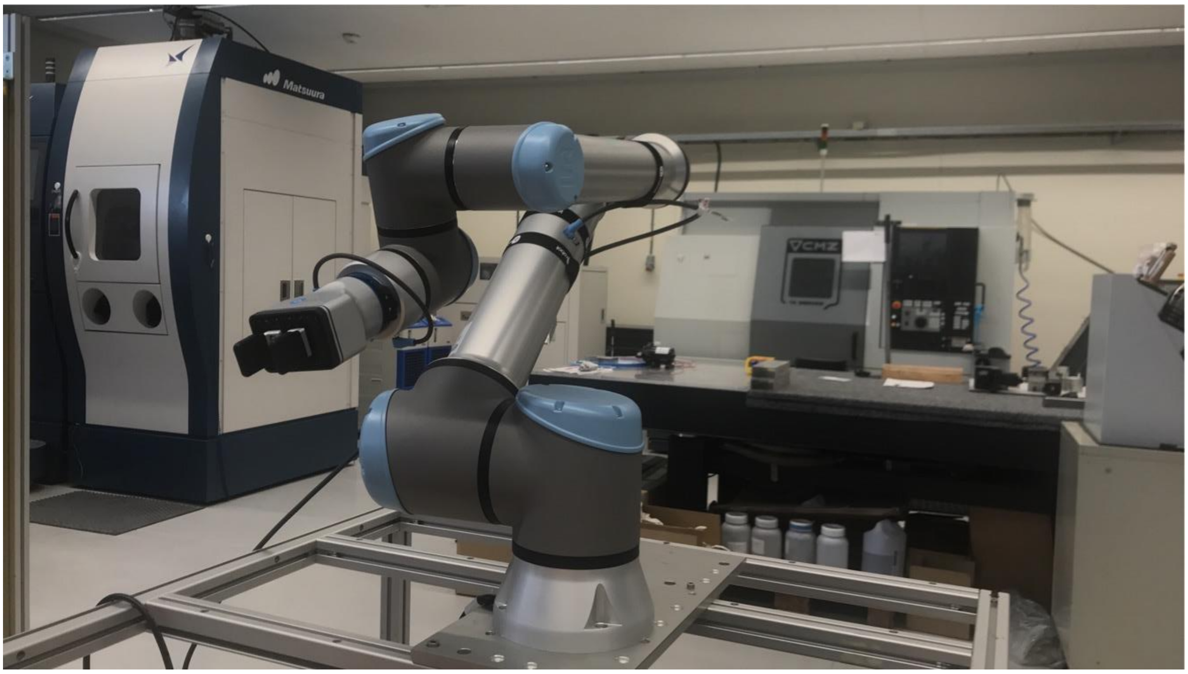
Faculty of Engineering Science and Technology
Department of Industrial Engineering

Master of Science – Industrial Engineering

Master Thesis – Pre Study Report

(INE-3900)

Technology transfer framework review for easy Cobot adoption by SMEs



Author(s):
Stud. Techn. Caleb Nyamadi

17th February, 2023

Title: Technology transfer framework review for easy Cobot adoption by SMEs	*Date:* 7th November, 2022 *Classification:*
Author(s): Caleb Nyamadi	*Number of Pages:* 15 *Number of Attachments:* 7
Subject Name: Master Thesis - Pre Study Report	*Subject Code:* INE-3900
Faculty: Engineering Science and Technology	
Master Program: Industrial Engineering	
Supervisor: Professor Bjørn Solvang	
Co-supervisor: Dr. Beibei Shu (Researcher)	
External Organization/Company:	
External Organization's/Company's Liaison:	
Keywords (max 10): Cobots, SME, human-machine interaction, Industry 5.0, technology transfer, collaboratve robots	
Abstract (max 150 words): Collaborative industrial Robots (Cobots) were introduced as an advancement to traditional industrial Robots. Some advantages that were incorporated in Cobots included the ease of human interaction, safety and size. However, many Small & Medium Enterprises (SMEs) in Norway do not seem convinced of the merits of adopting these Cobots into their operations. This study seeks to understand the marketable features of the UR10e, and link these features to the operations of manufacturing SMEs in northern Norway. A literature review would be conducted to understand the evolution of industrial robots and the current applications of Cobots in various industries.	

