KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

German Nushtaev

ANALYSIS AND IMPROVEMENT OF ROBOTIZED GLASS PANEL INSTALLATION PROCESS

Master's Degree Final Project

Supervisor

Assoc. prof. dr.Rasa Mankutė

KAUNAS, 2017

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Industrial Engineering and Management (code 621H77003)

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(Title and code of study programme)

"Analysis and Improvement of Robotized Glass Panel Installation Process"

DECLARATION OF ACADEMIC INTEGRITY

____ ________________ 20 _____

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I confirm that the final project of mine, **German Nushtaev**, on the subject "Analysis and Improvement of Robotized Glass Panel Installation Process" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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Approved:
Head of
Production engineering
Department

____
(Signature, date)

Kazimieras Juzėnas
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Analysis and Improvement of Robotized Glass Panel Installation Process

Approved by the Dean Order No.V25-11-8, 21 April 2017

2. Aim of the project

Analyze the existing glass panel installation process of co-bot and improve it by using the CAD modeling, implementing simple safety standards

3. Structure of the project

Introduction, 1. Robotics industry analysis. History of the construction robots, their functions and input into modern engineering, 2. Analysis of the Company X and its glazing robot project “Wallmo”, 3. The analysis and improvement of installation process of glass panel mounting robot, 4. Analysis of the possible results of the structural improvement for Company X, Conclusions, References, Image references

4. Requirements and conditions

Research project should not violate Company X and its customers information and data confidentiality. The theoretical research should be performed using academic research data from other facilities than KTU. The conclusions and final review should be based on practical results, obtained during the duration of practical research.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 20__ ________ __st.

Student ___________________________ ___________________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor ___________________________ ___________________________
(*Position, Name, Surname*) (*Signature, date*)

German Nushtaev. Robotizuoto stiklo paketų montavimo proceso analizė ir tobulinimas. Pramonės inžinerijos ir vadybos magistro baigiamasis projektas / vadovas Doc. dr. Rasa Mankutė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Mokslo kryptis ir sritis: Technologiju mokslas, inžinerija, gamybos sritis

Reikšminiai žodžiai: *Robotai, stiklo paketų instaliavimas, trajektorija, matricos struktūra*

Kaunas, 2017. 45 p.

SANTRAUKA

Šiais laikais kiekvieną technologijos rūšį galima apibūdinti kaip sudėtinį komponentų rinkinį, kuris jungiasi su skirtingomis valdymo priemonėmis. Dėl šių priemonių kiekviena pramonės sritis pasižymi funkcionalumu ir dideliu darbo našumu. Svarbu pabrėžti, kad tobulas mechanizmo veikimas, saugumas, kokybė ir galimybė atlikti tiesiogines funkcijas be pastovios priežiūros poreikio priklauso nuo atidžios mechanizmo analizės ir jo nagrinėjimo. Tai taikoma beveik visiems mechanizmams, tačiau pati svarbiausia sritis yra robotika –

pramonės sektorius, reikalaujantis daug patikrinimų ir tyrimų.

Šio baigiamojo magistro darbo tikslas – atlikti kruopščią Kompanijos X „kobotų“ projekto analizę ir užtikrinti jų tolimesnį patobulintą funkcionalumą ir žymiai saugesnį veikimo procesą. Atliekant tyrimą buvo suformuluotos ir išaiškintos šios užduotys:

- Išnagrinėti „WallMo“ projektą, įgyti žinių apie jo fukcijas, struktūrą bei suformuluoti problemą, kurią reikia išspręsti;
- Atlikti projekto analizę remiantis dabartine įmonės valdymo sistema. Apibūdinti galimus pavojus ir klaidas, kurios gali atsirasti įgyvendinant projektą;
- Pateikti praktinį sprendimą naudojant CAD programinę įrangą, sutelkiant dėmesį į veikimo trukmę, saugumo patobulinimą bei rezultatų analizę;
- Pateikti pasiūlymą dėl Kompanijos X dabartinės vidinės politikos ir išnagrinėti galimus rezultatus.

Toliau kalbama apie šio darbo tyrimą ir rezultatus, padėjusius išaiškinti užduotis. Praktinės dalies tyrimą papildo teorija, kurioje pateikiama svarbiausia informacija apie robotikos pramonę ir pagrindinius robotizuotos stiklo paketų montavimo įrangos veikimo etapus. Praktinė darbo dalis buvo parengta naudojant CAD programinę įrangą ir gauti rezultatai buvo išanalizuoti remiantis saugumo standartais ir veikimo trukmės tobulinimu. Po „kobotų“ praktinio tyrimo, Kompanijai X buvo pateiktas pasiūlymas tam, kad būtų užtikrinta patobulinta veikimo struktūra ir jos efektyvus panaudojimas.

German Nushtaev ANALYSIS AND IMPROVEMENT OF ROBOTIZED GLASS PANEL INSTALLATION PROCESS: Master's thesis in Industrial engineering and management / supervisor Assoc. prof. dr. Rasa Mankutė. The Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Research area and field: Technological sciences, engineering, production field

Key words: Robots, glass panel installation, trajectory, matrix structure

Kaunas, 2017. 45p.

SUMMARY

Every type of technology in these days can be described as the complex set of components combined with different control mechanics that provides the functionality and high working performance in every area of industry. But to work flawlessly or close to perfection the great amount of work and analysis should be done to the mechanism to ensure its safety, quality and ability to perform its direct functions without the need of constant supervision. This applies to almost every machine, but the most important area where the great amount of checks and analysis needed is robotics sector of industry.

The aim of the following Master‘s thesis is to perform a thorough analysis of the co-bot project of Company X and to ensure its further improved functionality and more safer working performance. During the research the following tasks were formulated and solved:

- Analyse the project "WallMo", gain understanding of its functions and structure and formulate the existing problem that needs to be solved;
- Perform the analysis of the project from the corporate management side of it. Describe the possible risks and errors that can rise during the performance of the project;
- Submit the practical solution using CAD software, apply it to the project, focusing on the performance time and safety improvement, and analyse the results;
- Give suggestion to the current situation of Company X internal policy and analyse possible outcome.

The results of the work and research done to solve the mentioned tasks are presented below. To support the practical research the theory analysis was carried that provided sufficient knowledge about robotics industry and the main milestones of robotized glazing equipment performance. The practical research using the CAD software was done and received results analysed according to the safety standards and working time improvement. After the co-bot practical research the suggestion to the previously mentioned Company X was made to ensure the suggested for implementation working structure would be efficiently used.

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And also I would like to thank all the professors of the Kaunas Unviversity of Technology who shared their experience and wisdom with me, who was a part of my life for more than 6 wonderful years and who was the architects of everything that I am today.

(name and surname filled in by hand)	*(signature)*

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INTRODUCTION

Each technology these days is the complex set of components combined with different control mechanics and components that provide the functionality and high working performance of every machine. But to work perfectly or close to perfection the great amount of work and analysis should be done to the mechanism to ensure its safety, quality and ability to perform its direct functions without the need of constant supervision. This applies to almost every machine, but the most important area where the great amount of checks and analysis needed is robotics sector of industry. Indeed the safety and working performance is essential for all robots, and in this Master's thesis these parameters will be analyzed thoroughly in respect to the project of the industrial glazing robot "WallMo", that is manufactured by the Company X. The project itself is a complex objective and as follows, contains a possibility of improvement, which will be analyzed more in the practical part of this thesis. The main objectives of the following thesis are as follows:

1) Analyze the project "WallMo", understand of its functions and structure, review its working principle and installation cycle and formulate the existing problem of the cycle that needs to be solved

2) Perform the analysis of the project from the corporate management side of it. Describe the possible risks and errors that can rise during the performance of the projects

3) Submit the practical solution, found using CAD software, apply it to the project, focusing on the performance time as well as safety improvement for the first part of the movement cycle and on universality for the installation part, and analyze the results

4) Give suggestion to the current situation of Company X internal policy and analyze possible outcomes

The following Master's thesis includes the solutions of the mentioned objectives and serves as the improvement suggestion for the Company X. The thesis contains three most important segments which are the practical research, the management analysis and received results analysis with following conclusions. To support the practical research and the management analysis theoretical analysis of the industrial segment and Company X' structure was made.

1. ROBOTICS INDUSTRY ANALYSIS. HISTORY OF THE CONSTRUCTION ROBOTS, THEIR FUNCTIONS AND INPUT INTO MODERN ENGINEERING

Nowadays the technology known as robots has spread widely in the modern technological world. They vary from entertaining toys, made of plastic and simple controllers, to the heavy-duty industrial machines that can carry on various tasks and jobs and include a thousand of moving parts and micro-controller interfaces. The growth of industry and the rapidly growing progress made the robots an inseparable part of modern technology spheres. The rapid increase and the popularity of the robots usage came to the second half of the 20th century when the growth of computer technologies and (micro)controllers began. The technology growth that was caused by the technological race of many countries in the search for technological superiority made the biggest minds in the world to search for an ultimate technology that could bring one of the country to the leading position in not only the military sphere but in industrial areas of progress.

The past centuries futurists were dreaming about the principle of machines making machines and in 20th century the fairytale has become a reality. At the very same moment, the billions of manufacture sites, consistent of only industrial multi-task robots are creating various products from cars and electronics, to the high-precision parts and compounds. But each technology has its niche and present robots also are created to serve their own purpose in the selected technological areas. The following project will cover a product that operates in the area, that until present days was mostly done manually, and only a rapid growth in the robotics, micro-controllers and automation technologies made the impossible a reality. In this paper we are analyzing the construction robots, their purposes and their structure and in the second part we will perform a more thorough analysis of the particular product that has taken its own niche and became a worldwide phenomenon due to its functions and infinite possibilities of improvement. The history of the robots in the construction area is short, comparing to the whole building construction industry but it includes a vast amount of interesting products and exemplars.

1.1. The main highlights in the world's history of robotics

Without a doubt, robotics is a natural logical continuation of technology as a phenomenon. The desire to automate any work gradually displaces a person from many spheres of his activity, providing in exchange all new possibilities for the application of efforts. Part of the total labor performed by mankind for the receiving as the result the more advanced production technology, instead of the final product for consumption, is gradually increasing from 0%, apparently striving towards the 100% Nonetheless any advanced production technology creates a burst in the consumable product quality, quantity and the complexity. Already, the efforts of most of the best modern created robots are aimed at the production of other machines: machines, cars, computers, etc.

But what is the robot itself? Is there a simple explanation that could be given to describe the technology as complex and variable as the robots? The robot in its nature is an indefinite concept, to which one can refer any kind of machine. The term is usually used for artistic effect or means that the machine uses manipulative mechanisms that allow the machine to manipulate objects. An important property of any created robots is a certain degree of autonomy. In various sources the meaning of the term “robot” will have several common characteristics, which are:

- Robot is an automatic device or a machine that performs work operation instead of the human person
- Robot’s working performance can be connected with the transportation and movement of several objects, or fully consists of.
- Robot is equipped with the computing unit, which purpose is to process the information from the sensors and to generate the control signals for the action mechanisms in accordance to the installed program

So based on the statements above, the answer for the previous question could be as follows: a real robot is an automatic or operator-controlled machine that instead of a person performs a physical work moving objects in space and doing functions in accordance with the program stored in it, taking into account the information coming from the built-in sensors or inputted manually in the work operations performance process. We can say that a programmable mechanism with the clear purpose that helps to replace the human labor is clearly can be called a robot

The first programmable mechanisms with included manipulators have appeared in the 1930s in the United States. The impetus for their creation was the work of Henry Ford (1863-1947) on the creation of an automated production line or the assembly line (that first started in 1913). Having broken down the whole process of manufacturing the product for a large number of small steps, Ford has reduced the requirements for the qualification of an ordinary worker. Before him, the car could only be collected by a team of high-level professionals. Now, professionals were required only to develop a clear plan for the production process. However, the conveyor had the reverse side - prolonged monotonous work quickly tires a person, reduces productivity and is the cause of occupational diseases not previously known. In addition, the freedom now available to choose a location behind the conveyor line forces you to pay more for the least qualified and harmful work. And the first of them - painting, because the layer must lie very evenly, given the thickness, in time to dry quickly, be strong, and do not spend too much paint on yourself.

In a huge number of sources, for example, *Business Week's Robot Milestones,* it is pointed out that the world's first industrial robot was built in 1938, by two American scientists Willard Pollard and Harold Roseland who worked for the company DeVilbiss, located in Great Britain - at that time the largest compressor and sprayers for industrial production manufacturer. In reality, the story is completely different. In 1938 the American scientist Willar L.V. Pollard does invent a controlled manipulator. To be precise, the machine was not just a simple manipulative mechanism but a parallel connection manipulator. Three proximal links were controlled by two actuators on the base. Three distal links were attached to the proximal links by cardan transmission. Two of them were respectfully fixed to the third one, using the simple hinge connection. The head of the nebulizer in the manipulator was attached to the third distal link again by the cardan gear, which provided a horizontal move. Vertical and horizontal rotation angles of the head were controlled by two more drives using a cable that resulted in the total of 5 degrees of freedom. However, it was not the first robotic manipulator and not the one that went to DeVilbiss. The robot, made by Willard L.V. Pollard in 1938 has never been put into the production. But the big invention was made by his son, also Willard Pollard, and it is the one, that changed the world.

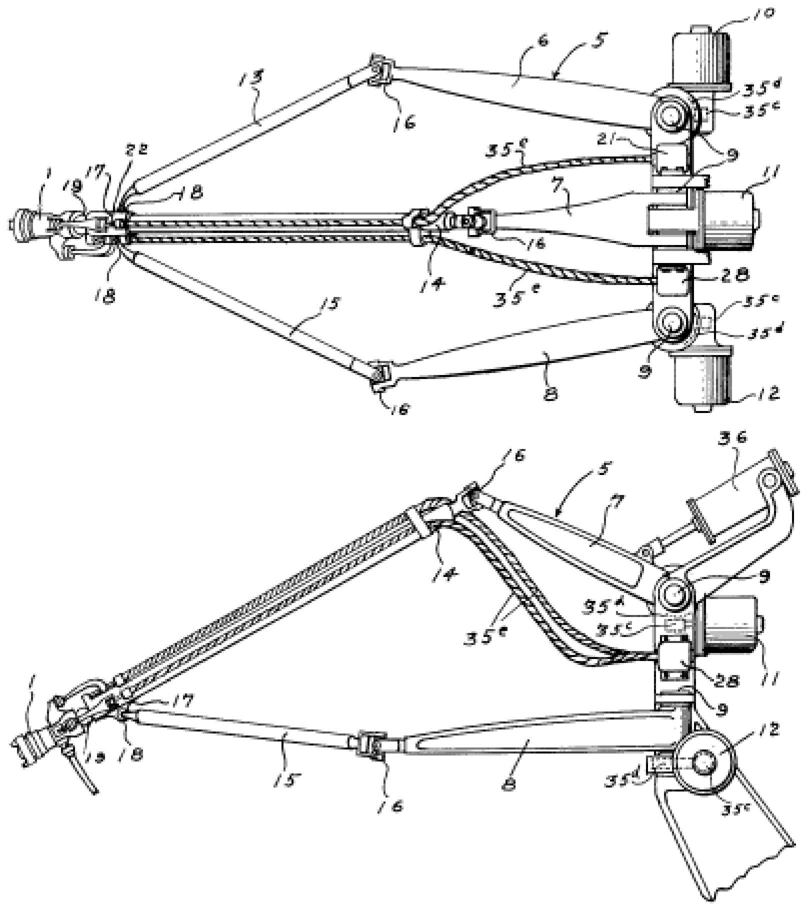

Fig. 1.1. Willard Pollard Jr. apparatus – parallel spatial industrial robot. Patented in 1942. [1]

The first really existing in the iron industrial robot belongs to a slightly different Pollard. Four years earlier, on October 29, 1934, Willard L.G. Pollard (Willard L.G. Pollard Jr., son of Willard L.V. Pollard) filed an application with the Patent Office for inventing a new fully automatic device for coloring surfaces. The patent consisted of two parts: an electrical control system and a mechanical manipulator. It was a great enhancement comparing to the design of the father's manipulator. On the figure above (Fig. 1.1) you can see the representation of the first real robot, patented in 1942. The program specified the speed of rotation of the drives with the depth of the holes on the tight punched tape, and the mechanical part of the robot was a parallel pantograph type manipulator with only two drives. And although Willard applied in 1934, they did not hurry with the issuance of the patent. The patent was in his hands only in 1942, and between deeds in 1937 the license to manufacture this manipulator somehow went to the company DeVilbiss. It was DeVilbiss in 1941, with the help of Harold Roseland, built the first prototypes of this device. However, the final Rosewood version, patented and released on the market in 1944, was a completely different mechanism, borrowing from Pollard Jr. only the idea of a management system.