Table of Contents

List of Tables

1. Introduction

Collaborative robots (Cobots) are very versatile to various applications of different industries. As an improved version of the traditional robots, Cobots were designed to be safe for humans to work around [1]. It was designed for easy collaboration between human and machines.

2. Background

Over the years, industrial robots have been developed and improved to achieve the aim of aiding humans to do work. However, the safety risk associated with these traditional robots were great. People could be maimed or pinned to death when within the operating area of the robot.
With the introduction and advancement of industry 5.0, the collaborative robots (Cobots) were designed to eliminate the safety risk with added benefits for not too large production facilities. Manufacturers of Cobots are compelled as every other technology, to prepare a Technology Transfer documents and events to enable any business entity to easily purchase and use the tool to achieve some efficiency in their operation, create ease of work while saving cost.

3. Problem statement

Contrary to theory, there is some reluctance to the adoption of the Cobots by SMEs. This can be attributed to little or no knowledge by the SMEs about the technology transfer from the manufacturers offers to the SMEs [2].

4. Project description/benefits

This project seeks

i. to review and improve the existing technology transfer frameworks for Cobots
ii. undertake a survey to understand the possibilities to attract the SMEs towards the new generation robots
iii. set up a Cobot (UR10e) and showcase its application as an Industry 5.0 tool
iv. provide a tool to ease the transfer of knowledge to SMEs

5. Theory/hypothesis

The marketable features of the Cobots have to be linked with the operation of the SMEs to increase patronage.

6. Assumptions

The following assumptions are considered as reasons for the low patronage by the SMEs to adopt Cobots:

1. High cost, time and knowledge implications of the adoption to the company
2. Low efficiency by the industrial robots/Cobots/advanced manufacturing systems to the company's operation
3. Inability to prepare and setup for multiple tasks
4. Most operators who were trained on traditional robots prefer the traditional robots to the new generation robots

7. Risks/constrains

A comprehensive risk analysis would be performed to understand risks such as the reluctance from companies to divulge information and the mitigations that can be employed.

8. Objectives

This study aims to:

i. Review existing technology transfer frameworks for industrial robots/Cobots/advanced manufacturing systems
ii. Suggest improvements on how to increase the availability of knowledge on technology transfer
iii. Understand the setup of the UR10e and its applications
iv. Connect some marketable features of the UR10e to the operations of the SMEs

9. Scope

The scope employed shall involve

i. Conduct a literature review on the evolution of industrial Robots and the current applications of Cobots in various industries towards Industry 5.0.
ii. Review how many SMEs employed the use of Cobots in their operations
iii. Perform a study on the current use of Cobots by SMEs and their challenges
iv. Install the UR10e Cobot and peruse its applications
v. Develop a user-friendly Graphical User Interface (GUI) to ease the knowledge transfer to SMEs

vi. Establish remote connections of the robot to monitor, operate and collaborate
vii. Demonstrate the applications and tools of the UR10e Cobot to industry players within the SME sector
viii. Collate feedback on the ease of use, further improvement opportunities and challenges
ix. Prepare a Report on the findings.
x. Prepare a PowerPoint presentation and present an oral presentation of the prepared work.

10. Organization

10.1 Main activities

Table 10.1 Main activities

Main Activities	Sub Activities		Description	
	ID		ID	
Planning	A	Project Management	A01	Scope Management
			A02	Risk Management
	B	Pre-study Report	B01	Project Description and definition
			B02	Project planning
	C	Literature review	C01	Cobot and applications
			C02	Technology transfer framework
Research and Development	D	Research Study	D01	Existing acceptance rate
	E	Development	E01	Setup and test of UR10e applications
			E02	Outreach and Surveys
Completion	F	Documentation (Final Report)	F01	Report writing
			F02	Presentation of suggested solution

10.2 Milestones

Table 10.2 Milestones

Phase	Milestone	ID	Event

Part I	8th November 2022	MS01	Submission of Pre Study Report and Task Description (part I)
	6th December 2022 at 12:15	MS02	Progress report Submission
	11th January 2023.	MS03	Submission of Literature review (part I)
	13th January 2023.	MS04	Presentation of part I: PowerPoint presentation and an oral presentation of the work done
Part II	10th May 2023	MS05	Submission of part II for review, Presentation of part II: PowerPoint presentation and an oral presentation of the work done
	15th May 2023	MS06	Final Submission of part II (final report)

10.3 Progress monitoring

This progress of this project would be monitored in accordance to the attached Gantt Chart and other project management techniques .