The history of serious robotics begins with the advent of the nuclear industry, almost immediately after the end of the World War II. The industry of those years was not yet capable of producing high-precision programmable manipulators, robots were not yet capable to perform work behind the conveyor. However, the time dictates its own. The task was set - to secure the work of personnel with radioactive drugs - and was successfully solved with the help of manipulators copying the movements of the human operator. These were not exactly "honest" robots, because they still consist only of mechanical parts: belt and chevron transmissions are used. [Мацкевич В.В., Занимательная анатомия роботов, М., "Радио и связь", 1988] The modern name of such devices is copy manipulators or MSM (master-slave manipulators), that after some time and additional research in the area of mechanics, control robotics and servomotors have given us the image of the robots we are so used today.

As the history went further the robots became more and more advanced. They were not already limited by one function, but had multi-purposes and were more and more widespread across the planet. From the simple design the robots began to include more highly developed technologies and components, use new materials and alloys and be the complex solution to many problems. Now, the robots are the inseparable part of modern technological world and manufacturing. According to the reports, the possible industry growth by 10.5% in the nearest 5 years is predicted (Fig. 1.2). We can expect even higher results with the new technologies being invented and tested every day. But to get closer to the project that is analyzed in the following thesis it is needed to perform a deeper analysis of the sub-division of the robot that would be construction robotics and more precisely glazing robots.

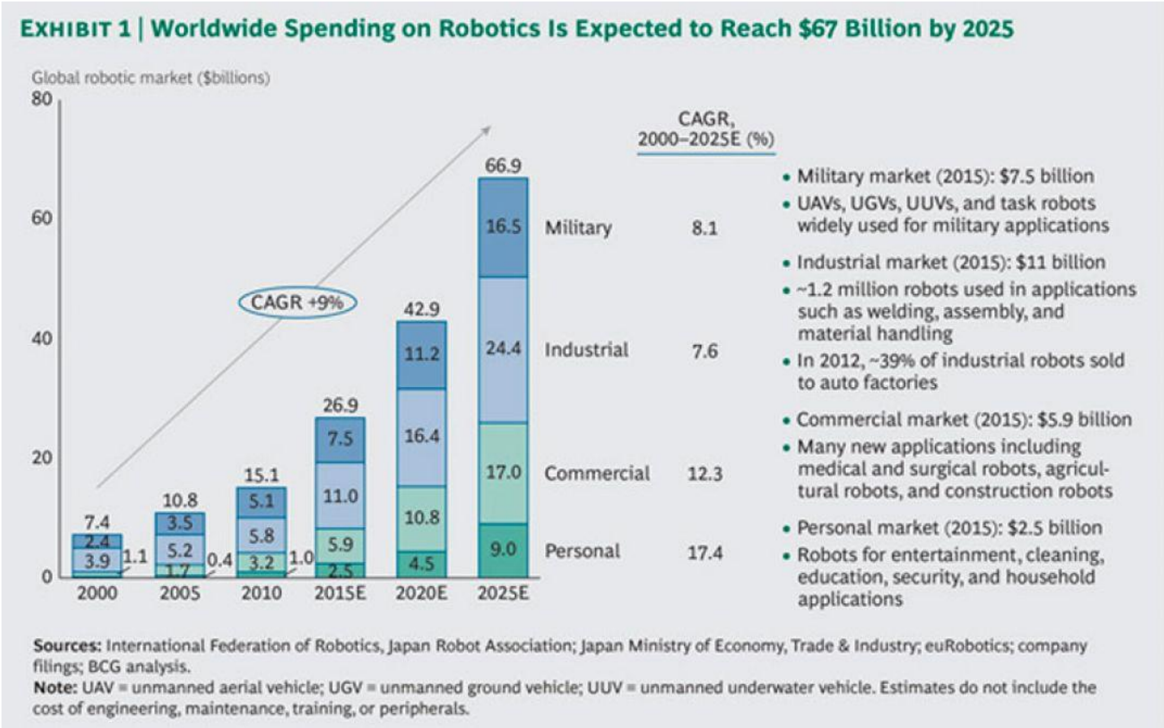

Fig. 1.2 The spending of world companies in the robotics industry and its segregation according to the end markets [2]

1.2. Construction robots, their history and impact in modern industry

Construction work was always known as the hard, exhausting and meant only for the strongest men, with no fear and no limits. Pyramids are built by men, castles are built by men, the great thousand-floor skyscrapers are made by strongest men alive. A great history of building construction has seen many astonishing objects and many amazing technologies, but in the late 20th Century everything has changed drastically. The many years of internal research and development, thousands of investments, a “brain drain” effect and the need to recreate the status of the country from military conqueror to the worldwide-known leader in many technological areas, has made own work, when in the second half of the 20th Century, or to be precise in 80’s Japanese companies has presented to the whole world their first construction robots.

They were bulky, maybe short-functioned, but they were working and having in comparison the United States, whose main building construction power was the human power, it was a great innovation that the world has never seen. It was just the beginning as in year 1983 “the Building Materials and Construction Procedure Committee of AIJ (Architectural Institute of Japan) formed a subcommittee to investigate construction robots” [Construction Robots– The Search for New

Building Technology in Japan, Leslie Cousineau,Nobuyasu Miura] As they have stated in their manifesto, the largest associations were gathered together to collect data from the researches, conduct and analyze the studies and to spread the information about the construction robots and their possibilities across the world. The first biggest survey was released already in the 90s and contained thousands of the analyses and studies about the single-task and multi-task robots developed in Japan and all across the world. The technology has started its path to gain its own place in the history of building construction.

As the construction robots development began its growth as well as the integration of new automation technologies began, the main goal was the best optimized way to combine the technological advancement with the received for the millennia knowledge. The deep integration of information into construction robotic systems became one of the important areas of development for many researchers and engineers. The main principle of the information integration is that it must occur in a cost effective and most productive manner without the possible loss of current construction functionality. The newly created robots should represent the integration of many different ideas and technologies into a whole, construct working system. [Advanced Robotics, 1991. 'Robots in Unstructured Environments', 91 ICAR., Fifth International Conference].

Nowadays the construction robots of various types, purposes and sizes are highly used in many areas of the construction industry. They can vary according to their control methods, their purposes and their construction. According to the statistics the latest usage of industrial robots has increased drastically, and the demand for not only full-automated, or AI controlled, but also for the collaborative robots, where the work of the machine is supported with the knowledge and the reflexes of the real person, has risen up, and is predicted to be even higher in future 5 years. We can only imagine, what the future technological process, the possible usage of Virtual Reality technologies and the advanced manipulators usage can bring to the industrial robots and construction robots.

1.3. Glass panel robots and their advantages in building construction industry

As we have been analyzing the construction robots at large, we could be more specific and move to the construction area, where the future analyzed project will take place. The construction industry has many branches of work and technology and one of them is the panel installations. There could be many types of panels, but mostly we can associate this term with the “glass panel installation”. So usually this type of work was performed by several workers with professional skills that using the needed equipment would install the glass panel, or door into the framework, and then fix it in the position for the further usage. But as any technology goes forward even the glass panel installation processes needed to be automatized. So that's when some companies decided to put their innovation into and created the fully or partially automated, collaborative or independent construction robots. They vary on size, and the capable carrying load, because duo to the parameters of the panel, some of the robots just simple could not handle them. The size also is as important as the functionality, because the capability to perform the needed operations in the closed and minimal area is a great add-on for any mechanism there is.

Nowadays there are several construction robots that are worth to pay an attention. During the analogue research in the area of glass panel, or just simple panel installation there were found three mechanisms. As one, the Danish collaborative robot "WallMo" is the object of the following practical research, it means that it will be shortly described the remaining two models of glazing robots that share resemblance with the "WallMo" on the working principle and purpose, but are very different in the structure, so that the basic working principles and their own differences from each other are understood.

The first construction robot that will be analyzed is the Winlet 600, whose representation you can see below (Fig. 1.3). The British company Winlet that is connected with Hird Group has created their own vision of how the glass installation should be performed and have designed the Winlet series – a series of glazing robots that differ according the possible maximum lifting capacity, that varies from 350 to 600 kg, and the own physical dimensions, like the size, the possible lifting heights and etc. The working principle of the Winlet glazing robots is not complex, and differs not so much in comparison with the analogues. The machine is regulated by the operator, who controls the length of the actuators and their positioning in the area. Operator also controls the vacuum lifters – the mechanism that allows grabbing the glass panel and lifting it, without the possible chance of dropping. The vacuum lifters are connected to the frame that has the capability of rotation about 180° due to the yaw joint. The interesting add-on of the Winlet that can be a great advantage in its usage is the installed gyroscopic sensor that allows holding the glass lifter frame at the exact same angle, while the actuator beam is changing its position. The robot can be positioned around the construction site, as it's equipped with the two pairs of pneumatic from wheels and the pair of back wheels that allow the robot to be turned around and placed in the needed position with the installation framework. But as any technology Winlet has own limitation, the obvious one would be its size and weight. The Winlet is used widely in the outdoor installation procedures, as due to the weight (that for light model is around 500 kg) the robot can damage the indoor flooring and would be too bulky to move around having a chance of possible indoor damage.

Fig. 1.3 The Winlet 600 glazing robot made by the Winlet Company. [3]

The other product that will be analyzed is also made in Great Britain by the GGR Group Company. The meant company has developed a variety of models of glazing robots each of them serving their own specific purpose and designed for different areas and environments. The model that is analyzed and compared to the previously mentioned Winlet and the following project “WallMo” is called Oscar. It is an internal glazing robot that has similar functions as the Winlet. It can also be modernized for the outdoor usage and can be provided in two types that differ on the maximum lifting weight. The representation of the Oscar 600 model of Oscar glazing robots is presented below (Fig. 1.4). This particular model is the new addition of the GCR Group Company into the industry of the glazing robots. This particular model is capable to lift up to 600 kilograms and has the unique lifting and moving capacity. It is equipped with the frontal pair of wheels that are designed for the internal usage of the Oscar; it also has additional side stabilizers that allow to steadily locating the robot in the working area without possible destabilization or movement risks.

Fig. 1.4 The graphic representation of the GCR Group Oscar 600 indoor glazing robot. [4]

As much as Oscar 600 is the great robot it also has own limitations. The glass gripping panel is moved by the actuator cylinder that can sometimes be the cause of unstable movement and possible low high positioning clearance. The connection of the telescope arm and the arm raising actuators are interesting but as the movement of the glass panel is performed in close area or small rooms, such size of the actuator would not be efficient as the vertical movements of the glass mostly are performed by the telescope arm, and in this case the arm's actuator is just having the purpose of the support. But without the mentioned limitations the Oscar 600 is one of the most efficient models that exist on the market of glazing industrial robots.

To conclude it is needed to be said that the glazing robots are now the part of growing industry segment of robotics and it surely has the full right to exist, as their functionality and design helps to perform tasks that required many skills and human resources

2. ANALYSIS OF THE COMPANY X AND ITS GLAZING ROBOT PROJECT “WALLMO”

As it was mentioned in the previous part, the main aim of this Master’s thesis is to thoroughly analyze the project of glazing robot “WallMo” that is manufactured and programmed by the Company X. But to perform deeper analysis of the project the analysis of Company X should be made, as to gain understanding of the control apparatus of the company as well as to understand its main impact on the project performance. To do that, the working areas, the structural analysis and the main staff responsibilities on this project should be reviewed, evaluated and given the suggestions that could be used by Company X to ensure the positive results of the project finish, and the results of that evaluation are presented in the following sub-chapters. We have divided the second chapter of this thesis into two parts. One will address the intercourse of the Company X and project as whole, and another will focus more on the inner structure of the Company, so that the further analysis would be supported by this reviews.

2.1 Company X and its external project “WallMo”. Description and analysis of the project.

Any type of organization is a complex, unique mechanism that combines multiple types of resources, such as financial resources, human resources, information and material flows and as a result of this combination provides the targeted market with the goods and services. The quality of these provisions is in straight dependency from the quality of the input resources and it is in the priority for the organization to have these resources organized. So to be a successful part of the industry each company is revised dependent on the input and output resources quality as well as the quality of the personnel that performs the conversion of the resources into the final product.

To understand the project we should first review the Company X that is responsible for it. The Company X is a medium-small Lithuanian automation and electrical engineering company, focused on energy, human and environment resources saving technologies, working in branches of:

- hybrid power (wind, diesel generators, combined heat and power (CHP)) systems
- refrigeration automation and building management (heating, ventilation and air conditioning (HVAC), lighting) systems
- monitoring systems for diesel engines, diesel and CHP generators and ship monitoring.
- robotics, automation and the control systems for industries

The Company was created in 2003, and provides the high quality services in the area of automation, control systems, programming and technical installation. The more wide range of available services will be as follows: automatic control systems, industrial computers, operator panels, programmable logic controllers (PLC) and SCADA (Supervision Control and Data Acquisition) for industry and building management systems (BMS), PLC and SCADA programming, design and installation works. The company has a good reputation and works in cooperation with many Lithuanian companies, as well as the international corporations and enterprises. Being the distributor of Beckhoff Automation and Block companies in Lithuania, Latvia and Belarus, the Company X supplies industrial and embedded computers, PLC, I/O, servo-motors and drives hardware as well as TwinCAT, HMI (human-machine interface) and SCADA software.

Company's profile is well-known in the Lithuania as the projects were carried out by the company in collaboration with many local enterprises and institutions. The control systems, whole automatic solutions and plain component provision made the reputation for the company that has spread not just in Baltic States, but through the European countries such as Denmark and Germany, as well as the third countries like Russia, Belarus and Ukraine.

Company is located in Kaunas, which allows, due to the central position of the city, to easily reach as other regions of Lithuania, as the close-by European countries, like Poland and Latvia, and other regions like Belarus and Kaliningrad district. Due to proximity to Klaipeda, the sea transport services are more available for the Company X, which widens the possibilities of project areas. As Company performs its services from 2003, the projects portfolio is impressive. The geographical map of the performed projects is presented below (Fig. 2.1).