11. Costs

There would be no direct costs associated with this project, however, materials and equipment employed are available by the Industrial Engineering department.

12. References

[1] IFR, *Demystifying Collaborative Industrial Robots, Positioning Paper*, 2020.

[2] M. Schnell and M. Holm, "Challenges for Manufacturing SMEs in the Introduction of Collaborative Robots", in *SPSS2022: Proceedings of the 10th Swedish Production Symposium*, pp. 173-181, 2022.

13. Acknowledgements

I wish to acknowledge my supervisor Professor Bjørn Solvang for the dedication of his time and resources towards the achievement of my Masters thesis. I also acknowledge my co-supervisor, Beibei Shu for his guidance, and other colleagues in the Industrial department for sharing resources towards the study.

14. Attachments

1. Activity description 1
2. Activity description 2
3. Activity description 3
4. Activity description 4
5. Activity description 5
6. Activity description 6
7. Gantt-chart

Activity description: 1

Project title: Technology transfer framework review for easy Cobot adoption by SMEs	*Date:* 07.11.2022	*Sign:* CN

Activity no: 1	*Activity name:* Project Management

Responsible:

Caleb Nyamadi

Task description/intention:

The project is planned, monitored and managed as it progresses

Scope:

Completed tasks would be evaluated and new or ongoing tasks would be planned

Method:

Project Management tools will be employed to manage the progress

Dependency:

Effective throughout the period of the project

Documentation/results:

Project Management tools like Gantt Chart and Risk Analysis

Written by: Caleb Nyamadi	*Duration (days/weeks):* 27 weeks

Activity description: 2

<table>
<tr><td colspan="2">Project title:
Technology transfer framework review for easy Cobot adoption by SMEs</td><td>Date:
07.11.2022</td><td>Sign:
CN</td></tr>
<tr><td>Activity no:
2</td><td colspan="3">Activity name:

Pre Study Report 1</td></tr>
<tr><td colspan="4">Responsible:

Caleb Nyamadi</td></tr>
<tr><td colspan="4">Task description/intention:

Some studies are carried out to understand the scope of work to be performed in the project</td></tr>
<tr><td colspan="4">Scope:

Completed tasks would be evaluated and new or ongoing tasks would be planned</td></tr>
<tr><td colspan="4">Method:

Project Management tools and Document Processing tool like Microsoft Word</td></tr>
<tr><td colspan="4">Dependency:

None</td></tr>
<tr><td colspan="4">Documentation/results:

Written report</td></tr>
<tr><td colspan="2">Written by:

Caleb Nyamadi</td><td colspan="2">Duration (days/weeks):

3 weeks</td></tr>
</table>

Activity description: 3

Project title: Technology transfer framework review for easy Cobot adoption by SMEs		*Date:* 07.11.2022	*Sign:* CN
Activity no: 3	*Activity name:* Literature review		
Responsible: Caleb Nyamadi			
Task description/intention: Published materials on industrial robots, Cobots and the technology transfer framework of Cobots would be studied. Relevant content would be collated to build a basic understanding of the current situation.			
Scope: Description of the development in robotics towards Industry 5.0			
Method: Use of research tools and word processor (Microsoft Word)			
Dependency: Pre-study 1			
Documentation/results: A written report			
Written by: Caleb Nyamadi	*Duration (days/weeks):* 9 weeks		

Activity description: 4

Project title: Technology transfer framework review for easy Cobot adoption by SMEs	*Date:* 07.11.2022	*Sign:* CN

Activity no: 4	*Activity name:* Research Study
Responsible: Caleb Nyamadi	
Task description/intention: The project is planned, monitored and managed as it progresses	
Scope: Study the marketable features of a Cobot (UR10e) and how to connect these features to the client's needs	
Method: Use of Research tools, learn from the setup and use of the UR10e in the lab	
Dependency: Literature Review	
Documentation/results: A written report	
Written by: Caleb Nyamadi	*Duration (days/weeks):* 3 weeks