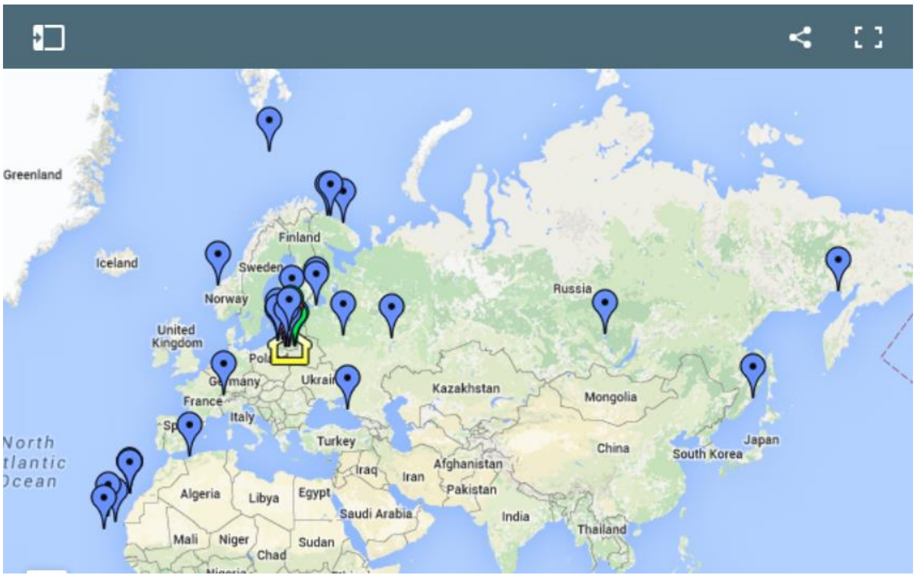

Figure 2.1 The map of projects, done by Company X [5]

The Company X services include electrical system modeling, design and layout of automatic control system and control cabinets assembly, industrial and embedded PC-based PLC programming, modern high-speed communication network and data transfer design, web based remote access services, SCADA programming, installation, start-up and maintenance activities. This all is just a small part of the engineering and mechanical activities that Company X is involved with. Having participated in almost all global exhibitions as the part of the Lithuanian Industrial Engineering Association and as the free-roam enterprise, being a part of the multinational projects and activities and representing Baltic states as the retailer of the world-known manufacturers, this all makes Company X a great reputation and working portfolio and of course the project WallMo is just one addition to it. But to continue this thesis the project should be analyzed more thoroughly and following is the deeper analysis of the WallMo glazing robot

WallMo is the project created in collaboration by two companies: Deko and Blue Ocean Robotics [http://wallmo.eu/ Retrieved at 11.04.2017]. Their idea was to create the universal solution for the glazing (glass installation) industry. In 2013 they have started with the first concept and in 2014 they have already finished the initial design for the WallMo 100. At the same time the spin-off company, that was named in respect to the project idea was created and gave its name to the first prototype that was manufactured in April 2015. This time was the birth of the WallMo 100 model. After that the constant search for the perfection in the model and construction began. The WallMo A/S, the company that has been involved directly with the production of the mentioned glazing robot has searched across the Europe for the enterprises that could join in the project and perform some of the tasks, as the demand for the WallMo robots started to grow. One of such companies became Company X. At the start the agreement was made just for the parts supply, but starting from 2017 Company X is responsible for the whole component supply and assembly of the WallMo robots.

It is also required to analyze the main working principle of the WallMo robot. WallMo glazing robot is designed to handle heavy lifting operations and difficult transportation of the walls and thus improves working conditions for the construction workers. The operation principle is as follows: the cooperation robot WallMo, supported by the human operator that locates the needed glass panel and helps in positioning the robot, picks up the partition panels from the stack and transports it to the mounting site. After the positioning near the installation frame, the robot then raises the glass plate up and installs it, using the calculated algorithm. The solution is maneuvered steadily and adjusted into the mounting position, and the wheels operate safely in the construction site environments and do not damage the floor or door panels.

With glazing industrial robot WallMo, the mounting work team consists of one operator and the WallMo co-bot. WallMo is prepared for any types of transportation to the mounting site and is operated by only one worker. Due to its compact construction its transportation and movement across the construction site is safe and easy, as the drive consists of two moving wheels on the back of the robot and one turning wheel in front.

The co-bot fits in a service wagon and operates in confined workspace with limited dimensions, such as narrow corridors. WallMo can carry weights up to 90 kg and manipulate panels up to 100 x 300 cm. In the table below (Table 2.1) it can be seen the technical data of the robot.

Table 2.1. The Technical Data for the WallMo robot

Weight w/o load:	325 Kg
Max. width:	600 mm
Max. length:	900 mm
Max. load:	90 Kg
Max. total weight:	415 Kg
Min. pick-up height:	350 mm
Max. pick-up distance:	300 mm
Vacuum system:	Built-in, two circuits
Pick-up time:	< 75 sec.
Installation time:	< 75 sec.

The pictures below (Fig. 2.2, Fig. 2.3) represent the earlier designs of the WallMo glazing robot – WallMo 100 and WallMo 300. As can be seen the initial design of WallMo 100 was more edgy and the main moving wheels are located on the back, right below the telescope hand connection points. In the model 300, that will be the object of the practical part of the following Master's thesis, the moving wheels are located in front, to ensure stability and the ease the movement and turning for the robot in loaded state. The batteries of this design model were located in the front of the robot, whereas in the current model batteries were moved to the back, so as the control mechanics.

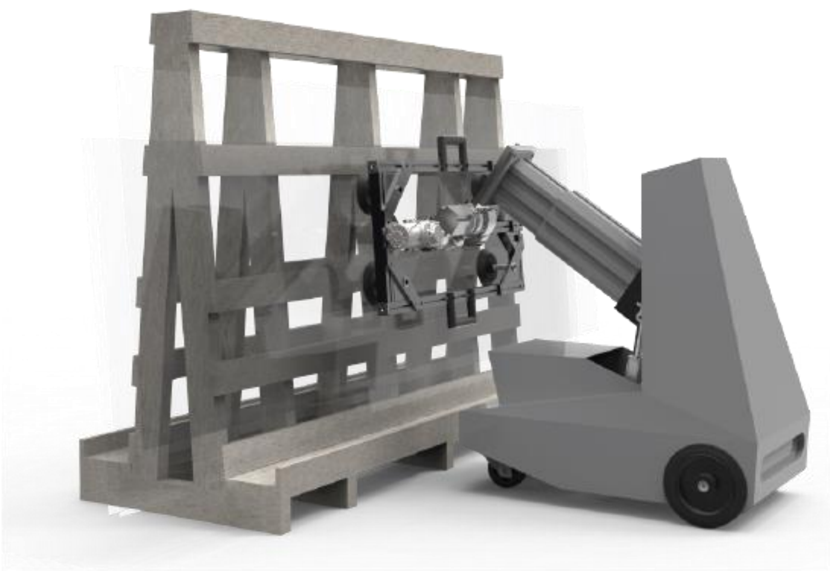

Fig. 2.2 The early representation of the WallMo co-bot in its 100 model [6]

Right now the WallMo robot is close to the final beta stage, where the changes done do not impact so much the whole system or the design. The cosmetic changes are always used, as the tool to improve not only the main working principle, but the whole machine's look, but the main construction and design are already confirmed and produced in several batches. WallMo 300, the latest model implements all the needed functions of its predecessor and also includes some additional components and improvements. As was mentioned before and as can be seen on the picture below (Fig. 2.3) the changes were made in the main frame construction, the moving wheels have been moved to front, also can be seen two supports on the back panel, that ensure stability of the robot during the working performance. The control automatics are hidden under the metal covers and located on the vacuum gripper. The components of the WallMo co-bot include EtherCAT modules, made by Beckhoff, such as analog and digital input/output modules, the motor modules that are dedicated to the stepper motor, also made by Beckhoff, the one that is responsible for the location of the gripper in space and its angle according to the vertical. The moving of the co-bot is done by the drive, produced by Dunkern Motoren GmbH that moves the moving wheels. The control elements are located on the panel of the co-bot as well as are duplicated and moved to distant control remote that allows the operator to easily adjust needed parameters of the WallMo as well as move it from place to place.

Fig. 2.3 The third design of WallMo co-bot – WallMo 300 in two positions [6]

The gripper, the main part that is responsible for taking the glass panel is a unique example of the combination of automatics and pneumatics. The gripper' vacuum suction cups are combined with Festo and Hoff pneumatic solutions, as valves and sensors and controlled by the Beckhoff terminals. The gripper also includes manual yaw and roll joints, that are adjusted manually and put into positions by the magnet brake, that allow the steady hold of the gripper in any desired position.

Another needed feature of the co-bot is the height and position adjustment that is done without the work of human operator. The mentioned adjustment is done by the telescope hand, which serves as the actuator to connect the gripper with the main frame of the co-bot and allow adjusting the height of the gripper and glass panel attached. To connect the telescope to the frame, two actuator cylinders are used. Actuators in robotic systems operate as the human muscles that change the different kind of energy into the body motion [CAD, 3D Modeling, Engineering Analysis, and Prototype Experimentation, Jeremy Zheng Li, University of Bridgeport,2015, ISBN 978-3-319-05920-4]. Electric motor is a very common type of actuator and in WallMo it, as was previously mentioned, powers the drive, linear actuators are used when strong force is needed in linear motion and their length can be altered by electricity. Such types of actuators are very important, as the telescope itself is not capable to lift both the gripper and the glass panel attached.

As any technology, WallMo can't be flawless, but the Company X and the creators of the WallMo are always in the search for perfection. The brainstorms, deep engineering and as a result – the technological break-through and improvements, that's all that is needed for any project to have constant improvement policy. But the road from WallMo 100 glazing robot model to the current WallMo 300 was covered with small and major modifications and changes. Some of them were already mentioned before, such as the frame changes, the positions of the robot components and the location of the moving wheels as well as the turning wheel type changes. These were changes that were caused by the imperfections in the initial design that could cause the failure for the WallMo project. But some changes, like program improvement, some automation components replacement and small mechanical changes are caused by the constant need of improvement, the search for the safe and flawless working performance.

As the working principle of WallMo has been analyzed we have unveiled that the main working principle is in need of the improvement. As we know the WallMo 300 is an industrial glazing robot, created to work in cooperation with human operator, but perform most of the hard lifting and installation works. The operator is a guide for the movements of the WallMo, but all the movements and the tasks are inside the robot's program. Looking through the working cycle it has been noticed that the installation process can be broken down to 3 main points: the taking, the transportation and installation. These points are part of the main working trajectory of the glass panel, taken by the WallMo and prepared for the installation. The movement between these points is programmed using the interpolation between the mentioned before points and requires a great amount of additional adjustment from the operator. We do not include into the review the positions, when the operator manually adjusts the glass panel for the transportation, or rotates the panel to continue the installation procedure and prepare for the insert in the frame. The main problem is, that interpolation between these points is solid and does not allow the possibility of the different glass sizes or the different environment, where the operational field would be specialized and would require additional programming and calculations done. This said, such performance is not perfect, and can be modified if not to better operation time, but to the safer, steadier and adjustable way of preparation to installation.

The main problem that was described above is the need for the possibility to create the movement trajectory that is based on the constant of the robot and on the variables that can be easily measured, such as height of the frame and the size of the glass panel. The WallMo A/S in cooperation with Blue Ocean Robotics already had some practical prototypes of the calculation pattern, created Matlab programs and tried to implement the concept of different glass panels into the final installation process cycle, but the following suggestion and practical solution includes the CAD simulation of the movement, supported by the standard movement calculations and the further analysis of the frame installation, that should reveal the linear dependence of the movement from the different sizes of the glass panels being installed. The carried research will be targeted on the implementation of simple environment and human resource safety standards in the movement cycle of the co-bot, on the representation of the movement by modeling it in the SolidWorks and on the review the positions for the main drives that characterize the motion of the glass panel carried by the WallMo co-bot

2.2 Company X, its structure, personnel and their involvement in the "WallMo" project

In any type of project there would be no positive results without the involvement of the personnel and their organized coordination from the control apparatus of the Company. In company X there are currently 15 workers, and obviously not all of them are involved in the project, but to understand what is the strategy for the performance of the project it is needed to analyze the tasks separation and the involved staff that directly influence the project.

To start the analysis of the involved employees, there should be performed a short description of the Company X' human resources policy. The personnel of Company X are highly skilled, and perform high-quality services with available support on English, Lithuanian and Russian language. The number of Company X does not exceed 15 members of staff, which make the Company a medium-small enterprise according the personnel criteria. The important part of the Company is its organizational structure. It is hierarchical vertical structure with possibility of project assignation to the managers or specialists. The scheme of the Company is presented below (Fig.2.2).

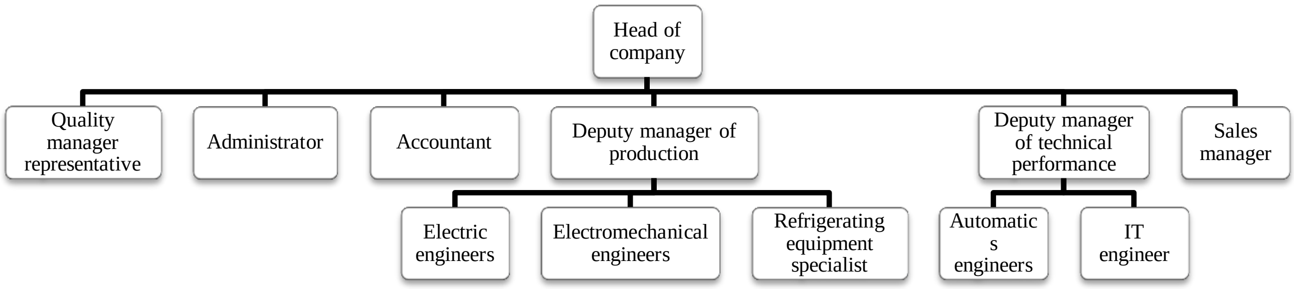

Fig. 2.2 The current vertical control structure of the Company X

The scheme above shows the actual organizational structure of the Company X. Each of the members can interfere during the working performance, and is assigned to the various tasks or the projects by the higher management. As we can see this is the hierarchical structure in which all of the connections go from lower levels to the higher ones, which states that the working relationships are straight-forward and employees are controlled by one Head of the Company that regulates almost all operations, except those, where the duties of the Head's deputies are. As we know such direct responsibility can be hard for the workers and especially for the Head of the Company as the financial or the organizational problems influence him/her directly. Looking from the position of the project WallMo implementation such structure can cause several problems as the disorganized connections on the human resource and performance levels inside the company as well as the narrow scale of working responsibilities of employees comparing to the versatile requirements of the project can damage the work flow and even cause some financial and performance damage to the project. But the problems that may appear in the Company X during the project implementation and their solution as well as the short description of implemented managerial results will be presented in the further chapters.