Activity description: 5

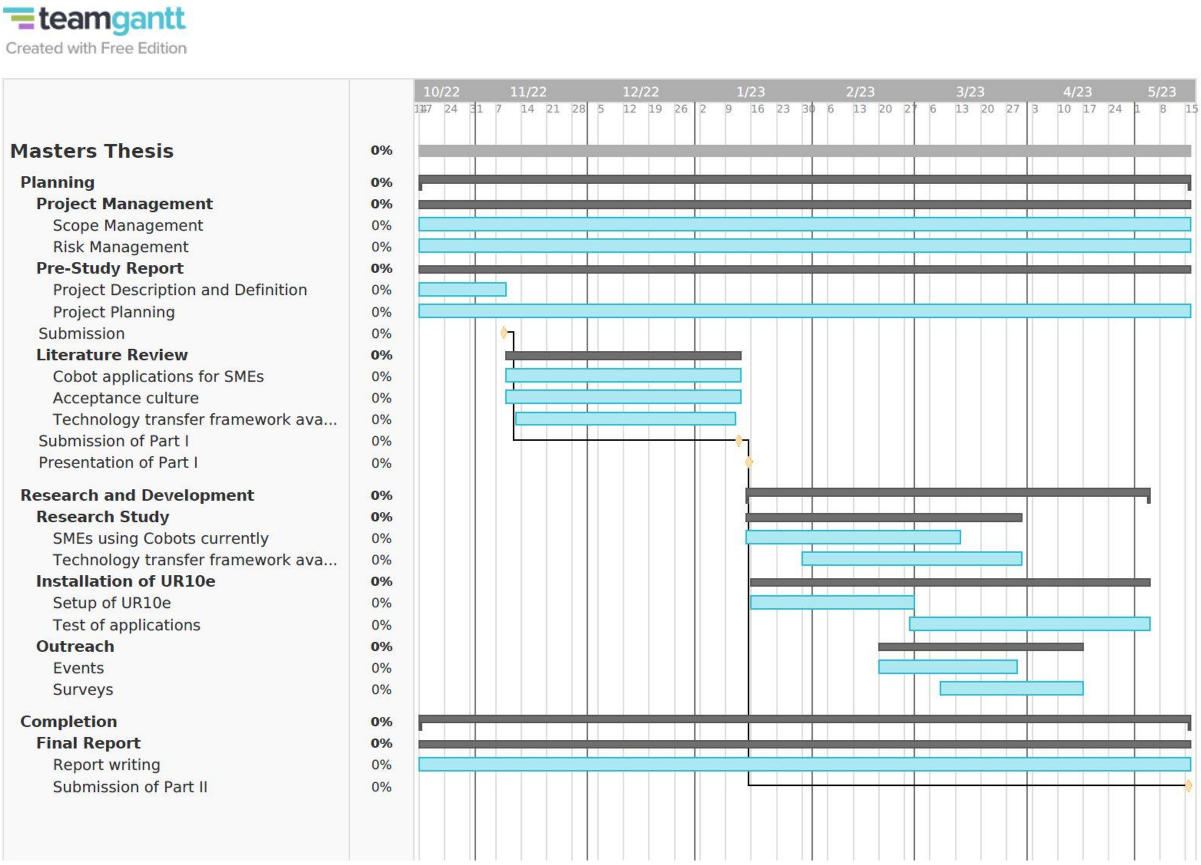
Project title: Technology transfer framework review for easy Cobot adoption by SMEs	*Date:* 07.11.2022	*Sign:* CN
Activity no: 5	*Activity name:* Development	
Responsible: Caleb Nyamadi		
Task description/intention: The project is planned, monitored and managed as it progresses		
Scope: Completed tasks would be evaluated and new or ongoing tasks would be planned		
Method: Project Management tools will be employed to manage the progress		
Dependency: Research study		
Documentation/results: A written study		
Written by: Caleb Nyamadi	*Duration (days/weeks):* 10 weeks	

Activity description: 6

Project title: Technology transfer framework review for easy Cobot adoption by SMEs	*Date:* 07.11.2022	*Sign:* CN

Activity no: 6	*Activity name:* Documentation (Final report)
Responsible: Caleb Nyamadi	
Task description/intention: Documentation of all relevant literature, tools and	
Scope: Written report that encapsules all the work done	
Method: Word processor	
Dependency: None	
Documentation/results: A final report	
Written by: Caleb Nyamadi	*Duration (days/weeks):* 27 weeks