The WallMo project is the complex, multi-stage challenge and it requires the highly-skilled management and the optimal usage of human and physical resources. As Company X is the part of the mentioned project the employees were chosen, according to their work qualities and specializations to be a part of the WallMo creation. As the most important task is to assembly the WallMo, to ensure its work and to perform all the needed tests, the most qualified automatics and electric engineers of the Company X were selected to carry on these tasks. As can be seen the hierarchical structure of the engineering sector of the Company X puts the responsibility for the actions of the specialists on the company's deputy manager on production, who must ensure the quality of the performed work and analyze the results of it. As the assembly of the co-bot requires the details, and as was mentioned above the Company X has no production sites, the sales manager should be included as the part of the project. Due to the vertical structure of analyzed company, the sales manager is in direct responsibility from the head of the company, which does not allow any additional interrelations between sales and engineering departments, due to the different functions in the company. As the result of such strict work separation, the lack of the technical knowledge of sales manager could be the cause of additional problems, as the human mistake is the common occurrence in the small enterprises, and if the inner communication channels are not advance, the performance of the project could be endangered.

Any type of organization is a complex, unique mechanism that combines multiple types of resources, such as financial resources, human resources, information and material flows and as a result of this combination provides the targeted market with the goods and services. The quality of these provisions is in straight dependency from the quality of the input resources and it is in the priority for the organization to have these resources organized. But what make the organization special are the human resources, or the staff, to be precise [Управление человеческими ресурсами / под ред. А. Я. Кибанова. – М.: ИНФРА – М,1997]. Of course the higher management, such as CEO (Chief Executive Officer), heads of the departments and the higher ranks of the company influence the company performance directly, nevertheless the staff, the departments by performing their duties are making the needed reputation for the organization of any kind. But as any mechanism has its flaws, so do the organizations.

3. THE ANALYSIS AND IMPROVEMENT OF INSTALLATION PROCESS OF GLASS PANEL MOUNTING ROBOT

According to the analysis done on the glazing co-bot WallMo there was unveiled the possibility to optimize the installation of the glass panel process. The main process highlights were briefly mentioned in the previous chapter, but the main analysis of the installation process, its working specific and practical solution and optimization using CAD software SolidWorks will be more thoroughly described in the following chapter.

3.1 The practical analysis of the installation process of glass panel mounting robot, its optimization using CAD software

As was previously mentioned, the working principle of the WallMo co-bot is based on the moving of the glass panel from the initial point, that usually being the pallet and taking it to the position, where the frame installation is possible. Current automatic cycle includes the interpolated trajectory between the points that are described by the three constants: the actuator length, the telescope length and the stepper angle according to the installation to the actuator frame. The values will be hereby stated as A_{length}, T_{length} and S_{angle}. The mentioned interpolation is the more accurate method of approximation, when the function or the trajectory is calculated, using the values, received by known calculations or the practical research. As the three main points, described In previous chapter are known and can be described by the A_{length}, T_{length} and S_{angle} constants it seems logical that the original approximation does not apply here, and that's why interpolation is so important. The movement trajectory was calculated from original data using Matlab software and then compiled into the program that operates the controllers of the WallMo. But taking a closer look at the movement of the co-bot it can be noticed, that some movements between the original points can be long, unsafe, putting the attached glass panel and the co-bot equipment at risk. Knowing that there was suggested a solution that could implement standard safety requirements, approved by the owners of the project and could be used to ensure the stability and safety of the interpolation method, or even come up with more advanced one.

The suggestion was to create so-called "midpoints". The points that are logically and practically measured, that could be added as the original points in the interpolation equation, or without the mentioned method, be formed into the movement equation, using simple machine movement theory. Doing that would give a possibility to set up the safety ranges for the standard sized glass panel, and after small changes, would be even be able to suggest the trajectory for different sizes of the panels. The calculation of such points, should be based on the three constants and be able to show the movement of the glass panel chosen points as to transform it into the movement curve. To do that the CAD software SolidWorks was chosen to carry one the modeling of the mentioned points as well as to represent the movement of the robot and the glass panel attached. Using SolidWorks software and the practical values of the known parts of the real WallMo 300 co-bot the 3D model assembly was created so that the positioning of the robot would be first tested in the CAD environment and then, if necessary, using the calculated values of A_{length}, T_{length} and S_{angle} the co-bot could be tested, using already build models.

To carry on the research in SolidWorks there were needed some values. As already mentioned A_{length}, T_{length} and S_{angle} were known only for three points, the others were needed to be taken as the mathematical model. Also as the research will continue the model should include the value ranges for the absolute parameters of A_{length}, T_{length} and S_{angle}. The telescope length' maximum is 500 mm, when the telescope actuator is fully extended. As the telescope is fully retracted the T_{length} value is equal to 0 mm. The actuator drives maximum extraction patyh equal to 200 mm, where at that point the telescope and gripper are raised to the highest possible angle. The stepper motor can rotate at full 360 degrees, but included brakes and encoder decrease the available angle range, so the value range for S_{angle} parameter is 0°-180°. The scheme, showing the main T_{length}, A_{length} and S_{angle} parameters is presented in the appendices (Appendix №1). One of the other most important values to choose in mathematical model was the glass panel size. To continue the modeling the size of the panel, was chosen to be the one, stated in the Technical Data table (Table 1) and would be 1000mm x 3000mm x 10mm. This is the maximum capable glass wall panel that can be lifted and operated with by WallMo. The weight of the panel is not necessary, as strength and stress analysis will not be carried, but it should be mentioned that the weight should not exceed 90 kg, as vacuum suction cups could hold on only such maximum weight.

The first part of the practical research the transportation and installation positioning should be optimized to allow more precise and safer movement of the glass panel, without the need of the 3-value non-linear interpolation. To perform the first part of the research there were necessary some initial means for the CAD software, such as the model of the WallMo. The model itself is the precise representation of the co-bot with all the details and wirings included. But the main movement of the glass is carried by the three drives: telescope, actuator and stepper motor, so for further analysis the model will be presented by those parts of co-bot. The initial position, that was described earlier is known and is set to be the grabbing of the glass panel from the EU standard pallet. The height of the pallet is known: 144mm. The grabbing angle, to which the gripper should be placed, to be positioned straight in the middle of the panel will be 15 degrees, so that the future implementation of movement points will be connected with the initial data. As can be seen on the left picture below (Fig. 3.1) the grabbing position consists of the telescope in fully retracted position, the absolute value T_{length} is equal to 0, the actuators are in starting positions, which is 76 mm and the gripper is set to 15° from the vertical and 124° from the telescope connection face. The next positions are performed in the similar manner. It is the parallel lifting position that ensures that the glass panel is moved safely from the pallet. The parallel movement was chosen to carry on safer lifting from initial position, as the straight vertical movement with such extension of actuators would be a heavy task for WallMo, especially, if it is not stabilized in place, and the horizontal movement, could give a chance for some collisions with a pallet, as slight imperfections in horizontal wooden surface, may damage the glass carried from the pallet.

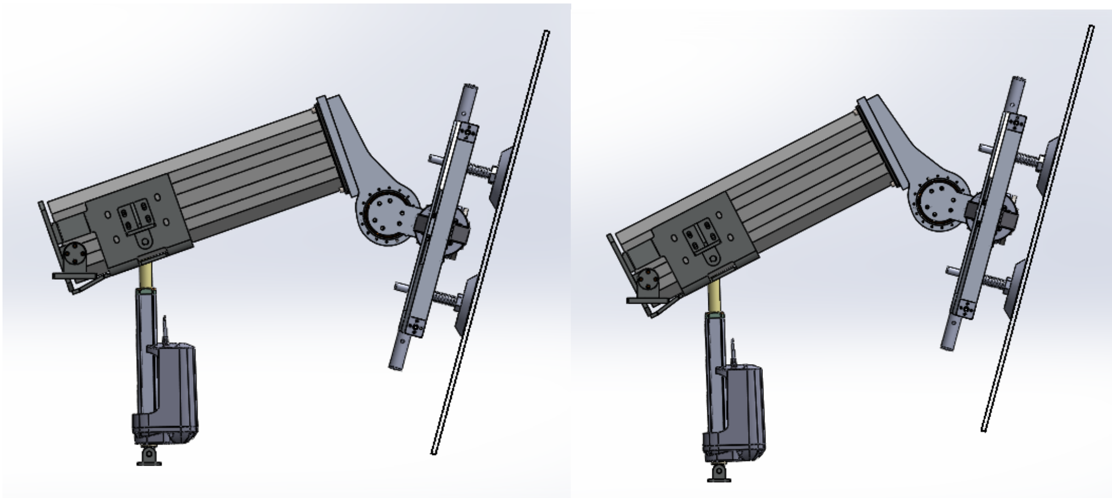

Fig. 3.1 The grabbing and parallel lifting positions of the WallMo co-bot. The glass panel is been taken from pallet and carefully lifted to the next position

The next three positions are the easiest to perform. In the vertical hold, 30 and 60 degrees hold positions, the only active drives are the actuators and the stepper motor. The vertical hold position is done, by locating the glass in parallel to the vertical and to the installation frame; this position was included so that the machine could be taken away by some distance from the pallet. The 30 degree and 60 degree holds, are the positions, where the glass is taken to the point of 30 and 60 degrees respectfully from the taking angle. The telescope actuator in the mentioned positions is still retracted, as the whole movement is done only by the remaining drives. The representation of the mentioned positions can be observed on the figure below (Fig. 3.2, Fig. 3.3)

Fig. 3.2 The vertical hold and 30 degree hold position. Gripper holds the glass in vertical position for further transportation

The last position, the transportation-ready, is the position, when the stepper motor is on its maximum available angle, and the actuators are fully extended. This position is needed, so that the co-bot with operator could be moved across the construction site, without the need of constant holding of the glass. For more stable transportation across the site, the operator also can unlock the magnetic brakes so that the glass could be positioned vertically about the yaw joint of the gripper. This ensures the compact state of WallMo and allows it to cross doorways, which other glazing robots cannot do. The magnetic locks are controlled from the handles on the gripper and the position changing of the gripper and the glass attached are eased by the support shafts of the yaw and roll joints. The representation of the transportation-ready position of the horizontal glass is presented below (Fig. 3.3)

As we have described the first several positions of the transportation and installation preparation movement cycle we haven't accented the needed safety rules that should be noted for the mentioned movement points. As the glass panel is at its maximum size, which in length gives 3 meter, the needed working range should be described, so that no possible operator casualties would occur during the working performance with the co-bot. The ISO 12543 "Glass in building — Laminated glass and laminated safety glass" standard states that the normal carrying and transportation distance from the glass should be from 60 to 100 centimeters, so taking into account the maximum resolution of the glass carried and the size of the co-bot the supposed safety distance for the operator would be approximately 170-200 centimeters away. Of course the manual operation of the co-bot from the sides would be complicated, especially with the movement of the glass from grabbing to transportation position, but, according to the structure of the WallMo co-bot there is a possibility of a remote control of the movement, using the compact control panel, attached by the power cord with the control elements of the co-bot. This allows the operator to manipulate the equipment, without the risks of the possible collision with glass panel and further injuries. The mentioned safety distance can be also applied in the second part of the installation preparation movement cycle, but in the vertical positioning of the glass panel the distance can be lowered to the 150 centimeters away from the sides of the co-bot. But on the other hand the environmental safety conditions should be met, while handling the glass in its vertical position.

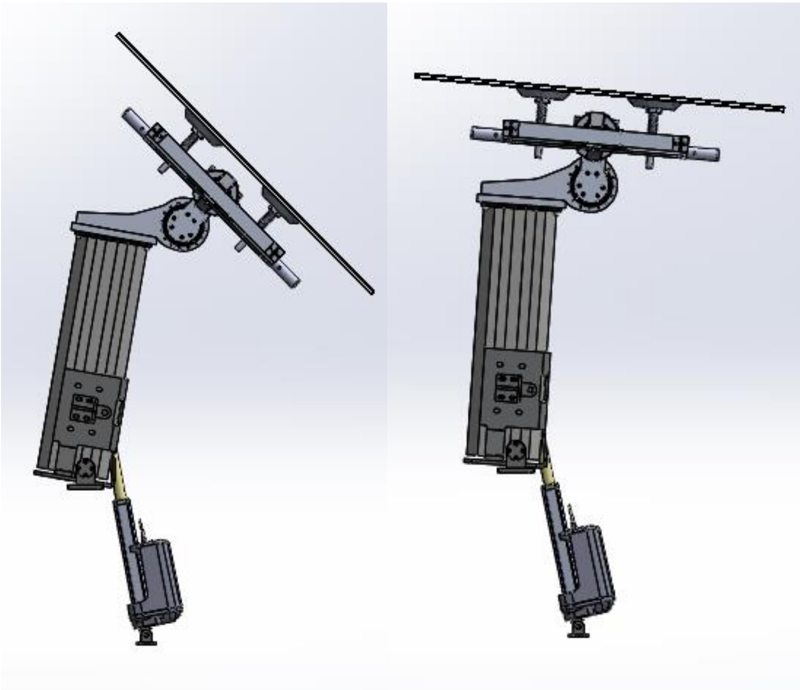

Fig. 3.3 The 60 degrees hold and transportation-ready positions

After the reaching the transportation position, the operator should manually turn around the glass panel, so that it could be later installed into the frame, as well as more compactly transported to the installation position. The vertical positioning of the glass is showed below (Fig 3.4). This position takes us to the next cycle of the installation positioning, where the co-bot is placed directly in front of the installation frame and prepared for the next positions.

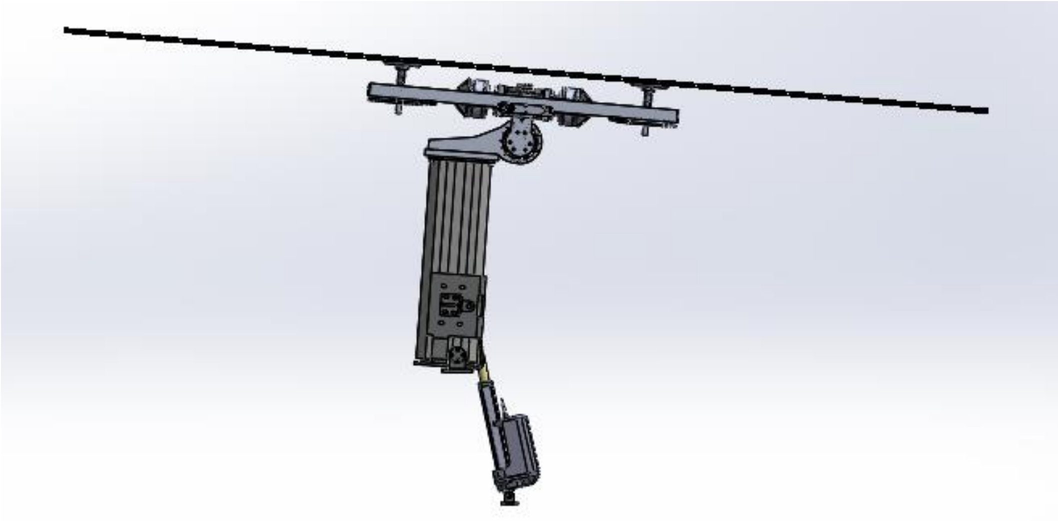

Fig. 3.4 The transportation-ready position of co-bot. The glass panel was turned manually to vertical position

The next several positions, showed below (Fig. 3.5 and Fig 3.6) are showing us the positions, created to be middle points between the transportation position and the final installation position. The 60 and 30 degree holds repeat the previously mentioned positions, only with activated telescope drive, so that the lower edge of the glass panel would be secure from hitting the floor or the edge of the robot. When we were analyzing the first part of the installation preparation movement there was needed some range safety standards to be applied, but for vertical positioning, the construction site environment should be taken into account. Using the SolidWorks software and the mathematical model of the installation site, where the installation frame have following heights: upper frame – 40 mm, lower frame – 25 mm and the height of the ceiling is 3030 mm, the limits for the glass panel were included as follows: the maximum distance between the ceiling and the higher edge of the glass panel (AB edge showed on the Appendix №2) would be 20 mm, the maximum distance between the floor and the lower edge of the glass panel (CD edge, showed on the Appendix №2) would be 10 mm, so that the glass could be manipulated more freely to be inserted in the upper frame and the maximum distance between the surface of the glass and the robot would be 20 mm to ensure that no possible collision between the glass panel and the co-bot would occur.

Fig. 3.5 The 60 degrees hold of vertical glass panel

The last positions, showed below (Fig 3.6) include the vertical hold and the installation-ready positions. The vertical hold position is essential as at this point the operator has the chance to stop the cycle and set the distance from the robot to the installation frame. Setting up the distance till the frame is needed to carry the next cycle – installation of the glass into the frame that will be more thoroughly described in the second part of the practical research. The distance between the robot and the installation frame is set to be 300 mm, to ensure the inclusion of the previously mentioned safety limits from the co-bot and the ceiling for the installation of the 3 meter glass panel.

Fig. 3.6 30 degree, vertical and installation hold positions. The glass is prepared to be inserted into the frame

The installation position that is presented above describes the glass panel to be positioned to the installation angle that varies for different sizes of glass panels. During the practical research using the SolidWorks software there were made different situations for the glass panels of following heights: 3 meters, 2.8 meters and 2.5 meters. Received installation angle of glass to the vertical values, presented below (Table 3.1) gave a possibility to calculate the polynomial function that would allow the users to calculate the needed installation angle, dependent on the used glass panel height.

Table 3.1 The installation angles for different sizes of glass panels, measured in SolidWorks

Installed glass panel height	3 meters	2,8 meters	2,5 meters
Installation angle, measured in SolidWorks models, degree	5,81694342	6,23418853	6,98616641

The described above values were used to calculate the installation angle equation using the method of polynomial regression. The calculated formula is presented below:

$$\mathbf{Y = 8.407347667 \cdot 10^{-1} \cdot X^{2} - 6.962487197 \cdot X + 19.13779211}$$

This formula allows the future users to calculate the installation angle for the different sizes of glass without the need of creating the different CAD models and measuring the angle directly in the simulated environment.

After the modeling of the movement points and the creation of the installation angle formula the most important calculations were needed to be made. As it was mentioned before the movement of the WallMo co-bot was done by interpolation between the known three points that were characterized by three absolute values: the length of telescope drive, length of linear actuator and the angle of stepper motor from the installation frame. The new movement points were also measured by the mentioned absolutes to allow the further programming of the cycle. The table of the measurements is presented below (Table 3.2)

Table 3.2 The results of the additional position creation. The main parameters and coordinates

Position № and name	**T_{length}, mm**	**A_{length}, mm**	**S_{angle}, outer**	**S_{angle} inner, deg**
1. Grabbing position	0	75,800	124,430	55,570
2, Parallel lifting position	0	97,600	132,240	47,760
3. Vertical hold position	0	158,500	141,570	38,430
4. 30 degree hold	0	187,000	140,130	39,870
5. 60 degree hold	0	211,700	125,140	54,860

6. Transportation Horizontal	0	219,500	90,900	89,100
7. Transportation Vertical	0	219,500	90,900	89,100
8. 60 degree hold vertical	57,800	219,500	130,900	49,100
9. 30 degree hold vertical	133,300	214,500	157,200	22,800
10. Vertical position	306,800	200,000	162,500	17,500
11. Installation position	415,400	183,700	160,530	19,470

The measured values were transferred to the already built WallMo co-bot that Company X has already assembled and were tested in the real environment. According to the technical limitations of the co-bot equipment, such as its encoder, the 1.9 mm mistake had a place during the performance, but it was ensured that the transportation and preparation for installation movement cycle would carry the safety limits mentioned previously.

After the measuring of the absolute values the time was supposed to be calculated. To carry these calculations the paths of the telescope were calculated, then according to the longest paths the slowest drive's velocity was applied, to later calculate the time of the movement from one position to another and then find the rest of the velocities. In most cases the slowest drive was the telescope, as it needs more time to position itself and its velocity is very low: the average velocity is about 7 mm/sec. But the half of the positions the telescope is retracted, and that's where the actuator's velocity is used to calculate the time. The linear actuator's velocity range is very high: 5-12 mm/sec, so we've taken the medium velocity to carry on the calculations. Stepper motor has very high speed, but the encoder slows the angular velocity to the medium of 12 deg/sec. Below will be an example of calculations for the 9th position "30 degree hold". The telescope was chosen as the slowest drive and its velocity was taken as 9 mm/sec.

$$Time = \frac{Tdistance}{Vtelescope} = \frac{75{,}500mm}{9{,}000\,mm/sec} = 8{,}389seconds$$

$$V_{actuator} = \frac{A_{distance}, mm}{Time, sec} = \frac{5mm}{8{,}389sec} = 0{,}596\,mm/sec$$

$$\omega_{stepper} = \frac{S_{angledifference}, deg}{Time, sec} = \frac{26{,}300deg}{8{,}389sec} = 3{,}135\,deg/sec$$

The results of the described calculations are presented in the table below (Table 3.3). We are taking the movement ass simultaneous one, but for real situation this would not be necessary. as can be seen from the results, the actuators' velocity should be very small to take the path in such time, so for the practical implementation, there should be done a multiple-stage movement, when the telescope drive starts its movement, then the drive, that should make the second longest path will be included and concludes the motion the fastest drive. Usually the order of movement for the straight line movement between the positions would be the telescope, then the stepper motor and then the linear actuator to position the glass panel completely.

Table 3.3 The calculation of telescope, actuator and stepper paths, movement time and velocities

Position № and name	**T distance, mm**	**A distance, mm**	**S angle difference, deg**	**V telescope, mm/sec**	**V actuator, mm/sec**	**ω stepper**	**Time, sec**
1. Grabbing position	-	-	-	-	-	-	-
2, Parallel lifting position	0	21,800	7,810	7,000	7,000	2,508	3,114
3. Vertical hold position	0	60,900	9,330	7,000	7,000	1,072	8,700
4. 30 degree hold	0	28,500	1,440	7,000	7,000	0,354	4,071
5. 60 degree hold	0	24,700	14,990	7,000	7,000	4,248	3,529
6. Transportation Horizontal	0	7,800	34,240	7,000	7,000	30,728	1,114
7. Transportation Vertical	0	0	0				
8. 60 degree hold vertical	57,800	0	40,000	9,000	0,000	6,228	6,422
9. 30 degree hold vertical	75,500	5,000	26,300	9,000	0,596	3,135	8,389
10. Vertical position	173,500	14,500	5,300	9,000	0,752	0,275	19,278
11. Installation position	108,600	16,300	1,970	9,000	1,351	0,163	12,067

The second part of the practical research is the thorough analysis of the installation process. In this part we are focusing more on the dependencies of the movement between the different types of glasses. This research was also supported by the CAD software SolidWorks that allowed to design a model of the installation process for different sizes of glass panels. We have chosen three different glass panels with lengths of 3, 2.8 and 2.5 meters each. For each of them a set of the positions was applied each with own distances and parameters. The whole amount of the positions for the full installation was chosen to be 13. The absolute parameters of the telescope, actuator and stepper motor (presented in the Appendix №3) were measured for each position of installation and the path differences were calculated to carry on the further research.

The positions were chosen in accordance to the selected installation frame and described above installation constants. We have chosen the distance from the WallMo co-bot to the frame to be the 300 mm, the frame itself has the parameters of 40 mm for upper frame and 25 mm for lower frame. But to set up the movement points of the installation process some additional constants were needed. For the initial installation process we have already discovered the angle, that depends on the glass panel size, the installation frame on the other hand does not change, so we have set for the initial point the distance between the upper edge of glass panel (marked AB on Appendix №2) and the ceiling (the connection face between ceiling and frame) to be 41,4 mm for all the glass panels. Such distance was chosen to be the optimal one, as it ensures the possibility for the glass panel to reach the frame and to be lifted for further insertion into it. Another distance that was set was the distance from the upper edge of the glass to the inner face of frame – 1mm. This ensures that the glass won't be pushed to the walls of aluminum installation frame, which could lead to cracks or breakages. The next points were calculated from the mentioned above initial data, and the further installation points were measured the similar way.

The more thorough analysis of the positions should be made. The 12 movement points can be splitted into the several parts that are described by the movement the glass panel is doing in accordance to the vertical. Positions from 1-4 (1 turn, 1 rising, 2 rising, 3 rising) is the straight vertical motion up with keeping the initial installation angle, right until the possible connection with the left side of the frame. On the picture below (Fig. 3.7) the position "3 rising" can be seen, as it can be observed that the glass panel is been risen up to the point where the next lifting motion will change the angle from initial and so change the motion type from straight vertical

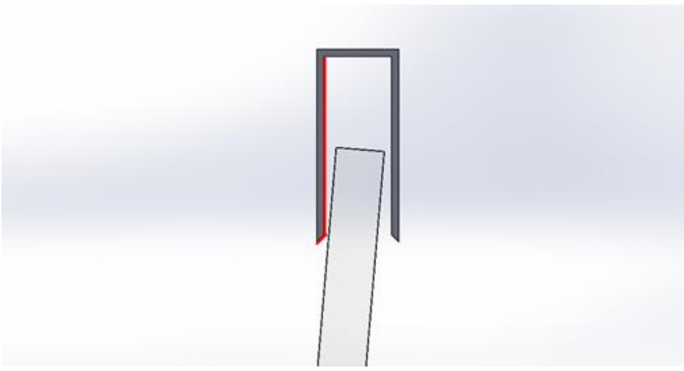

Fig. 3.7 the 3 rising position of the installation cycle

The next 8 positions (4 rising, 4.5 rising, 2 turn, 3 turn, 4 turn, 5 turn, 6 turn and last turn) are set to be the rising and turning vertical motion. Starting from the 4 rising position it was decided to add in the SolidWorks model an additional limit to the previously mentioned left side of the frame (highlighted with red on the Fig. 3.7) that for the first 4 positions was set to be 1mm and starting from the position "5 turn" to be 1.5 mm to ensure that the glass is set to the middle vertical position in further points. The remaining two points (lowering the glass, insertion point) are described as the straight down vertical motion with the glass being already set in the middle position inside the installation frame and being lowered down to the final point, where the rubber supports would protect the glass panel from scratching and excessive influence of the metal surface of the frame. Also after the last position "insertion point" the rubber side supports should be inserted to ensure the glass stays stable and does not have any possibility to move to sides, which could be the cause of the deformation and further breakage of the panel.

The described positions were applied to the 3 types of glass panels, with included constant parameters for each glass in each position: the distance from the glass edge to the ceiling and the distance from the glass face to the right side of frame. Such choice was made to ensure that the further calculations of the paths and the dependencies coefficients were made in the same conditions for each glass panel. After setting up the movement points the absolute parameters were measured and placed in the form of a data table (Appendix №3) for further analysis. After the review of the measured TAS parameters (T_{length}, A_{length} and S_{angle}) the graph was made, showing the dependencies between the chosen glass panels. The representation of the graph is presented below (Fig. 3.8) showing us the changes of the absolute parameters. As we can see the 3 meter glass panel requires the positions changes to be higher than for the smaller panels. The graph shows that the operating of the bigger resolution panel requires bigger movements from each drive, whenever the smaller resolution, such as 2.5 meter glass panel has the parameters drastically smaller.

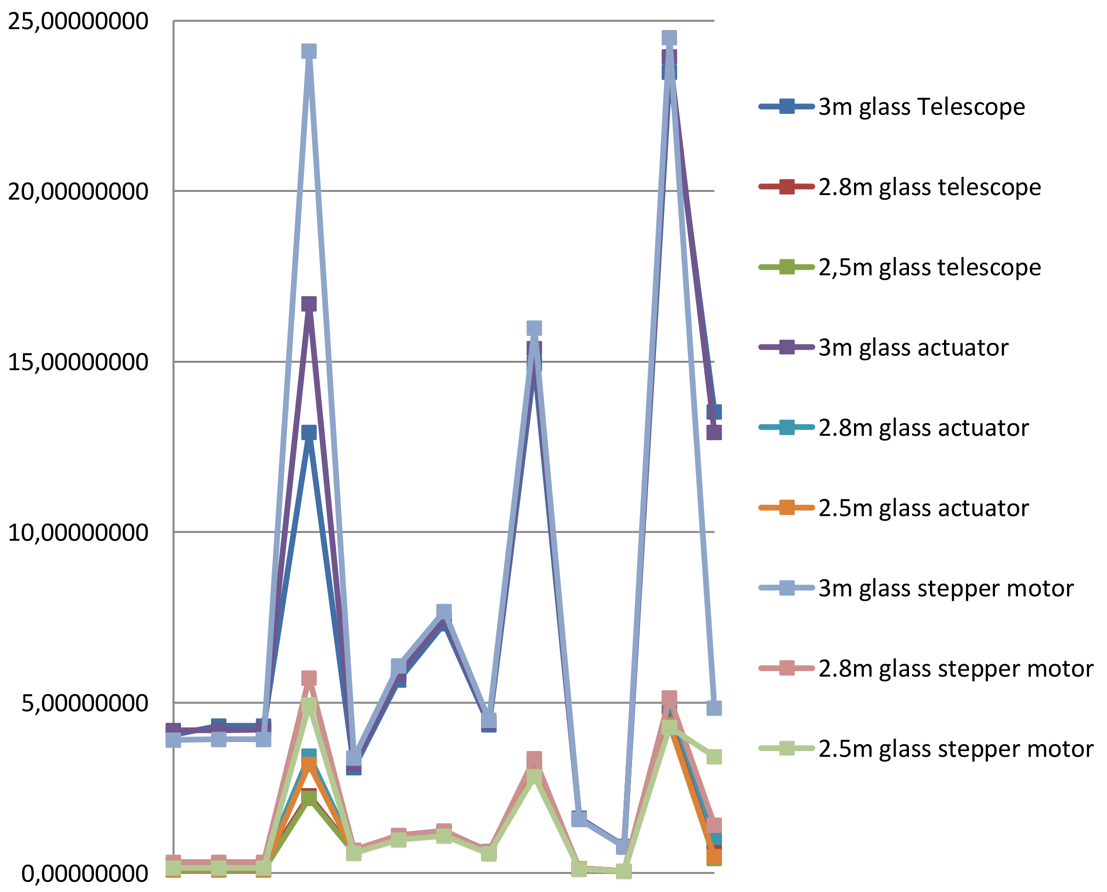

Fig. 3.8 the diagram, showing the dependence of absolute TAS parameters from glass size

After the calculation of the absolute parameters for different sizes of the glass panels we have been able to see the direct relationship between the movement done and the size of the installed glass as well as the initial constant values, that were describe earlier. The next part of the research was to confirm the linear dependence of the absolute parameters paths, so the data of the calculated parameter's paths was compared between the 3 sizes of glass panel and according to the coefficients, that were received, the linear graphical dependence was unveiled. The graphics (Fig. 3.9, Fig. 3.10) show the coefficients for telescope and linear actuator of 2.8 meter and 2.5 meter glass panel in dependence from the 3 meter glass panel, that was taken as the main one, as its movement requires the biggest amount of manipulation and the value for the coefficient for the 3 meter glass was taken to be 1.

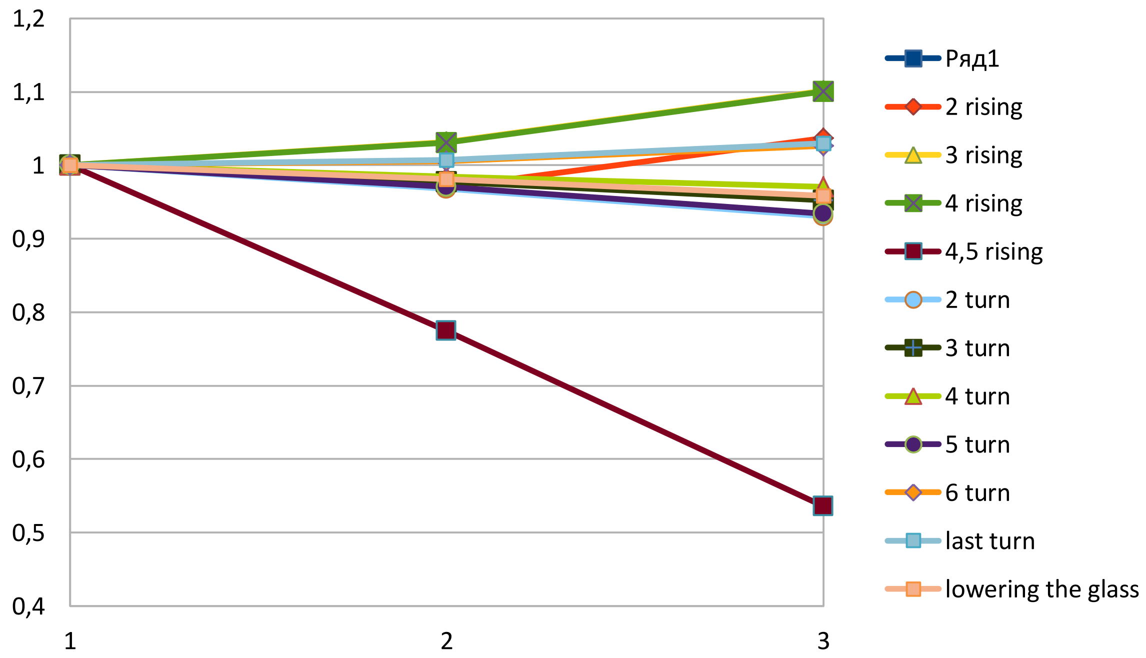

Fig. 3.9 The linear dependence of the telescope movement points coefficients from the glass size

As can be seen on the figures above (Fig. 3.9) the movement of the different glass panel is represented for each position and the linear dependence can be observed, which gives the idea that such coefficients, as well as the paths can be calculated for the different sizes of the glass using the polynomial regression method, which will allow to calculate the paths of the absolute parameters for any desired glass size within the working range of the WallMo co-bot.

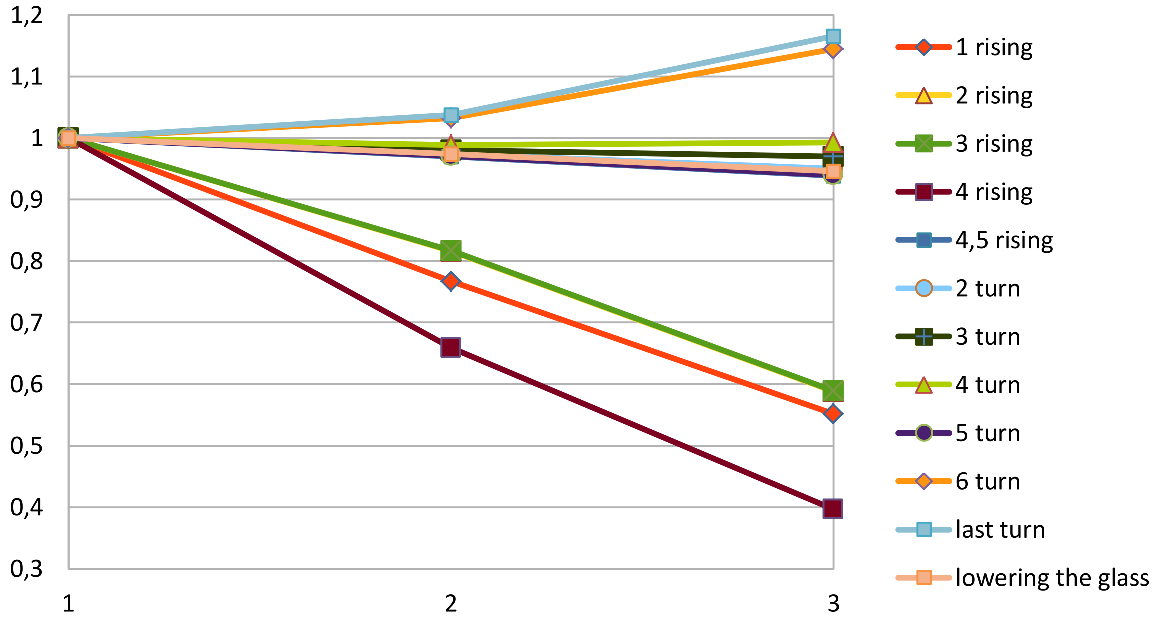

Fig. 3.10 The linear dependence of the actuator coefficients from the glass panel size according to the movement points

The linear actuator parameters show the linear dependence from the different glass sizes by putting the vertical straight lifting positions (1 rising, 2 rising, 3 rising, 4 rising) to show the lowering line that states that the smaller the glass is the less is the path made by the actuator to position the glass in frame. The last points that represent the lifting-turning movement of the glass show that the movement done is similar and the deviation is insufficient. This could be caused by the fact that the actuator in the mentioned movement positions is basically locked and the movement is performed by the stepper motor and the telescope drive, locate the glass by the vertical and about the angle to the vertical.

After determining the linear dependence of the coefficients and thus the absolute parameters it is necessary to test the theory using the known values of absolute parameter paths for the 3 default glass panel sizes: 3, 2.8 and 2.5 meters. Known values have been transformed, using the polynomial regression tools into the polynomial square formulas, each for the absolute parameter TAS and the position, total of 39 formulas. The table, containing the calculated formulas for the installation movement points is presented in the Appendix №4. Mentioned formulas would allow to the future users to easily calculate the paths needed for the drives and motors to do, so that the glass of the needed size would be positioned in accordance to the already calculated standard movement points. As we have already mentioned the movement points were characterized by the several constants such as the distance from the upper edge of the glass panel to the ceiling as well as the distance from the same edge to the inner face of the frame. The calculation of the formulas was carried, using the known 3 values of each absolute parameter path for each position, except the first, as it is the initial position and does not include the path done by the drives. Received formulas were used to calculate the paths for TAS parameters for the glass panel of unusual 2,9 m height. To check the values, as well as to determine the possible calculation mistake and the deviation from the average mistake value we have created the model of the WallMo co-bot carrying the 2,9 meter glass panel. As was mentioned the movement points are connected with the constants that remain the same for every glass panel, so recreating the already known points for the model was easier. The created model and its movement points were measured by the TAS absolute parameter values and the results were collected. The table of the results is presented below (Table 3.4), as well as the differences between the values, gained by the formulas and measured in CAD model in percent. The graphical representations of the average deviation for each of the absolute parameters are also presented below (Fig. 3.11)

Table 3.4 The absolute parameters paths for 2.9 meter glass calculated from the formula and measured from the CAD model

	Telescope		Actuator		Stepper motor	
	Formula	CAD Model	Formula	CAD Model	Formula	CAD Model
1 rising	4,15164	4,30615	0,20906	0,19574	0,11184	0,10604
2 rising	4,26184	4,31215	0,21154	0,19379	0,11337	0,10516
3 rising	4,26843	4,31807	0,20937	0,19187	0,11241	0,10429
4 rising	14,59626	13,69052	0,28205	0,29009	0,26775	0,32703
4,5 rising	3,15427	2,91405	0,64089	2,88954	0,59756	2,82164
2 turn	5,75679	5,34377	1,07565	0,98810	1,00543	0,96758
3 turn	7,41247	6,92994	1,21392	1,11635	1,14334	1,10184
4 turn	4,40243	4,14282	0,95479	0,58268	0,60293	0,58188
5 turn	14,90743	13,84497	3,21218	2,95989	2,89550	2,79220
6 turn	1,61080	1,54736	0,13405	0,12413	0,13839	0,13448
last turn	0,78575	0,75600	0,06212	0,05757	0,06490	0,06309
lowering the glass	23,72764	21,54894	4,92890	4,55742	4,36482	4,22086
insertion point	13,70306	13,52848	0,95968	0,87737	0,27449	0,42893

The Table 3.4 presents to us the different values for the paths of the main drives, or “absolute parameters”. It can be observed that the difference between the measured in SolidWorks values (that can be taken as the practical ones) and theoretical values, received strictly from the formulas, created from the already measured values is not as great as it was expected. Taking into account that the values here are measured in mm and the mistake of the regulation and positioning of the co-bot starts from 1.9 mm, the results are very promising. Of course we should not ignore the need of the practical testing, using the built WallMo co-bot, but the conclusion can be made, that the calculated formulas are clearly helpful for the theoretical calculation of the movement points for the randomly chosen glass size. Below we can observe the table of the difference (Table 3.5) between shown above values in percent, as well as the average difference, that will source the graphs of the deviation of the values.

Table 3.5 the percentile difference and average of the values received from CAD model and calculated formulas.

	Telescope	Actuator	Stepper motor
1 rising	3,588297	6,805824	5,474289
2 rising	1,166673	9,15945	7,808145
3 rising	1,149555	9,122289	7,781217
4 rising	6,615829	2,772038	18,12705
4,5 rising	8,243416	77,82033	78,82222
2 turn	7,729093	8,860776	3,911887
3 turn	6,962962	8,739651	3,766502
4 turn	6,266518	63,8625	3,617738
5 turn	7,673941	8,523557	3,699755
6 turn	4,099569	7,991021	2,911644
last turn	3,934752	7,909701	2,866217
lowering the glass	10,11047	8,15117	3,410759
insertion point	1,290431	9,380843	36,00674
	Average values		
	5,294731	17,62301	13,70801

The graphs below will show us the wider picture of how the values of absolute parameters are scattered according to the average difference value

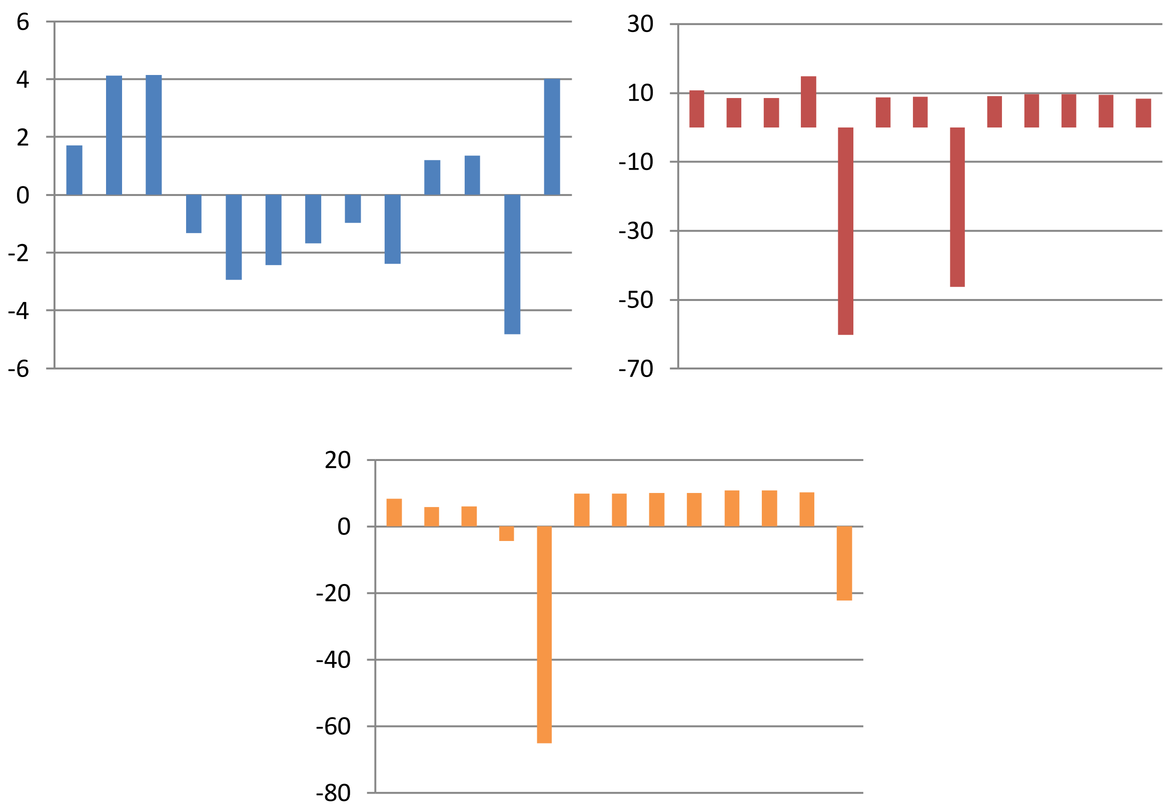

Fig. 3.11 The absolute parameter TAS differences deviation according to the average value

The graphical representation shows us that the deviation is very small, except for the several positions, where it is higher than usual, and taking into account that the calculated formulas are applied for the differences between the telescope, linear actuators and stepped motor positions, where the average deviation being a 0,0x number, and taking into account already mentioned fact, that the mistake of the controlling encoder is 1,9, allows us to say that the received values are, indeed, precise. The received formulas can be applied for any sizes of glass panels, and can ease the installation movement points' calculation without the need of additional CAD modeling or the manual set-up.

3.2 Results of the practical work and the deeper analysis of the current situation in the Company X during the implementation of the project

After the performance of the practical research the following statement can be done: the glass panel size directly influence the movement mechanics and this movement can be described by the polynomial functions, one for each position and the active drive. The carried research will help in future implementation of the project WallMo to access the faster method of calculating the movement points instead of using the 3-point interpolation method, that still would require additional measures and modeling. The safety standards were also included for the installation and transportation processes, so that during the working cycle the glass panel, the operator itself and the environment would not be damaged and no possibility of collision would exist.

For future of the project it is needed to include the suggestion of the possible installation of the distance sensors that would ensure that the distance from co-bot to frame is exactly as it mentioned above and needed for the installation cycle to begin. There are several variants of the solution; one would be the color sensors that could be programmed for the search of the color indicator on the frame or the floor, which would be recognized as the one, answering the conditions for the pre-programmed RGB color range stored in sensor. The limitation of such method is the low range of the sensor and the great possibility of the deflection, as in theory, the sensor would be installed on the edge of the co-bot and the carried glass panel, especially if its thickness will be more than 5mm (at this thickness the indoor panel glass mark would deflect the lowest), will be interfering with the values received by sensor and thus leaving a chance for a failure. The similar results would be received with using the proximity infrared sensors, which range would be deflected by the transparent materials. The working suggestion would be the microwave proximity sensor that would be the cost-high solution that could be used with transparent materials handling. Of course for the microwave sensor the material markers should be used so that the needed distance range would be targeted on the specific object.

But during the implementation of the project WallMo and the practical research described more thoroughly in the previous chapter, the performance of the project was complicated by the working performance of the Company X employees. As was mentioned before, Company X is a small enterprise with only 15 members of staff. This means that the centralized management of the company was forced to regulate the work of almost half of the staff, included in the project. This has been resulted in decentralized decisions, made as by the working engineers as by the managers, who were unable to intercommunicate with each other, that lead to the managers being unable to control the purchasing operations, done by automation engineers. The management of the Company X has noticed the occurred situation and was suggested with the following solution, that would allow employees to hold responsibility for their working performance, instead of the centralized responsibility held by the Company X director, as well as the working strategy be more flexible for each of the employee.

As it was previously described the Company X is a medium-small enterprise with a limited staff. Each of them have their own status in the company and own functions as the part of the company. Their positions were shown at the diagram above and we can see clearly the vertical hierarchical structure of the company. As it was mentioned the Company has many projects and services, as well as product lines, which it distributes as the assembly solutions, as the components for further installation. This means that for each project the particular person is held responsible which makes it difficult for the employee to perform all the tasks just by himself. This also means that if one person is assigned to the wide range of various projects that result in the additional knowledge, and the increased chance of this employee leaving the Company X due to the lack of further opportunities or personal motives. In any cases the risks are high, so the CEO of Company described the problem as the existing and asked for the theoretical and practical solution for this problem. To conclude the problem is in the scattered manner of the project, lack of the centralized structure for the product lines as well as for the similar projects and the lower responsibility for the flaws of the performed services or products.

To solve the described problem the matrix structure could be applied, replacing the old vertical one. The graphical representation of the suggested for the Company X matrix structure with included horizontal and vertical layouts of position in the enterprise is presented below (Fig.3.12 Taking into account the wide range of products and the similarity of the projects done by the Company the suggestion for the vertical and horizontal layouts would be such:

- Vertical layout consists of the similar positions, but with the assignments to the product groups. Splitting the all available products would allow constant improvements of them as well as the straight responsibility for the occasional flaws in the group members

• The horizontal layout would assign the existing and future problems between the members of the staff, as well as creating the person, acting as a manager of the following project. The amount of the managers would depend on the amount of the projects

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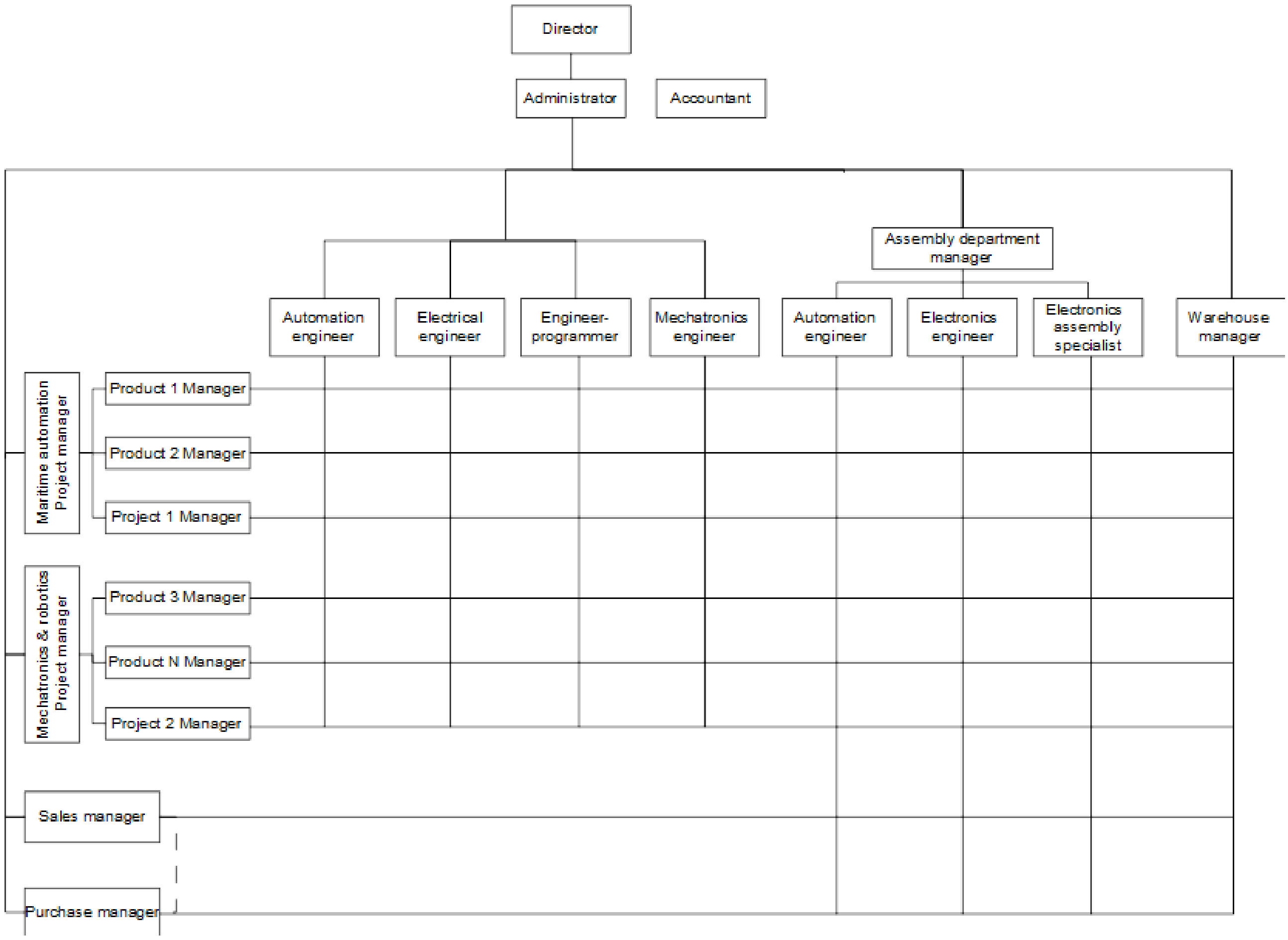

Fig. 3.12 The graphical representation of the suggested matrix structure for Company X

Possible outcomes of applying the matrix structure would be more responsible staff as well as the system that is focused not just on the projects but also on the constant improvement of the existing products, that actually describe the services and the status of the Company X. Such improvement would affect not just the personnel responsibilities and assignments. It would also be the cause of improvement on the manufacturing side, as the responsible person would be able to get assigned as a manager, so that various tasks that were not time-efficient would be eliminated by just splitting the responsibilities between the active employees. The logistics, the time-efficiency and quality of the services would also be improved by the matrix system, as the constant path for quality improvement of products, and ultimately, projects, would result in the strengthening of the position of Company X on the market.

Of course there are possible negative sides of the implementation of the matrix structure. As it comes from the name, matrix imply the complex, multiple-valued scheme of work, that should place the possibility to obtaining more high-quality results for a large number of possible projects, and products of the Company X. But “should” cannot be read as “will”, so the number of possible outcomes that would harm the state of the Company X still exists. That of course is the statement that the complexity of the matrix structure would mean the complexity of it for practical implementation, as its implementation requires a long training of workers and the corresponding organizational culture. Indeed, the long-time workers would be unsatisfied with the re-targeting of their working specifics and their routing to another field of work, if the means requires it. The splitting of the responsibility is the great achievement that would ease the high management’s work and put some more qualified decisions power in hands of the other workers. But the responsibility doesn’t always mean the positive change and can be damaging for the personal specifics and sometime lead to the person-centralized will of control from some of employees. To conclude we would say that the matrix structure is a needed, but heavy and expensive tool that with good handling, sufficient skills and knowledge would shape the company into something much bigger.

4. ANALYSIS OF THE POSSIBLE RESULTS OF THE STRUCTURAL IMPROVEMENT FOR COMPANY X

The matrix structure implementation is the hard and long process that, as was mentioned above requires not only physical resources, but also the human resources and simply the corporal spirit of the staff that would accept the changes and be willing to change. The most important aspect of such multi-stage structure implementation is the development of more unique and complex projects, that would influence the working and professional experience not only of the employees directly involved in the project work or management, but the staff that is in collaboration of the project, such as, at example, the financial management area of the company being involved more technically in the engineering product development. The assortment of technology is another milestone that needs to be crossed during the structural improvement cycle. The more technologically advanced the projects would be, the more knowledge exchange and more corporal correlations would occur, but it is needed to comment, that the work of the employees attached to the project should be conducted for a limited time. As soon as serial production of the product begins, further work on its improvement should be transferred to another group that would be allowed to brain-storm the possible problems while the project time.

The structure itself will not change the financial situation or the corporal ethics, but it will transform the internal relations, especially the management relations, as the implementation of the additional level of control for the project would transform the project performance and communication. In the matrix structure the project manager should directly interact with not one group of subordinates, but with the higher amount of them, that would be as the permanent members of the project team as the other employees of the functional departments who are subject to the project temporarily and for a limited number of issues impact the work inside of it. And of course the multiple projects implies the multiple stage management, that still is centrally controlled, which would be a hard task in the medium-small enterprise, especially if the average age of the Company X, where the system is about to be applied, is above 35 and according to the mentioned problem of the changes acceptation, the elder employees would need to be more inspired in the new style of work, than the youth

Using such complex schemes for the small enterprises, the main problem of management would be to achieve conflict-free management: to provide the necessary access to the same resources without creating mutual difficulties. The essential principle of matrix management and the most important requirement for the organization' management in this case is precisely based on the strict coordination of the interests of several bosses who claim to have access to the same resources.

In the Company X, the structure has already began to be modified and the results are below the expected, as the acceptation of the new duties and the restructuration was not fully supported and not fully understand neither by the staff, neither by the management, that hasn’t changed the whole vision of the enterprise, that should adapt to the current new state of the company. But from the project side, the implementation of the additional horizontal duty layout gave an access for the engineers of the Company X to gain deeper access to the core of the projects, to be able to regulate and make own decision on all stages of the work. The projects, such as WallMo, has received the additional staff members, that were interested in the project performance, and with their inclusion the improvement policy as well as the new knowledge and brain flows helped to gain more deeper and high-quality results as in the technical aspects of the project as in the whole implementation of it.

CONCLUSIONS

Any company has own inner strategy, vision and structure that can be applied in all daily activities of the enterprise. From human resources planning and financial operations, to the supply and demand creation, the management always tries to do its best to ensure stable growth and success to their employees and own firm. So when the problem occurs, is it some project imperfections or inner structural malfunctions, the first step to solve them is to understand them. In the thesis above one project performance gave the understanding of the existing structure's low capability, creating a possibility to improve not only project's implementation but the whole working system of the responsible enterprise.

In this Master's thesis we have taken the glazing co-bot problem of insufficient installation process performance and received the following results:

1) After understanding the project WallMo we have thoroughly analyzed its working cycle and found the possibility to improve the current situation by splitting the existing points into the smaller motions, thus receiving the possibility to modify the initial movement trajectory based on the interpolation into the trajectory equation with the possibility of receiving movement points for different glass panel sizes

2) During the review of the project implementation the structural problems of Company X were detected. After the deeper analysis the possible solution in the modifying of the existing structure into the matrix one was suggested. The implementation of the matrix structure has been already started and the first results were gathered and reviewed

After the review of the received result it is allowed to say that the goals, stated in the first chapter of this Master's thesis were achieved and results could be submitted to the initial party, who has provided the theme and the object of the thesis – Company X. The implementation of the described above suggestions on the matter of company's inner structure modification and optimization of the robot's installation process and further work is now the responsibility of the Company X and the employees involved in the glass panel mounting robot project.

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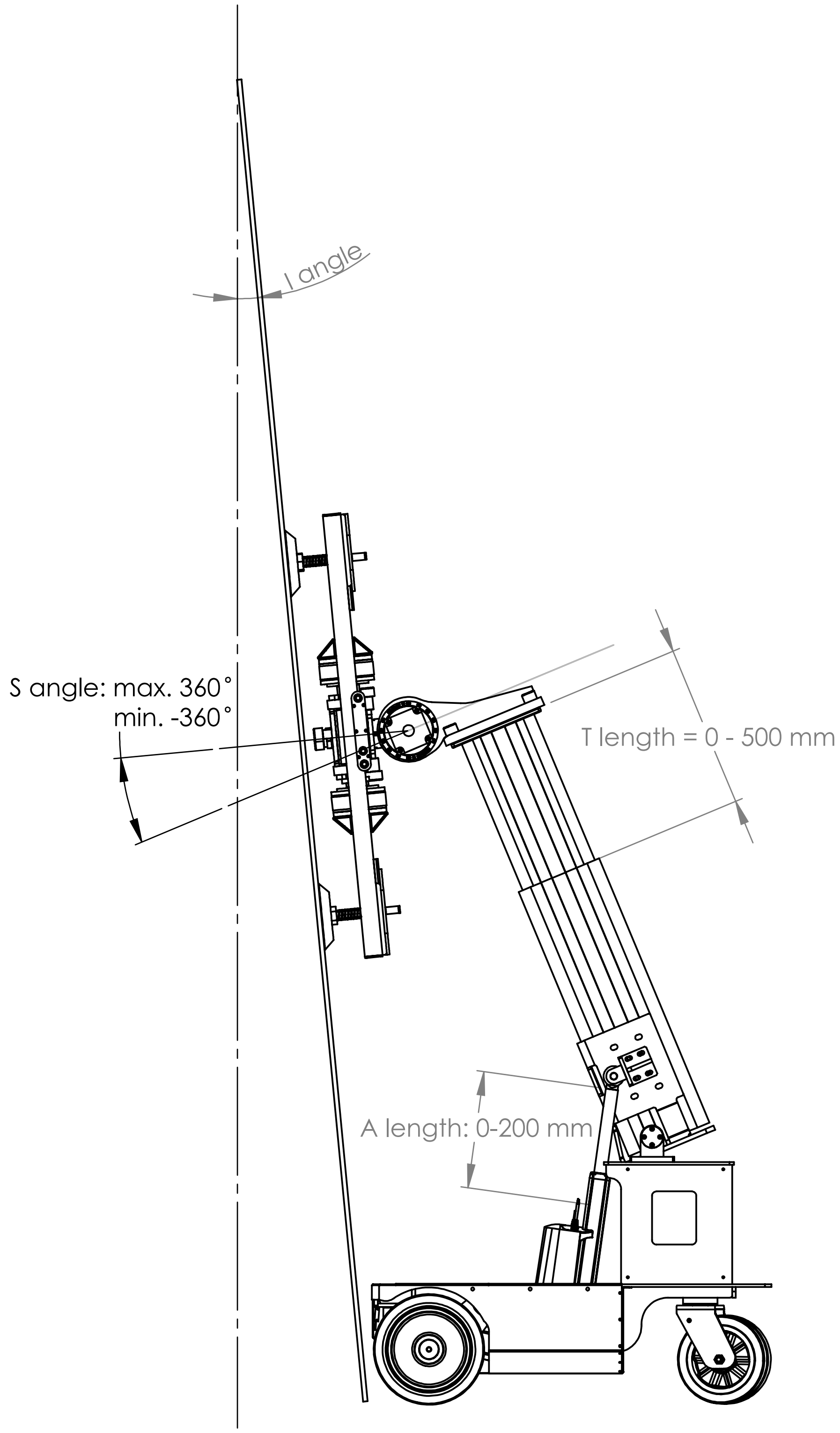
APPENDICES



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE	
DRAWN	German Nushtaev		2017.05.25	
CHK'D				
APPV'D				
MFG				
Q.A				MATERIAL:
				WEIGHT:

TITLE:

WallMo co-bot

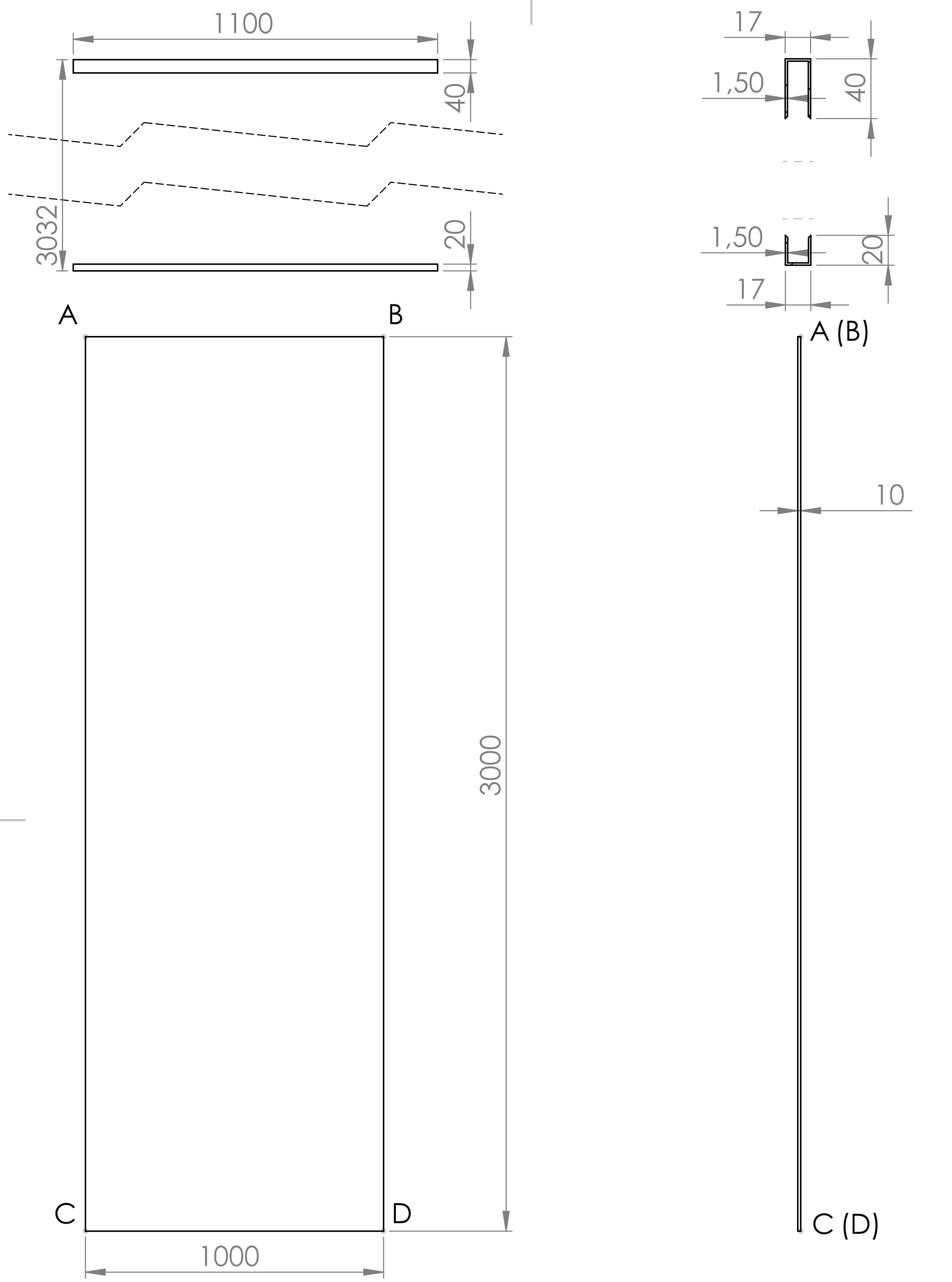
DWG NO.

Appendix №1

A4

SCALE:1:50

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	

	NAME	SIGNATURE	DATE
DRAWN	German NUshtaev		2017.05.20
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Glass panel and frame

MATERIAL:

DWG NO. Appendix №2

A4

WEIGHT:

SCALE:1:20

SHEET 1 OF 1

Appendix 3.1. Absolute parameters of Telescope, Actuator and Stepper Motor for installation cycle positions, measured for glass panel size of 3 meters

Position № and name	T length, m	A length, mm	S angle, outer	S angle inner, deg	T distance,mm	A distance, mm	S angle difference, deg
1 turn	373,12511966	190,17190598	162,67244454	17,32755546			
1 rising	377,18278508	190,35389451	162,77142834	17,22857166	4,05766542	0,18198853	0,09898380
2 rising	381,50520300	190,54562165	162,87588158	17,12411842	4,32241792	0,19172714	0,10445324
3 rising	385,83348150	190,73543841	162,97946953	17,02053047	4,32827850	0,18981676	0,10358795
4 rising	398,76443631	188,46712904	160,77406115	19,22593885	12,93095481	2,26830937	2,20540838
4,5 rising	401,85580670	187,83648524	160,17497138	19,82502862	3,09137039	0,63064380	0,59908977
2 turn	407,51735067	186,77602487	159,16604651	20,83395349	5,66154397	1,06046037	1,00892487
3 turn	414,84062623	185,57539732	158,01705007	21,98294993	7,32327556	1,20062755	1,14899644
4 turn	419,20618296	184,94723006	157,41013486	22,58986514	4,36555673	0,62816726	0,60691521
5 turn	434,13933403	181,78376207	154,50840091	25,49159909	14,93315107	3,16346799	2,90173395
6 turn	435,75335920	181,64802335	154,36788430	25,63211570	1,61402517	0,13573872	0,14051661
last turn	436,54112745	181,58495501	154,30193280	25,69806720	0,78776825	0,06306834	0,06595150
lowering the glass	460,03666993	176,72312505	149,92683741	30,07316259	23,49554248	4,86182996	4,37509539
insertion point	446,50818568	175,84575021	149,49790566	30,50209434	13,52848425	0,87737484	0,42893175

Appendix 3.2. Absolute parameters of Telescope, Actuator and Stepper Motor for installation cycle positions, measured for glass panel size of 2.8 meters

Position № and name	T length, m	A length, mm	S angle, outer	S angle inner, deg	T distance,mm	A distance, mm	S angle difference, deg
1 turn	289,89870267	185,92687423	160,82398007	19,17601993			
1 rising	294,08281284	186,16432544	160,94862094	19,05137906	4,18411017	0,23745121	0,12464087
2 rising	298,27448984	186,39924095	161,07216586	18,92783414	4,19167700	0,23491551	0,12354492
3 rising	302,47363801	186,63165616	161,19462753	18,80537247	4,19914817	0,23241521	0,12246167
4 rising	319,16910456	183,18930726	158,00774506	21,99225494	16,69546655	3,44234890	3,18688247
4,5 rising	322,38353086	182,53917774	157,41255638	22,58744362	3,21442630	0,65012952	0,59518868
2 turn	328,23000294	181,45037700	156,41207972	23,58792028	5,84647208	1,08880074	1,00047666
3 turn	335,72344370	180,22610622	155,27633286	24,72366714	7,49344076	1,22427078	1,13574686
4 turn	340,15732415	179,590348	154,67848474	25,32151526	4,43388045	0,63575824	0,59784812
5 turn	355,54222233	176,33349566	151,79264471	28,20735529	15,38489818	3,25685232	2,88584003
6 turn	357,14720129	176,20197534	151,65675609	28,34324391	1,60497896	0,13152032	0,13588862
last turn	357,92963796	176,14118226	151,59310448	28,40689552	0,78243667	0,06079308	0,06365161
lowering the glass	381,87545315	171,15113523	147,24325008	32,75674992	23,94581519	4,99004703	4,34985440
insertion point	368,95282123	170,09770345	146,74618831	33,25381169	12,92263192	1,05343178	0,49706177

Appendix 3.3. Absolute parameters of Telescope, Actuator and Stepper Motor for installation cycle positions, measured for glass panel size of 2.5 meters

Position № and name	T length, m	A length, mm	S angle, outer	S angle inner, deg	T distance,mm	A distance, mm	S angle difference, deg
1 turn	171,85163597	177,65326301	157,37047643	22,62952357			
1 rising	175,76420139	177,98348171	157,53358136	22,46641864	3,912565	0,330219	0,16310493
2 rising	179,68788534	178,30983574	157,69513888	22,30486112	3,923684	0,326354	0,16155752
3 rising	183,62253836	178,63238141	157,85516724	22,14483276	3,934653	0,322546	0,16002836
4 rising	207,74512311	172,90663150	152,91683416	27,08316584	24,12258	5,72575	4,93833308
4,5 rising	211,12358535	172,23483652	152,33382578	27,66617422	3,378462	0,671795	0,58300838
2 turn	217,20566982	171,11876037	151,35734906	28,64265094	6,082084	1,116076	0,97647672
3 turn	224,89273547	169,88113444	150,25570148	29,74429852	7,687066	1,237626	1,10164758
4 turn	229,38844597	169,24835186	149,67974300	30,32025700	4,495711	0,632783	0,57595848
5 turn	245,37595959	165,88171964	146,84348737	33,15651263	15,98751	3,366632	2,83625563
6 turn	246,94790943	165,76310705	146,71743206	33,28256794	1,57195	0,118613	0,12605531
last turn	247,71269803	165,70897837	146,65863906	33,34136094	0,764789	0,054129	0,058793
lowering the glass	272,22947936	160,57097519	142,38185358	37,61814642	24,51678	5,138003	4,27678548
insertion point	267,37822516	159,16753654	145,80875108	34,19124892	4,851254	1,403439	3,4268975

Appendix 4. Table of formulas for the absolute parameters of Telescope, Actuator and Stepper motor calculation, made for each position of the installation cycle

	Telescope	**Actuator**	**Stepper motor**
1 rising	$y = -3{,}074745833 \cdot x^2 + 17{,}20130208 \cdot x - 19{,}87352833$	$y = 0{,}06382313334 \cdot x^2 - 0{,}6474875734 \cdot x + 1{,}55004305$	$y = -0{,}0001436333321 \cdot x^2 - 0{,}1274522767 \cdot x + 0{,}48263333$
2 rising	$y = -0{,}4792111334 \cdot x^2 + 3{,}433129173 \cdot x - 1{,}6640694$	$y = 0{,}1777064333 \cdot x^2 - 1{,}246639163 \cdot x + 2{,}33228673$	$y = 0{,}06250053334 \cdot x^2 - 0{,}4579614934 \cdot x + 0{,}91583292$
3 rising	$y = -0{,}4719977 \cdot x^2 + 3{,}38323831 \cdot x - 1{,}57345713$	$y = 0{,}1748852333 \cdot x^2 - 1{,}227326603 \cdot x + 2{,}29782947$	$y = 0{,}0617074 \cdot x^2 - 0{,}45227152 \cdot x + 0{,}90503591$
4 rising	$y = 11{,}86900393 \cdot x^2 - 87{,}66278152 \cdot x + 169{,}098264$	$y = 3{,}4822781 \cdot x^2 - 26{,}06741063 \cdot x + 49{,}13003836$	$y = 1{,}8615965 \cdot x^2 - 15{,}70463015 \cdot x + 32{,}56493033$
4,5 rising	$y = -0{,}1369861667 \cdot x^2 + 0{,}1792402167 \cdot x + 3{,}78652524$	$y = -0{,}0504208 \cdot x^2 + 0{,}19501204 \cdot x + 0{,}49939488$	$y = -0{,}0421911 \cdot x^2 + 0{,}26421383 \cdot x + 0{,}18616818$
2 turn	$y = -0{,}2785318334 \cdot x^2 + 0{,}6908440833 \cdot x + 6{,}09579822$	$y = -0{,}1015676333 \cdot x^2 + 0{,}4473904234 \cdot x + 0{,}6323978$	$y = -0{,}07551750001 \cdot x^2 + 0{,}48024255 \cdot x + 0{,}24785472$
3 turn	$y = -0{,}4108194 \cdot x^2 + 1{,}53192652 \cdot x + 6{,}4248706$	$y = -0{,}1473979667 \cdot x^2 + 0{,}7366920567 \cdot x + 0{,}31713308$	$y = -0{,}09483273334 \cdot x^2 + 0{,}6162777534 \cdot x + 0{,}15365778$
4 turn	$y = -0{,}2710368667 \cdot x^2 + 1{,}230395227 \cdot x + 3{,}11370285$	$y = -0{,}0574753334 \cdot x^2 + 0{,}5173807934 \cdot x - 0{,}06224732003$	$y = -0{,}05526003334 \cdot x^2 + 0{,}3658436434 \cdot x + 0{,}006724579958$
5 turn	$y = 5{,}914934834 \cdot x^2 - 34{,}64086668 \cdot x + 65{,}62133762$	$y = -0{,}2019773 \cdot x^2 + 0{,}7045466899 \cdot x + 2{,}86762362$	$y = -0{,}1716234667 \cdot x^2 + 1{,}074885707 \cdot x + 1{,}22168803$
6 turn	$y = -0{,}1297320333 \cdot x^2 + 0{,}7976768433 \cdot x + 0{,}38858294$	$y = -0{,}04386753334 \cdot x^2 + 0{,}2755236933 \cdot x - 0{,}29602456$	$y = -0{,}0192755 \cdot x^2 + 0{,}13493785 \cdot x - 0{,}09081744001$
last turn	$y = -0{,}064338 \cdot x^2 + 0{,}3998183 \cdot x + 0{,}16735535$	$y = -0{,}02167673333 \cdot x^2 + 0{,}1371013533 \cdot x - 0{,}15314512$	$y = -0{,}009391833334 \cdot x^2 + 0{,}06597208334 \cdot x - 0{,}04743825001$
lowering the glass	$y = -0{,}6962861667 \cdot x^2 + 1{,}787096217 \cdot x + 24{,}40082933$	$y = -0{,}2957963667 \cdot x^2 + 1{,}074533577 \cdot x + 4{,}30039653$	$y = -0{,}2347162333 \cdot x^2 + 1{,}487559103 \cdot x + 2{,}02486418$
insertion point	$y = -47{,}7506615 \cdot x^2 + 279{,}9830984 \cdot x - 396{,}6648573$	$y = 0{,}5728097334 \cdot x^2 - 4{,}202581154 \cdot x + 8{,}3298307$	$y = 18{,}850938 \cdot x^2 - 109{,}6760905 \cdot x + 159{,}7987613$