Gantt Chart


teamgantt
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10/22
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4/23
5/23
Masters Thesis 0%
Planning 0%
Project Management 0%
Scope Management 0%
Risk Management 0%
Pre-Study Report 0%
Project Description and Definition 0%
Project Planning 0%
Submission 0%
Literature Review 0%
Cobot applications for SMEs 0%
Acceptance culture 0%
Technology transfer framework ava... 0%
Submission of Part I 0%
Presentation of Part I 0%
Research and Development 0%
Research Study 0%
SMEs using Cobots currently 0%
Technology transfer framework ava... 0%
Installation of UR10e 0%
Setup of UR10e 0%
Test of applications 0%
Outreach 0%
Events 0%
Surveys 0%
Completion 0%
Final Report 0%
Report writing 0%
Submission of Part II 0%

Part I Progress Report

The progress reports are of importance to control if the student performs the tasks according to the plan or not (see progress report template below).

Progress Report Template:

Progress report no: 01	*Performed by:* Caleb Nyamadi	*Date:* 05.12.2022

Project title:
Technology transfer framework review for easy Cobot adoption by SMEs.

Main focus of work performed in this period:
Prepare a scope of literature review to understand the evolution of industrial Robots, the need to introduce Cobots and the current applications of Cobots in various industries. Also, to understand some challenges SMEs currently face in adopting Cobots towards achieving Industry 5.0.

Planned activities this period:

- Identifying the areas to research, identifying limitations to the research and building a framework to research by.
- Search of relevant literature using crucial keywords and vetting of literature collated.
- Reading relevant literature materials and noting related thoughts.

Real performed activities this period: So far I have completed the following tasks:

- Identified that literature review should be carried out on the evolution of industrial Robots and the current applications of Cobots in various industries towards Industry 5.0.
- Various literature material was searched for using various iterations of the following keywords (Cobots, industrial robots, SMEs, Technology Transfer), and vetted for relevance.
- Understand the evolution of industrial Robots and the current applications of Cobots in various industries towards Industry 5.0.
- Understand some challenges faced by SMEs to adopt new technologies (Cobots)

Reasons for possible delays:
Illness

Describe how to catch up with possible delays:
Performing extra work within December and early January.

Requested changes compared with the original schedule:
None.

Main experiences this period:
With the rapid change of technology and the need to advance, some literature materials easily become irrelevant to the area of study.

Main focus next period: Preparing of literature review document
Planned activities next period: • Assist in the setup of the UR10e and understand the marketable features ease of adoption. • Writing review of relevant literature materials studied (findings, parallels, etc). • Submission of final review.
Other: None.

Part II Progress Report

The progress reports are of importance to control if the student performs the tasks according to the plan or not (see progress report template below).

Recommendation: Use Times New Roman 12 for the normal text, and use Times New Roman Fat 14 for the main headings. Use spellchecker.

Progress Report Template:

Progress report no: *01*	*Performed by:* *Caleb Nyamadi*	*Date:* *29.03.2023*
Project title: *Technology transfer framework review for easy Cobot adoption by SMEs*		
Main focus of work performed in this period: *Setup of UR10e robot and*		
Planned activities this period: *UR 10e Cobot installation, Study of UR 10e Cobot applications, OPCUA Server and Client setup, Stakeholder Engagement*		
Real performed activities this period: So far I have completed the following tasks: *UR 10e Cobot installation, Study of UR 10e Cobot applications, OPCUA Server and Client setup, Stakeholder Engagement*		
Reasons for possible delays: *Software malfunction, Illness, Cobot malfunction*		
Describe how to catch up with possible delays: *Liase with supervisors to request adequate support from product suppliers and perform some extra work to catch up for time lost.*		
Requested changes compared with the original schedule:		
Main experiences this period: *Major experiences were related to the enormous possibilities of the cobot manipulation with python scripts through two-way communication modes like the OPCUA.*		
Main focus next period: *To design a user-friendly Graphical User Interface (GUI) as a tool for SMEs to easily manipulate their cobots*		
Planned activities next period:		

Planning of UR 10e Cobot applications, GUI design, GUI connectivity, Testing & Analysis, Documentation
Other: