Projektiranje i upravljanje paralelnog SCARA robota

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BJELOVAR UNIVERSITY OF APPLIED SCIENCES
PROFESSIONAL PROGRAMME OF STUDY IN MECHATRONICS

DESIGN AND CONTROL OF A PARALLEL SCARA ROBOT

FINAL THESIS no.: 06/MEH/2015

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VELEUČILIŠTE U BJELOVARU
PREDDIPLOMSKI STRUČNI STUDIJ MEHATRONIKA

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2. ZADATAK ZAVRŠNOG RADA BROJ: 06/MEH/2015

U radu je potrebno opisati projektiranje i upravljanje paralelnog SCARA robota. U uvodnom djelu završnog rada opisati SCARA robot. Opisati i izraditi peteropolužni paralelni SCARA robot. Robot je potrebno upravljati pomoću aplikacije serijskom komunikacijom. Za upravljanje paralelnim SCARA robotom potrebno je koristiti Atmelov mikrokontroler. Opisati dijelove koji se koriste pri izradi paralelnog SCARA robota.

Zadatak uručen: 23.04.2015. Mentor: **Zoran Vrhovski, mag.ing.el.techn.inf.**

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Introduction

The subject of this final thesis is to describe the design and control of a parallel SCARA robot. This thesis will be presenting a five-bar parallel robot. Many would also refer to this type of parallel SCARA as dual arm.

This project had the best fusion of everything taught at the Bjelovar University of Applied Sciences. Information and skills were used from practically every course.

The first part of this paper provides an insight on what a parallel SCARA robot is and where these robots are mainly used. After some general info this thesis will proceed to show and describe the five-bar parallel robot while elaborating on the thought process that led to how it was designed. Thirdly, the hardware used to control the robot will be shown and described. Last and most important is the mathematics/kinematics and programming used to put the robot in action.

1. SCARA robots

1.1. What is a SCARA robot?

There are six different types of industrial robots: Cartesian, SCARA, cylindrical, delta, polar and vertically articulated. It's not fair to say one is better than the other, instead what must be looked at is the type of job that has to be done. There are about six main factors to look at when choosing the right robot for the job you need done. These factors include, but may not be limited to: load, orientation, speed/ travel, precision, environment and duty cycle [1].

1. **Load.** The payload the robot is supposed to carry should be less than the load capacity which is defined by the manufacturer. In terms of carrying weight, six-axis robots and SCARA robots have to carry the weight on extended arms. This means they don't have high load capacities. A lot of weight puts extra strain on joints and bearings.

2. **Orientation.** Another factor is the working space of the robot and the orientation of the part/ load and how it has to be placed or moved around. Cartesian robots can be mounted over the work area and move parts freely around without getting in the way. Six-axis robots have the advantage of being able to rotate the parts and move them in unique directions, so they have good flexibility.

3. **Speed and travel.** Distances traveled and speed of the movement are important also for jobs. How fast a robot can do a certain job in a certain distance. Cartesian robots can be measured in meters while six-axis robots and SCARA robots can reach only about 0.5m to satisfy certain efficiency.

4. **Precision.** Depending on the job repeatability can be extremely important. Six-axis and SCARA robots are exceptional when repeatability is crucial and accuracy is needed down to 0.1mm. For less accurate work these robots can be too complex and high cost which is where gantry and Cartesian robots would take over.

5. **Environment.** Another thing to look at is the environment in which the robot will be placed in, surroundings and hazards should be looked at when making the selection. Workspaces with limited space are perfect for six-axis and SCARA robots. Likewise these robots are great in situations where complex motion sequences are required to complete a task.

   However, areas with a lot of dust and debris can be bad for joints, bearings and complex joints.

6. **Duty cycle.** This is the amount of time for the robot to complete one cycle of operation needed. After looking at the duty cycle you must consider how long will your robot be working. Does it need to run 24/7 or will it work 8 hours a day. Robots working non-stop will break down quicker and be higher maintenance. Here you also want to find robots with better lubrication designs, less complex designs and lower maintenance costs.

So now that we established a few of the rules for choosing the robot needed for the task you want to accomplish, here's a short explanation of what a SCARA robot actually is. "The **SCARA** acronym stands for **Selective Compliance Assembly Robot Arm** or **Selective Compliance Articulated Robot Arm**." [2] SCARA robots are almost human like in nature in terms of build. Multiple arms with link together similar to a human arm. This is helpful in confined areas where the arm can then retract/ fold up and be out of the way and take up less space. The SCARA robot usually works in a parallel field and moves in the X and Y direction and will have an end effector that works in the Z plane. SCARA robots don’t take up a lot of room and can be very fast when compared with a Cartesian robot for example. However, a SCARA will typically be more expensive and a bit harder to program; they are programmed using inverse kinematics. Another way to spot a SCARA is that the first motor usually carries all of the other motors. The robot in this thesis, however, is called a double arm SCARA. It has two motors connected at the base and the end links are connected together via a ball-bearing. SCARA robots are extremely efficient in tasks that require speed and repeatability with point to point movements. All of its motions are circular and they are compliant in one selected plane.

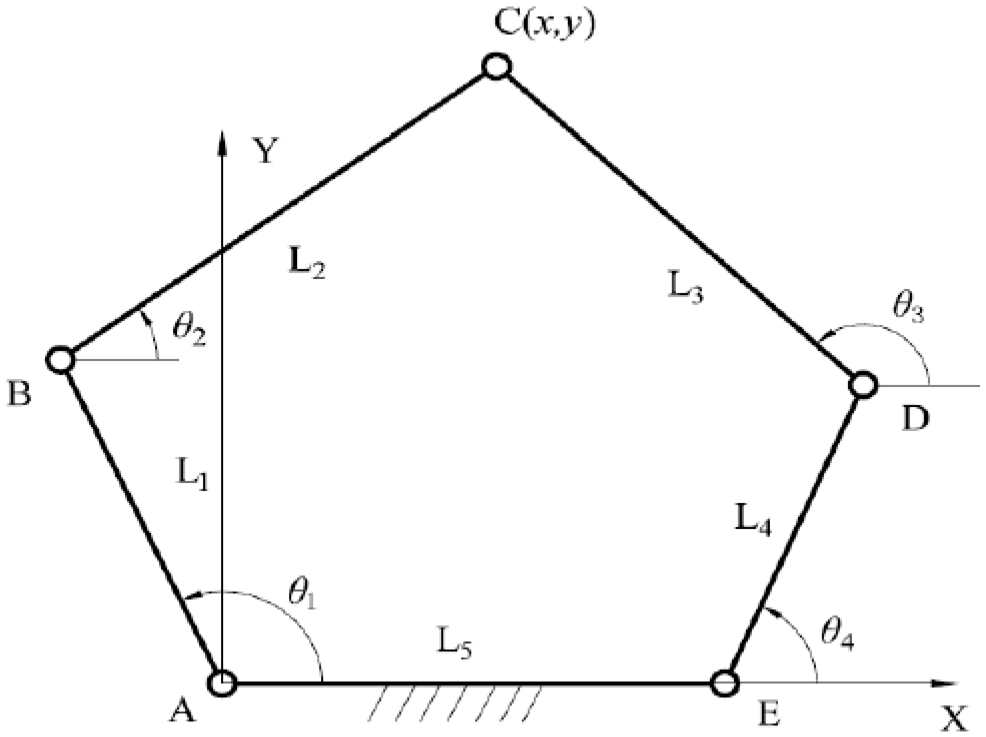

Figure 1.1. Simple drawing of a five bar mechanism (double arm SCARA) [3]

1.2. Double Arm SCARA

Briefly mentioned above was the double arm SCARA robot, this was the robot created for this final thesis. The parallel double arm SCARA has two motors connected at the base with a link/ arm connected to either motor, each of these links have another link attached which can be considered secondary arms. These secondary arms are connected to one another at the tip with a ball-bearing to allow for rotation. This type of SCARA allows for great precision and speed since there are two different motors controlling each link. Since there are two different motors, one can move each link simultaneously and at varying speeds which further allows for different combinations of speeds and accuracies.

Having the arms joined at the end in this fashion allows for a work area in the shape of an egg or more closely to the shape of a football.

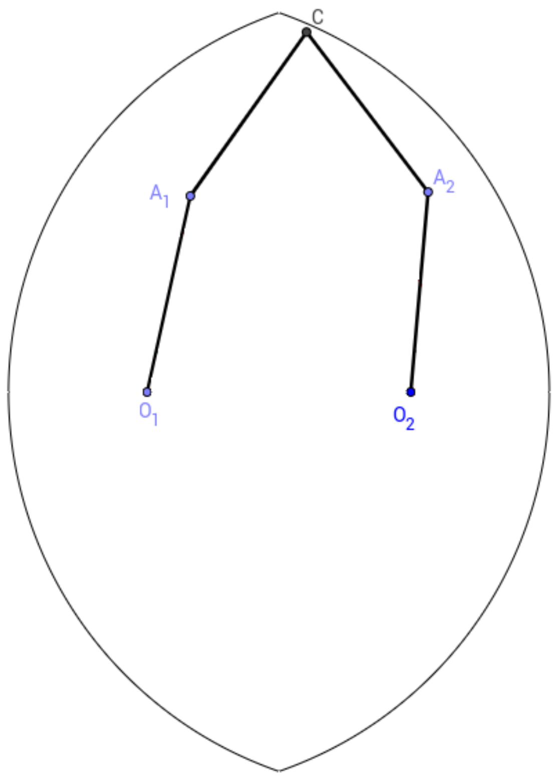

Figure 1.2. Work area of a dual arm SCARA [4]

2. Building the Five-Bar Parallel SCARA Robot

The SCARA robot made in this thesis was of original design and all the dimensions were based off of original calculations. The robot is comprised of three main components; a base box, a base construction and the arms/ links. The base box holds the main portions of electrical components while the base construction houses the two main stepper motors. The arms connect to the stepper motors housed in the construction and they hang above the base box. This is just a brief outline of the construction, as each portion of the SCARA is described the other components will be mentioned and described.

2.1. Base Box

This part of the robot was just as important as any other part even though technically one can say it's just a regular wooden box. However, this box contained all of the electrical components and hid them from plane sight. At the same time the top of the box had to be cut and holed out precisely to where the base construction would rest. This had to be done precisely so that the arms would align perfectly over the plexiglas that also rested on top of the box. The plexiglas was where all the work was being done and since the SCARA robot is a pick and place machine the plexiglas had to be aligned perfectly so that the end effector would come to the right position when programmed. At first a "professional" woodworker made the box to the specifications drawn in SolidWorks because it was assumed that they would make it perfectly. Instead it took almost a month to make it and the dimensions were completely off. Furthermore, low quality wood that was very heavy was used. Instead of this, the author decided to use a nice clean plywood at a thickness of 15mm. Plywood is very durable and lightweight, another huge plus is that plywood does not warp due to temperature changes.

One thing to note while reading is that not every dimension will be mentioned, instead at the end of this thesis attached will be all of the SolidWorks drawings to scale with accurate dimensions.

All of the wood was precut at the store to the proper dimensions. The store has a proper wood cutting machine that cut my pieces to the exact dimensions needed. When all of the pieces were precut, all that was left to do was assemble the box. The frame was step one.

No screws were used on the frame because a nice clean finish was sought after, and the screws would ruin the look and make it look sloppy. So instead for connecting joints, wooden dowel pins and wood glue were used.

Figure 2.1. Wooden dowel pins alongside wood glue for assembly

Another great tool that can be seen in the picture is a 90° vice grip. This was a major help when drilling the corner of the box. It would lock in one corner of the box at 90° and drill 5 holes along the side and through to the other side. The side of the drill was the same size as the wooden dowel pins, you can even use a slightly smaller drill. This will give a snug tight fit when putting it together.

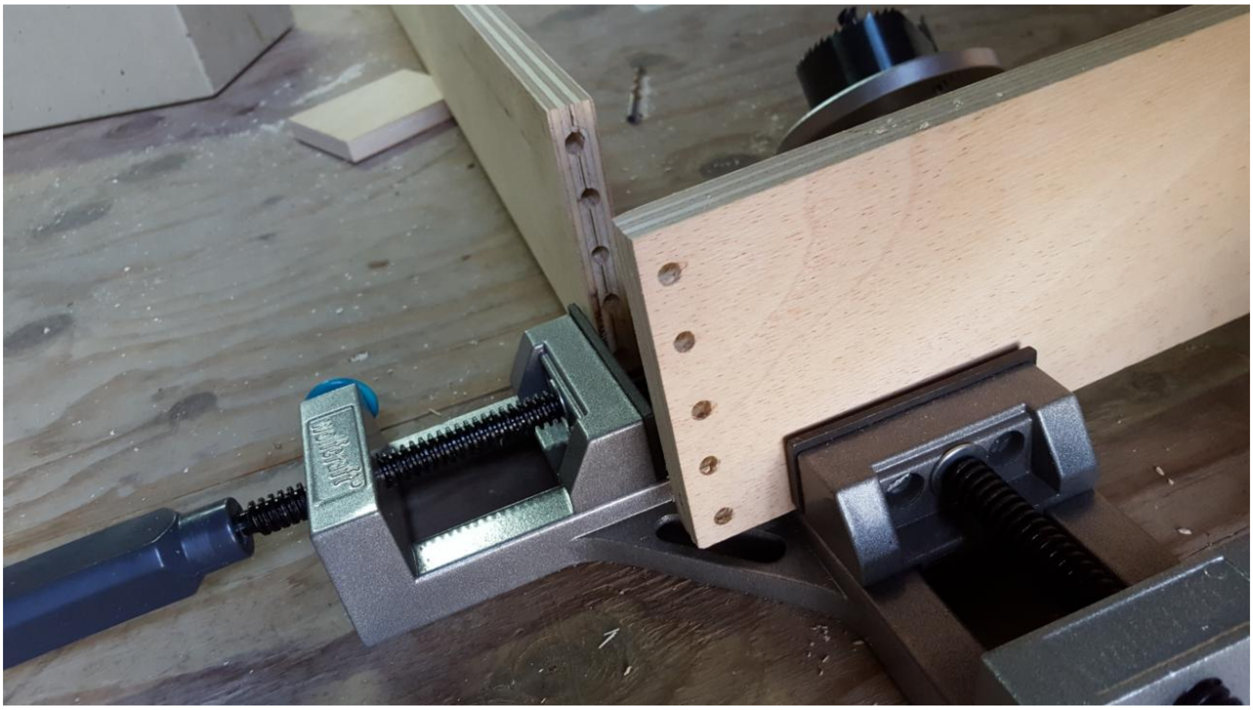

Figure 2.2. The vice grip holding two side of the frame with drilled out holes

After drilling the holes, the wooden dowel pins had to be banged in to one side with glue. Also an important and helpful tip is to mark which sides were in the vice grip together. This is important because not every piece will be drilled identically.

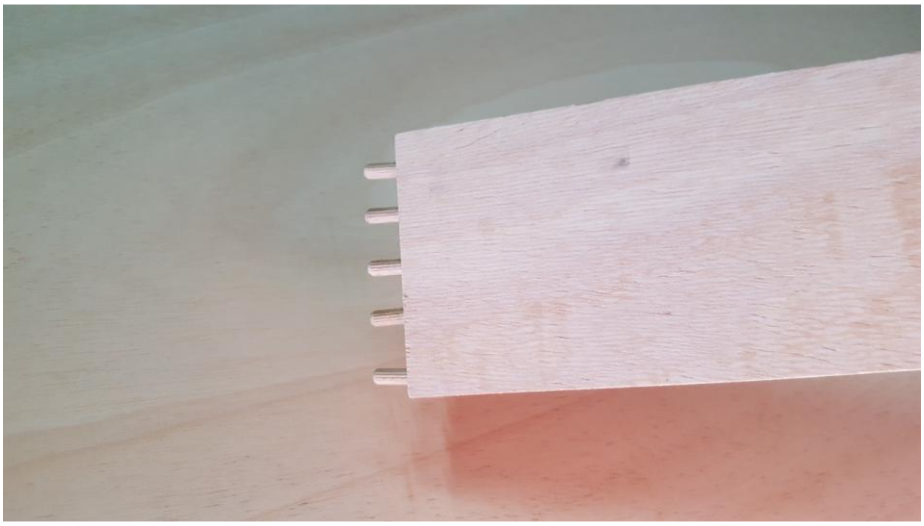

Figure 2.3. Wooden dowel pins banged in to one side with glue

Now that one side was set the next step was to move on to adding the other side.

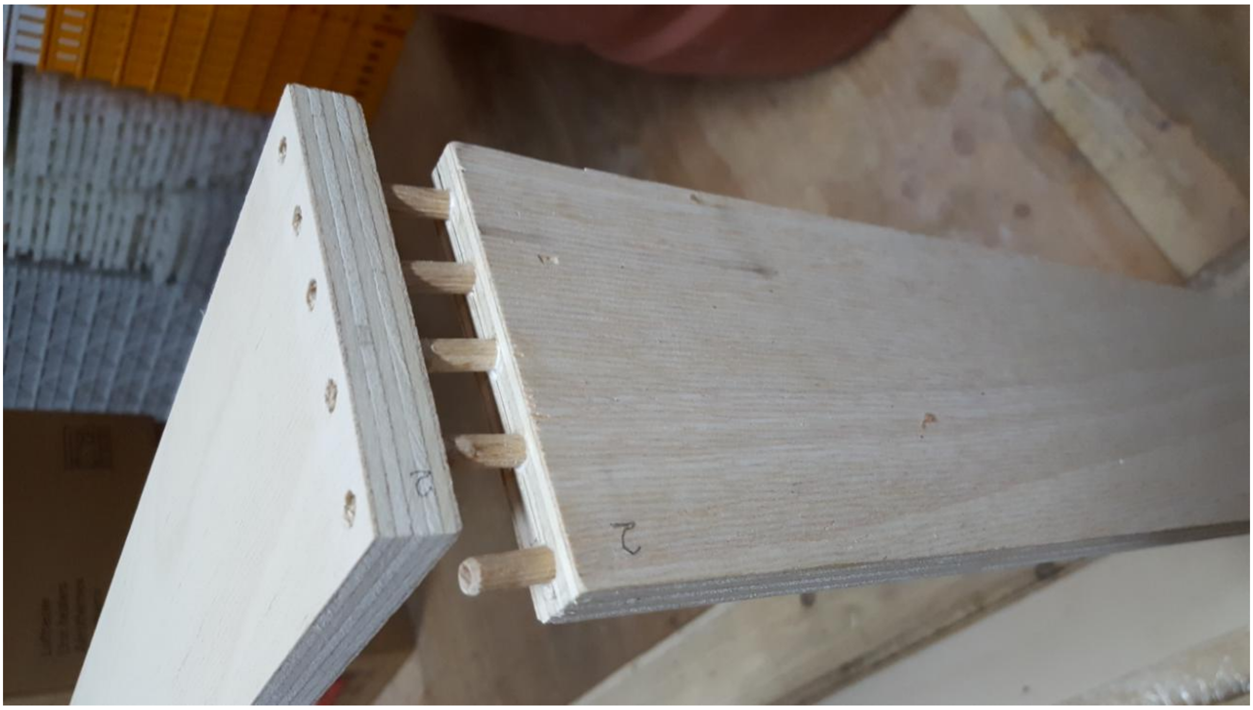

Figure 2.4. Adding the other side of the frame to get one corner piece

As it can be seen, this was corner number 2, this was what was mentioned above to mark the side piece that were in the vice grip together. It was easy to match which corners were together and they fit perfectly. These steps were repeated four more times to get a frame.

After getting a frame the next step was to find a way to place and hold the bottom of the box and so that the top cover of the box can rest on something and support the weight of the construction base. The best and easiest way was simply to use eight blocks that would be equally distributed along the inside of the frame. These blocks were set in to the frame also using wooden dowel pins.

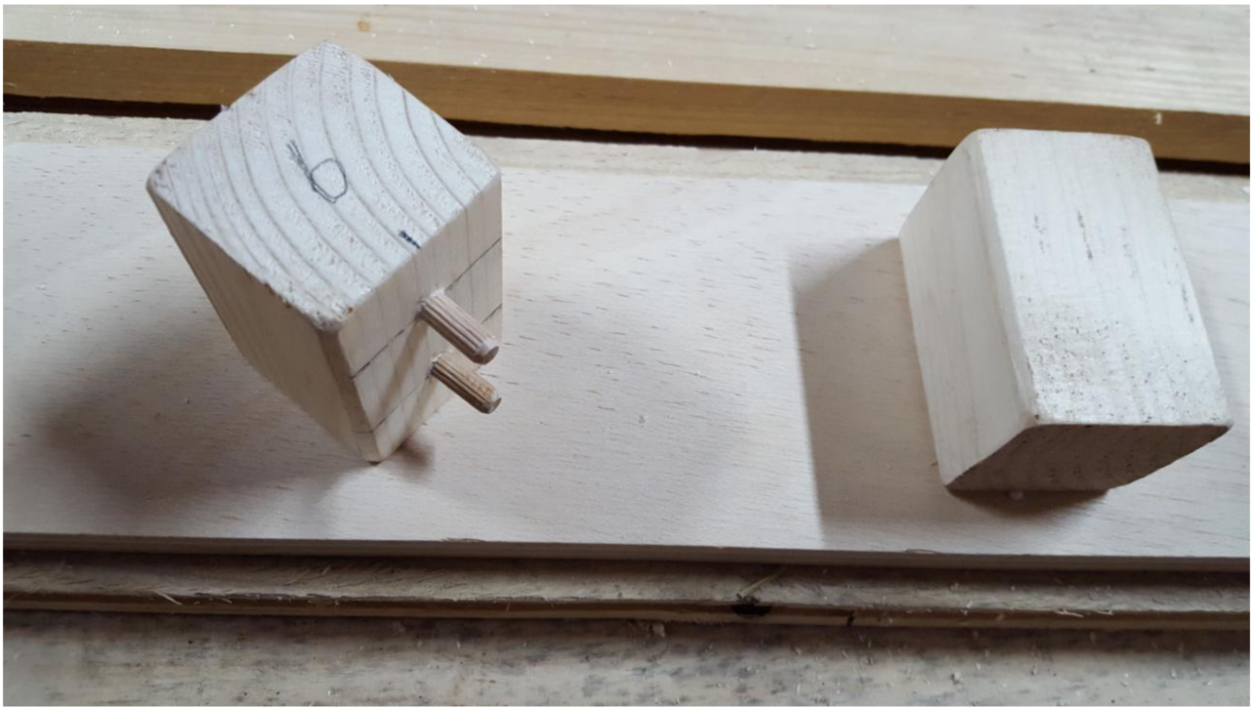

Figure 2.5. Wooden blocks used for supporting top and bottom of the box

Figure 2.6. Wooden support blocks distributed along the inside frame

The only time screws were used were to attach the bottom of the box to the supporting blocks, however it was screwed in from the bottom so the screws are not visible.

The next and most important step of this box was the cover. Obviously the cover is the same dimensions as the bottom of the box however holes needed to be drilled precisely so that the construction base can be mounted. These holes needed to be perfectly measured and drilled so that the actual robot was center over the plexiglas work area. The holes were there so holders for the construction base could be mounted, this holder holds the construction base in place and allows for the wiring of the stepper motors. This route was picked so that no wires were exposed while maintaining a clean look.

The way these holes were as accurate as possible was to first draw center lines on the box cover. When the center lines were drawn, perpendicular lines then had to be drawn across so you can have a center point for each hole. Next in a program called Google Sketchup the layout for the holes of the bracket were made and printed out at a 1:1 ratio. These drawings were lined up with the lines that were drawn on the board and each center point for the holes was marked.

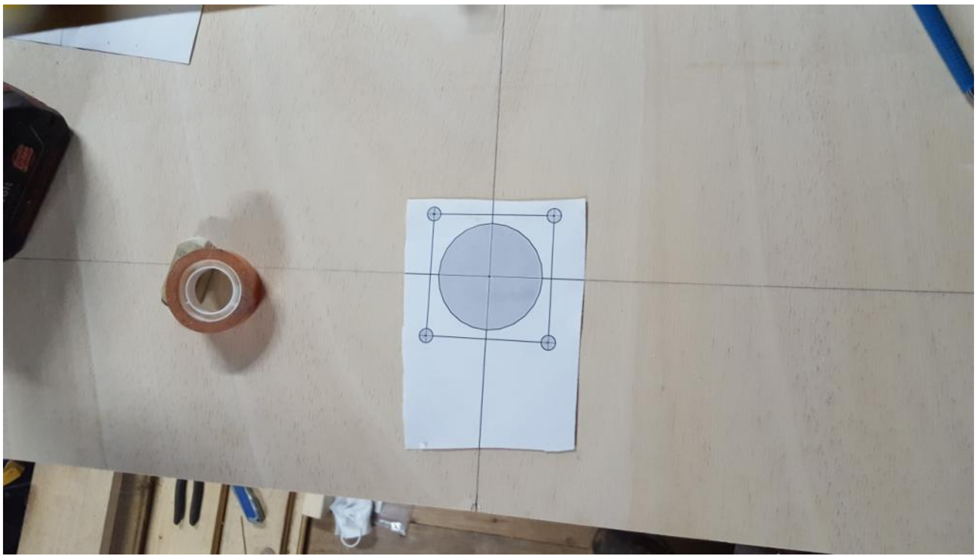

Figure 2.7. Template for the holes of the bracket that holds the construction base

Figure 2.8. Holes drilled out

Using a drill bit and a hole saw the holes needed on each side of the cover were cut and drilled out. After the holes were sanded off and cleaned up the brackets could be mounted and tested onto the construction to see if it lines up like it's supposed to.

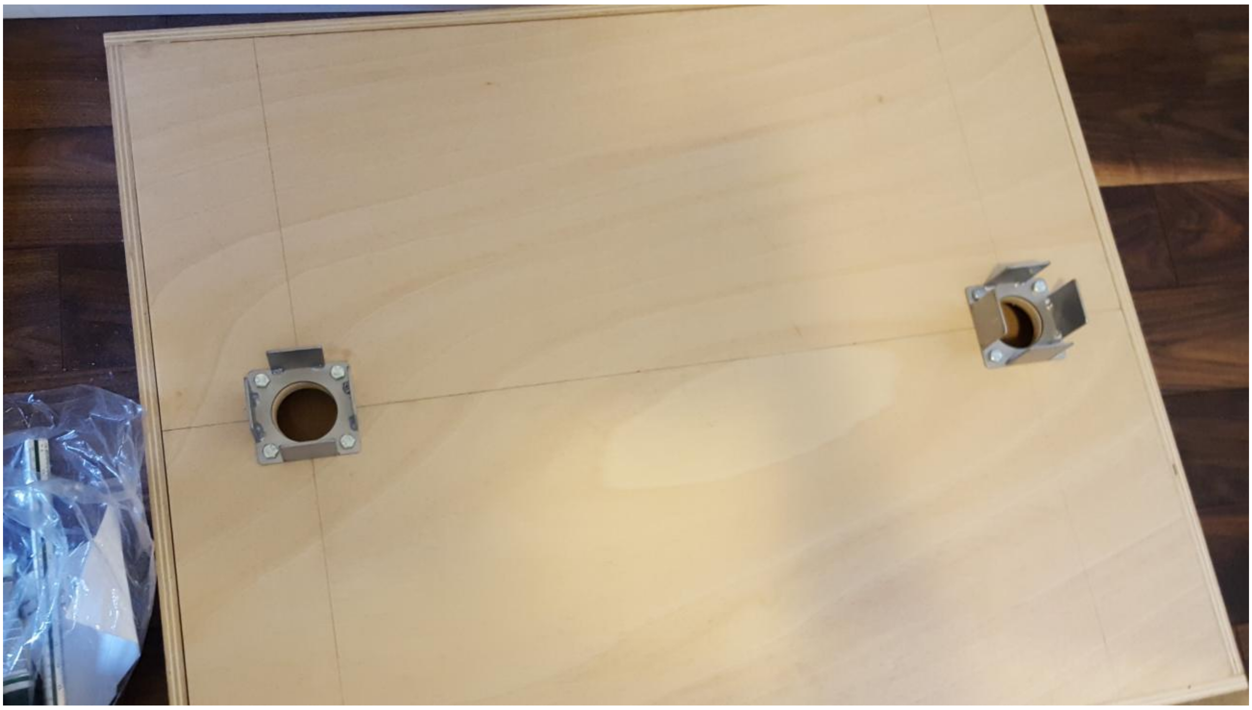

Figure 2.9. Brackets mounted and lined up correctly

It was unfortunate that the woodworker who was hired wasn't capable of making the box according to the dimensions needed.

2.2. Base Construction

A professional welder had the appropriate tools needed to craft the base construction. He welded together a steel frame out of 10x10cm tubing which was 3mm thick. Afterwards he drilled the holes needed for mounting the step motors on the top inside. He grinded away any rough edges and gave it a nice blue powder coating. Out of sheet metal he bended a cover that would enclose the step motors so they would be hidden from plain sight.

Figure 2.10. Inside of the base construction showing holes for stepper motors

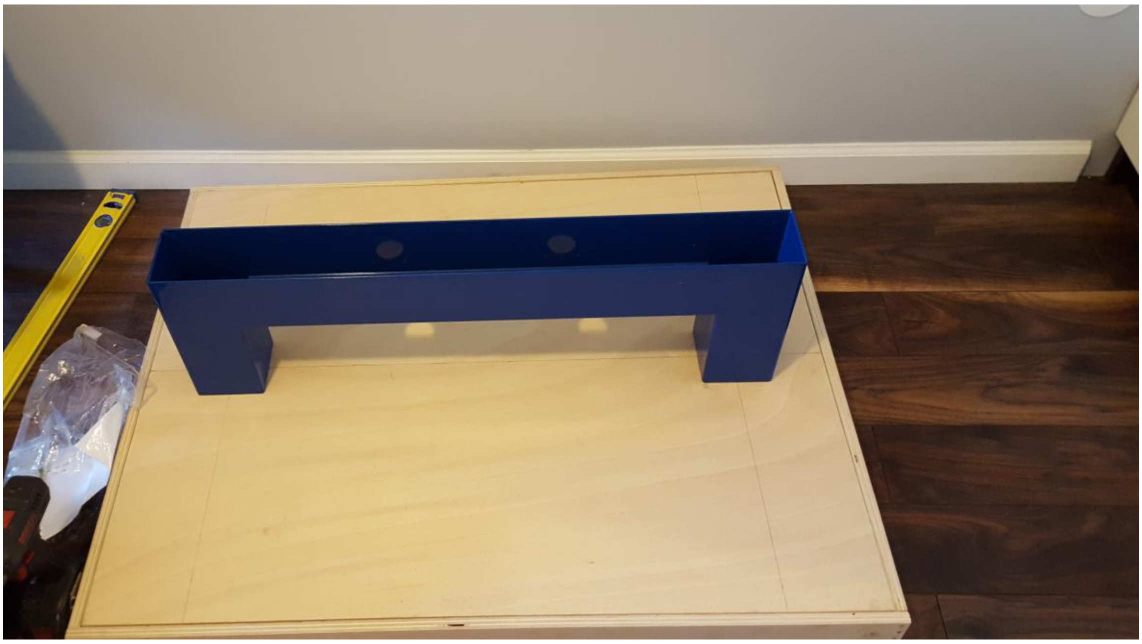

Figure 2.11. Base construction mounted on top of the base box

2.3. Robot Arms

The robot arms are a complicate part of the whole process and full of intricate details. Everything was drawn in SolidWorks and actually the arms were the first thing designed in this whole project and everything was original design and dimensions. It took about a month or two before the final version of arms were designed and there were about 5 different versions.

Before drawing a single line of the arms there were a few things to keep in mind that were going to help. All the links had to be the same size. The next factor to keep in mind is that any joints will need to have a ball bearing, so where ever the arms were joined with another link a ball bearing had to be present so there can be ease of rotation. The next and most complicated factor was to have an end effector. At the tip of the arms some sort of system was to be set in place where metal balls can be lifted and dropped within the work area of the robot. The idea was to fit a small actuator at the end of the arms and have a solenoid that would turn on and off via a microcontroller to pick and place metal balls.

However, the factors that were important for designing the arms also meant that the bearings, actuator and solenoid had to be chosen before drawing so that the robot can have normal proportions.

Figure 2.12. Bearing type 1 for end of arm connection

Figure 2.13. Type 2 bearing for connecting secondary arms to primary arms

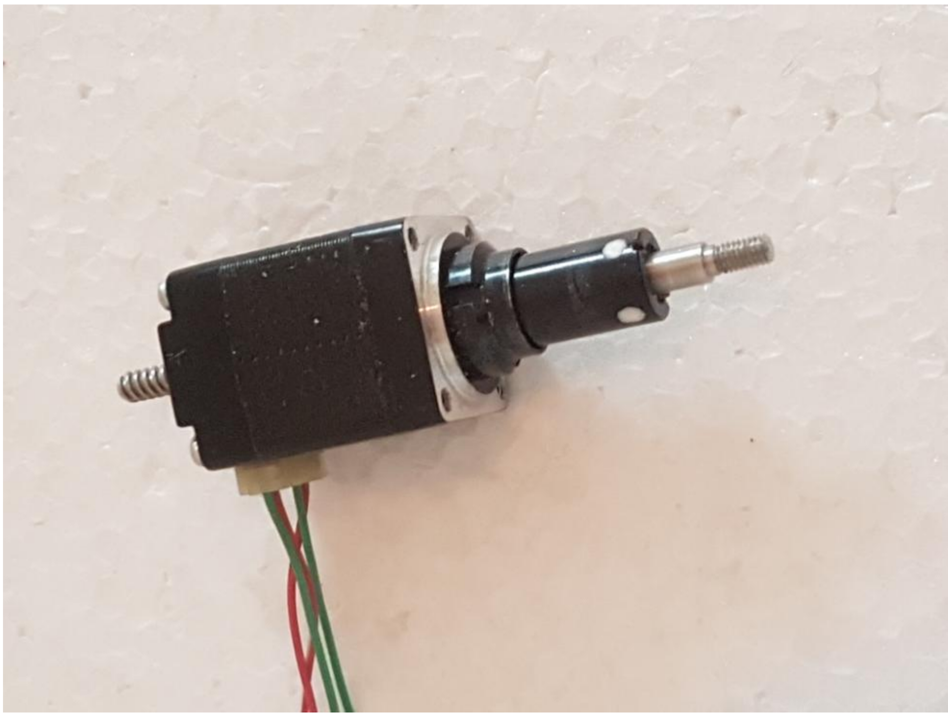

Figure 2.14. Actuator

Figure 2.15. Solenoid

An actuator from America was ordered with a threaded shaft at the tip and coincidentally a solenoid from China had the same dimensions of a thread on the back of it.

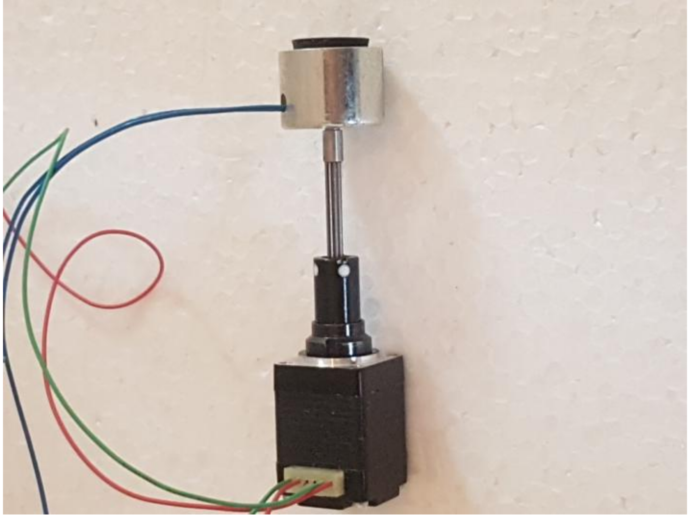

Figure 2.16. Solenoid screwed onto the tip of the actuator

The type 2 bearing was perfect for connecting the primary arm with the secondary arm. The type 2 bearing is a bearing with a bolt at the end of it that can rotate. This bearing can simply be dropped into a sort of cup shape in the primary arm with a hole at the bottom. The bolt end would come out of the hole and it would screw into the secondary arm.

Figure 2.17. Type 2 bearing sliding into primary arm

Figure 2.18. Thread on secondary arm where type 2 bearing can be screwed in to

Looking at figure 2.16. one can see the shape of the end of the actuator, in the design for the secondary arm that shape was copied so that the actuator can slide in. Holes were also drilled out so that the actuator can be secured with small bolts.

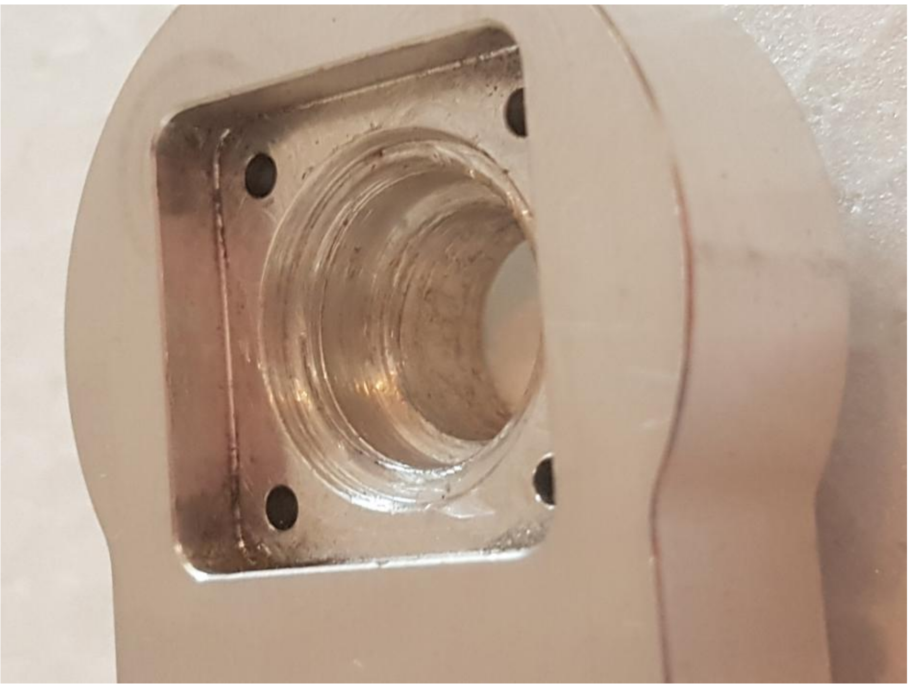

Figure 2.19. Shape of the end of the actuator for a snug fit

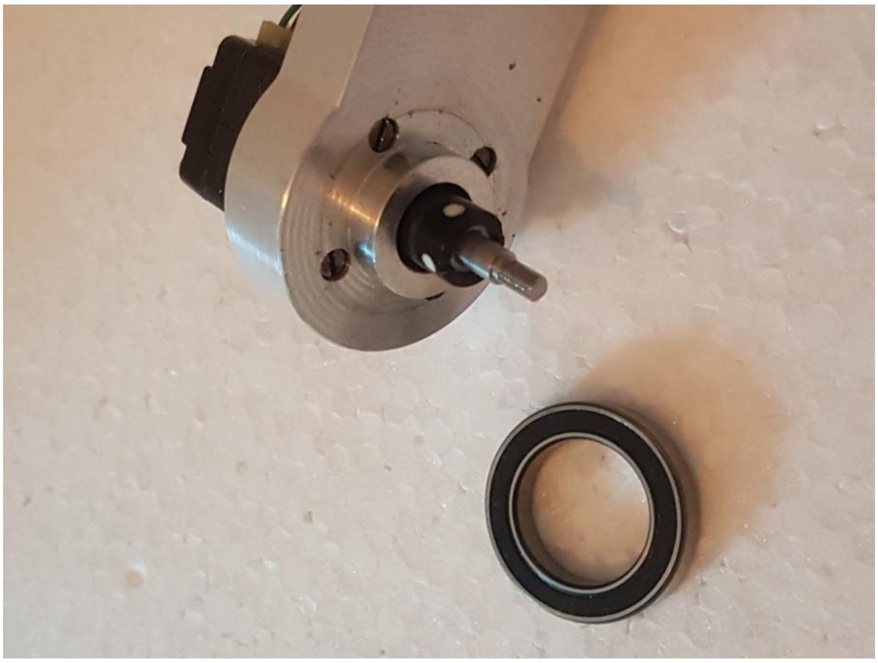

Figure 2.20. Type 1 bearing that slips on under actuator

Another important thing to take into account was that since the arms rotate and fold, one of the arms had to be lower than the other.

Figure 2.21. One arm lower than the other

Figure 2.22. All four links assembled with bearings, actuator and solenoid

All 4 links were CNC milled by a company called Balen d.o.o. from Pijeka. They did an extremely good job and milled the links accurately with appropriate tolerances for the bearings. The links were milled out of an aluminum mix to get as light as possible while still having strength and durability. It came out a bit expensive but it was worth it for the quality.

3. Wiring the Electrical Components of the SCARA Robot inside the Base Box

Wiring all the electrical components of the robot is the most important part of the entire project. As much time as possible should be taken with this part so mistakes can be avoided and so no components burn out. The steppers and drivers were pretty expensive and they were special ordered. Having a part burn out meant more money would be spent and one would have wait for the part to be delivered again.

All of the components were as hidden as possible to keep a clean look. It might not seem so but there are actually a good amount of components needed for this robot. Along with the components, a small "control panel" was needed where you can plug in the power cord, USB cables, an on/off switch and a push button.

The list of components used include:

- STP-MTR-23079 Stepper Motor,
- TB6560 Stepper Motor Driver,
- Haydon Kerk Hybrid Stepper Linear Actuator 21000 Series,
- 4A 2 Axis THB6064AH Stepper Motor Driver,
- 36V 10A Power Supply,
- IC1 7812 Voltage Regulator,
- 5V Optocoupler 2-Channel Relay Module for Arduino and
- ATMega 328P-AU Microcontroller

The biggest bottleneck for the wiring was the power supply, so before even choosing a power supply the list of all the electrical components was needed to calculate the volts needed and how much max amperage they can all pull. Considering all the parts at least 9A and a minimum of 25V was needed. A power supply was used that had the option to raise and lower the voltage from around 20V - 40V and it was rated for 10A. Keeping the voltage as low as possible was needed so there wouldn't be a lot of heat coming off any of the components.

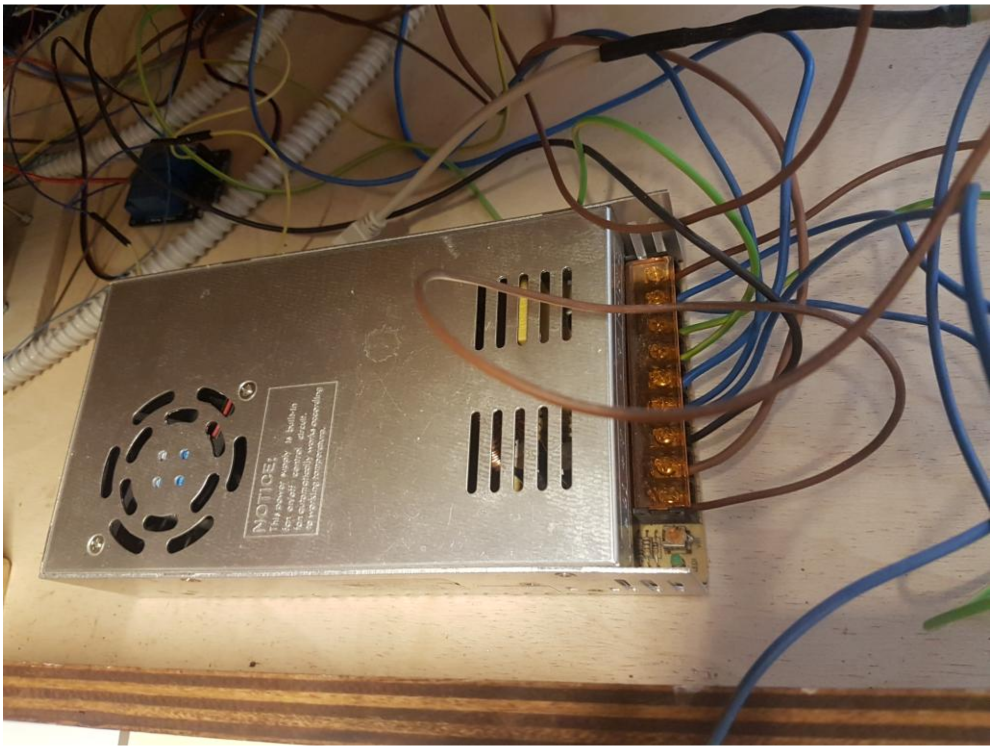

Figure 3.1. Power supply

The next step was creating the control panel. On this control panel four components were needed; a push button, an on/ off switch, an outlet for a plug and a USB hub. The push button is used for engaging the robot and to start the program. The on/ off switch has two switches built in, one for turning total power on to all the components and the other switch is used for turning the step motors that control the robot arms on and off. An outlet on the panel was installed to bring 220 V to the power supply. Lastly two USB plugs were also installed, one is used for power to the microcontroller and the other is used for programming the microcontroller. The panel was milled out of stainless steel.

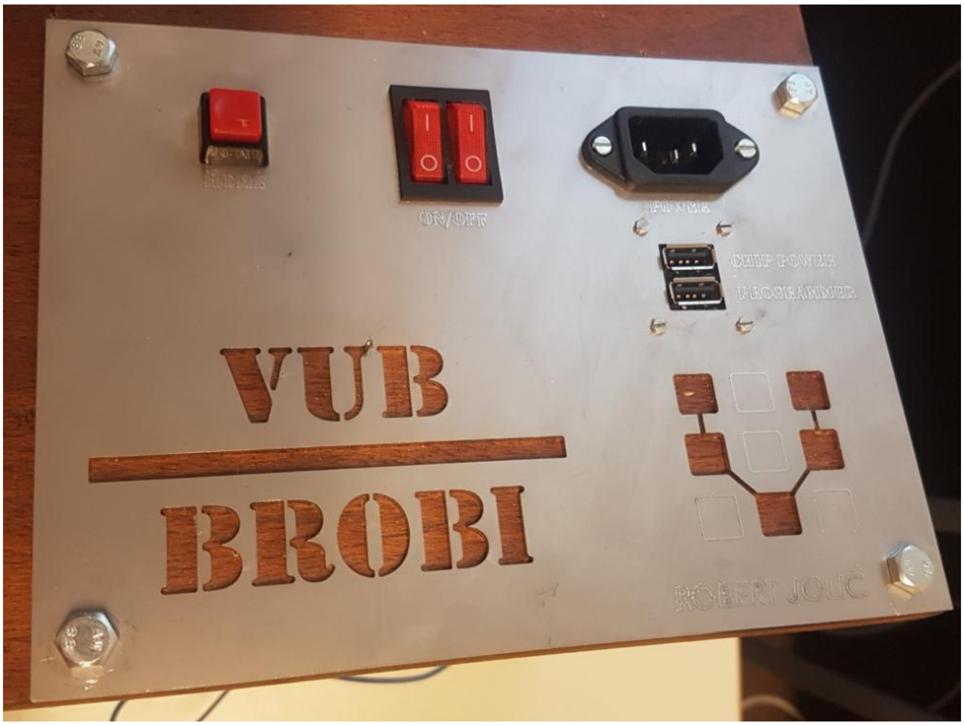

Figure 3.2. Control panel

Next the microcontroller was prepped, this was done by creating an expansion board to make it easier to connect all of the components to the microcontroller. Using an expansion board would help with clutter of wires and make it easier to make wired connections.

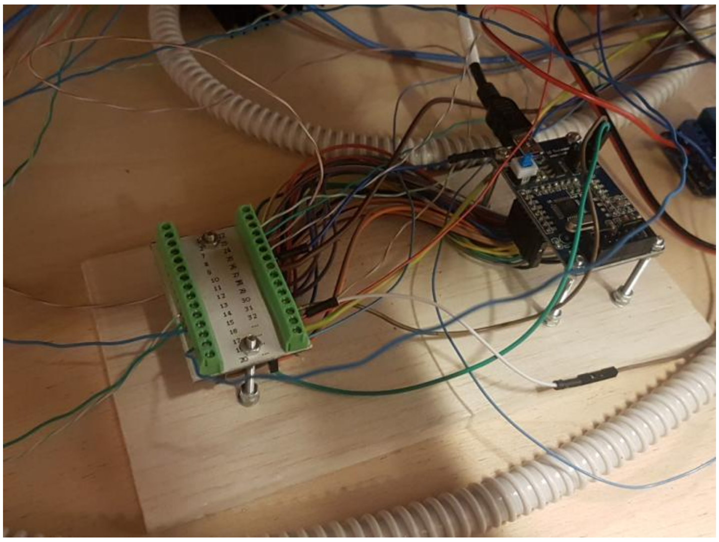

Figure 3.3. Microcontroller wired to expansion board

After the main parts were set up the wires needed to be pulled from all the motors and solenoid down into the box base. Cables were routed from the actuator and solenoid along one of the arms of the robot. On one side of the base construction a small hole was drilled that was just big enough to pull the wires through. The main stepper motor wires were pulled down through the legs of the base construction.

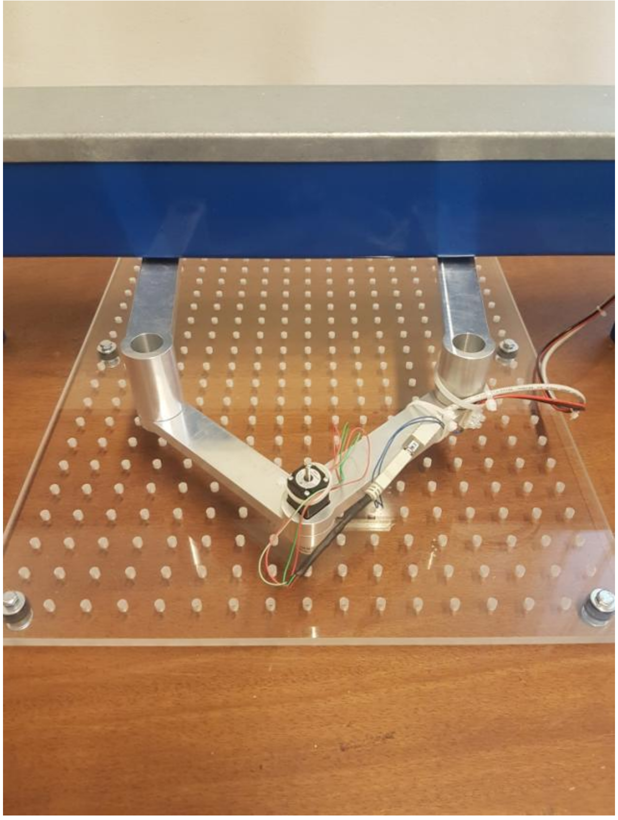

Figure 3.4. Wires from actuator and solenoid going into the base construction

Figure 3.5. Hole for wires from actuator and solenoid

The actuator in Figure 3.4. is connected via a USB connection so that it can be plugged and unplugged from the stepper easily in case repairs are needed to be made or to remove the motor without cutting wires. On the other end of that USB connection inside the box base the wires are connected to the stepper driver used for the actuator. A **TB6560 Stepper Motor Driver** was used. Connecting a stepper motor to the driver is very simple and can be found in the data sheet of the type you are using. All that's needed to connect to the microcontroller is a port for the clock or pulse and a port for the direction.

The solenoid is a little trickier to connect for two reasons. The first reason one can't connect the solenoid directly to the microcontroller or power supply is because the solenoid is rated at 12V and the power supply is outputting 25V. Connecting it directly meant it would probably burn it out. On the other hand the solenoid can't be connected directly with the microcontroller because the microcontroller was too low of a voltage(only 5V) and it wouldn't be enough to power the solenoid to lift the metal balls. So the trick to accomplishing this was to use two other components. The first component was a 7812 voltage regulator, this would step down the 25V from the power supply with the regulator so that the solenoid had exactly enough power it needed and at what it was rated at which was 12V. The other component needed was a relay module, and with this relay module higher powered components could be controlled (the solenoid) using a lower powered source (the microcontroller). A 5V signal would be sent via the microcontroller to the relay module to open and close the 12V power source coming through the 7812 voltage regulator which would magnetize and demagnetize the solenoid.

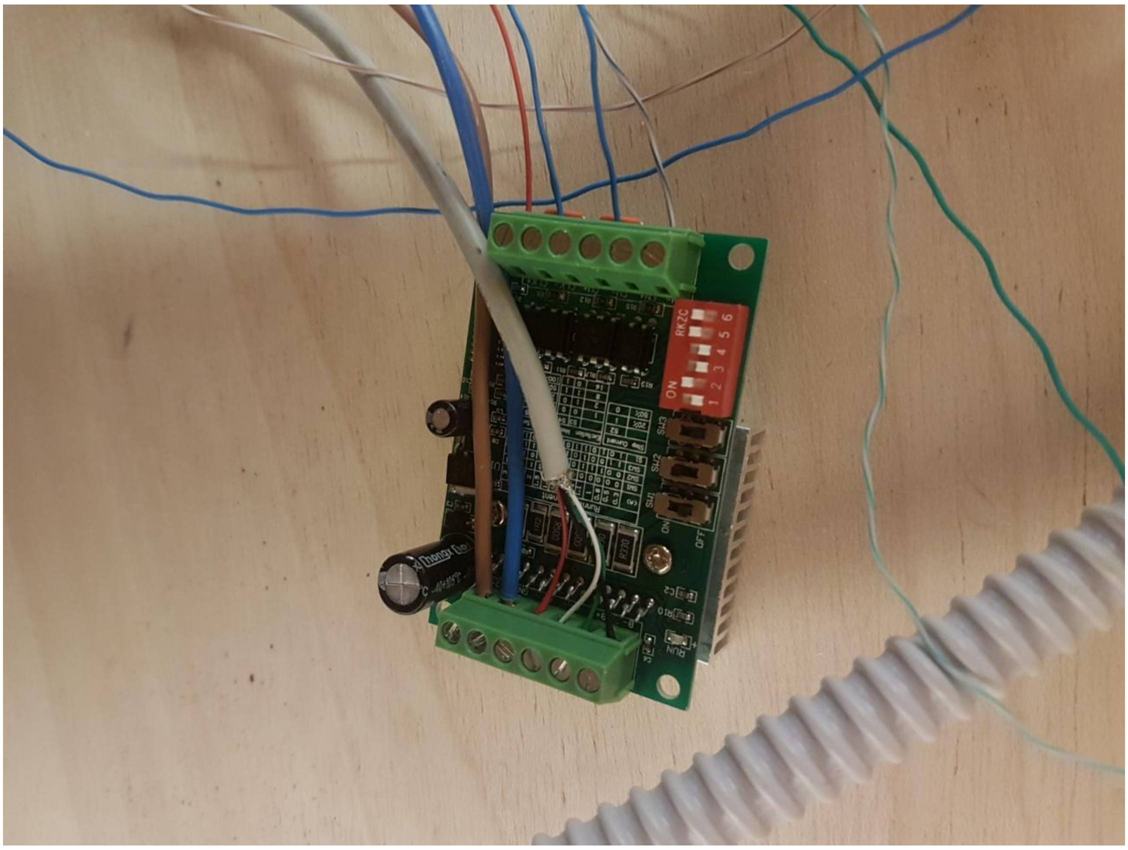

Figure 3.6. TB6560 stepper motor driver used for the actuator

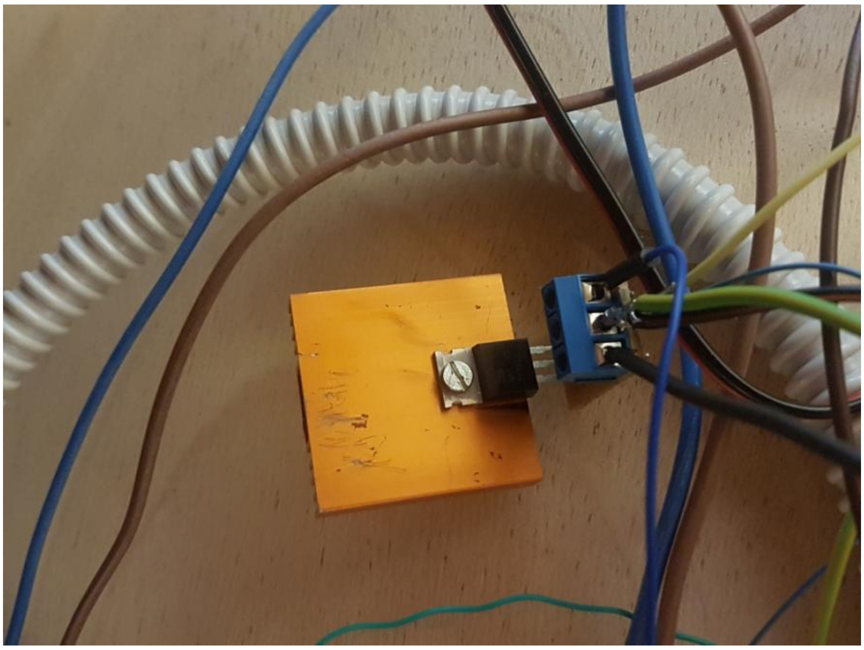

Figure 3.7. 7812 voltage regulator attached to a heat sink

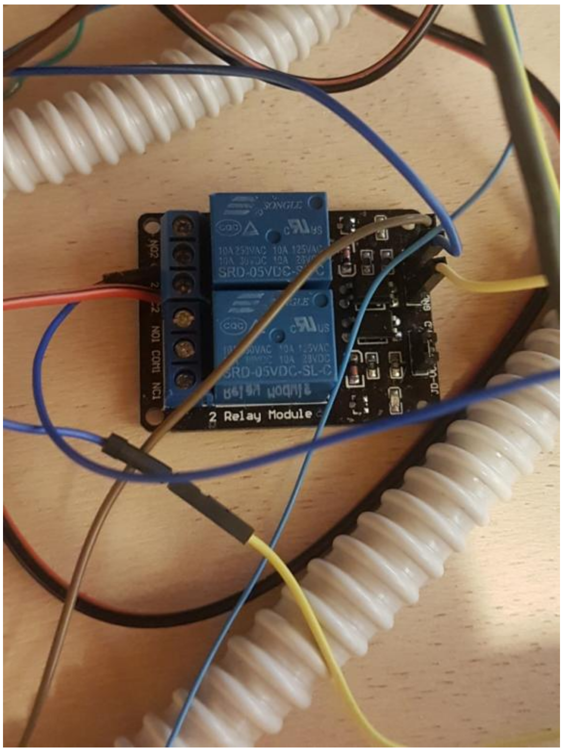

Figure 3.8. Relay module connected to the microcontroller, solenoid and voltage regulator

Lastly, the two main step motors had to be connected to the driver. This was just as easy as connecting the actuator. Just like with the actuator for the main stepper motors all that's needed to connect was a clock port and a direction port. All that's needed to be controlled is the speed via impulses and to control the direction (clockwise or anti-clockwise). The driver used for the main steppers was a 4A 2 Axis THB6064AH stepper motor driver. Since it's a 2 axis driver both stepper motors can be controlled on this single driver and still be able to control them separately.

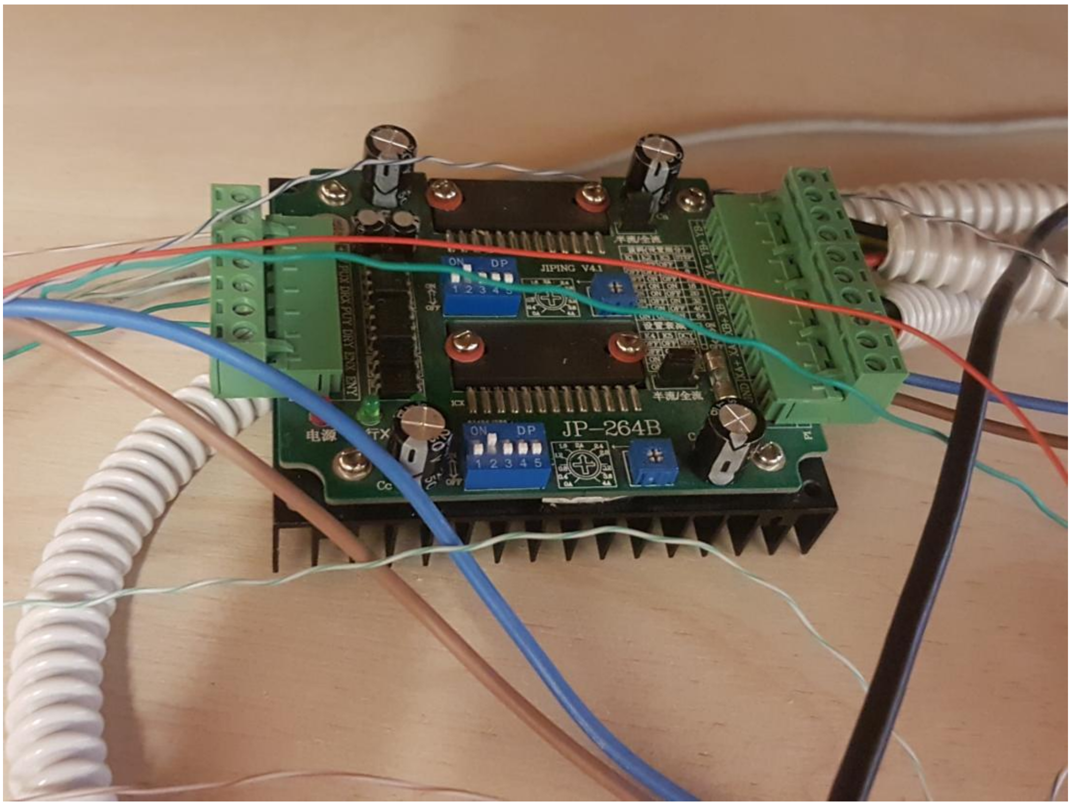

Figure 3.9. 2 axis step driver THB6064AH

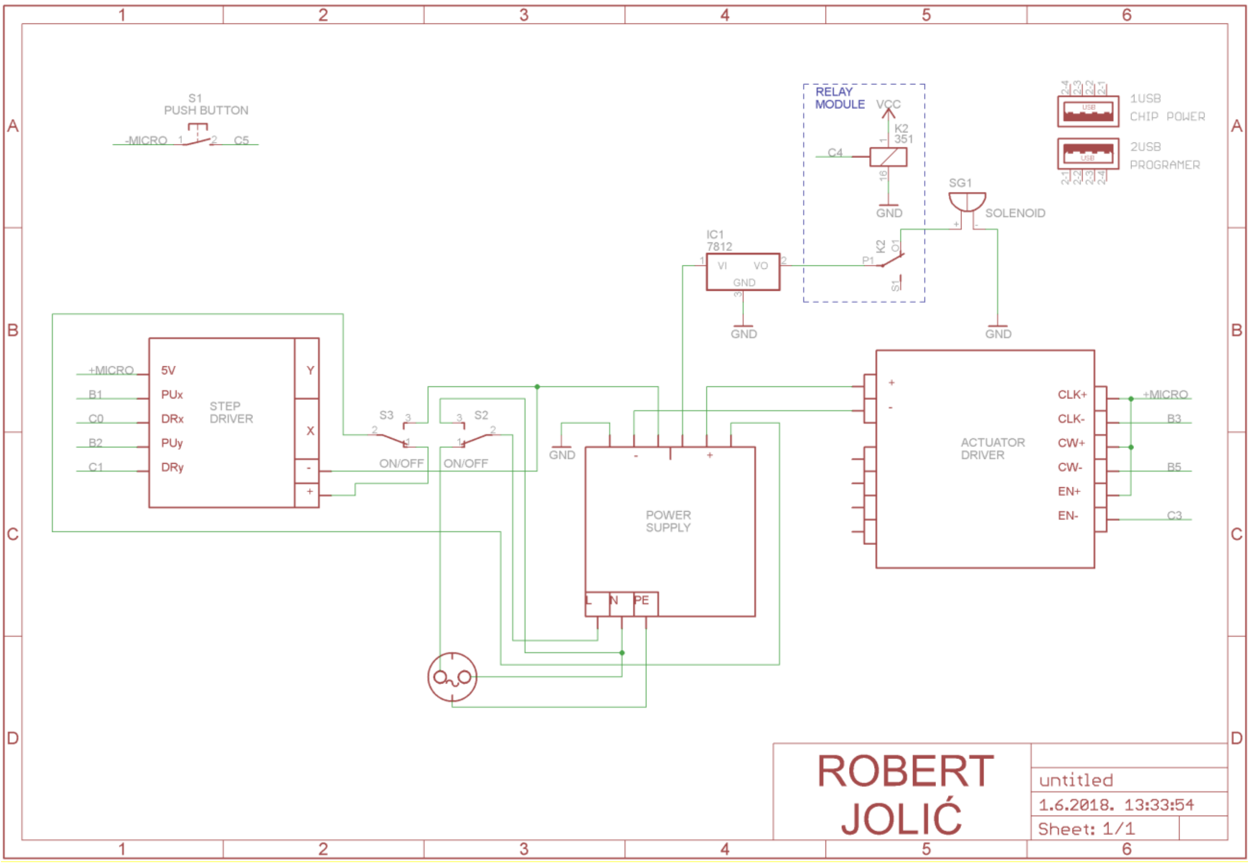

Figure 3.10. Schematic of wiring the whole robot and all of its components

4. Programming the SCARA Robot Using Inverse Kinematics in ATMEL STUDIO

ATMEL studio was used to write the code and upload it to the microcontroller. As mentioned above the chipset used was an ATMega328P-AU [5], it was the chipset that came on the minimal board that was ordered. A minimal board was used because there wasn't a big possibility of human error to occur when compared to making your own board. This was a good finished product that could be plugged in and used with an expansion board without any complications.

The way to program a SCARA robot is by calculating the angles the arms have to be to have the end effector come into position. This is done by back tracking or the correct term to use is called inverse kinematics. You have a set of formulas you use, and you plug into those formulas the position you want the end effector to be at.

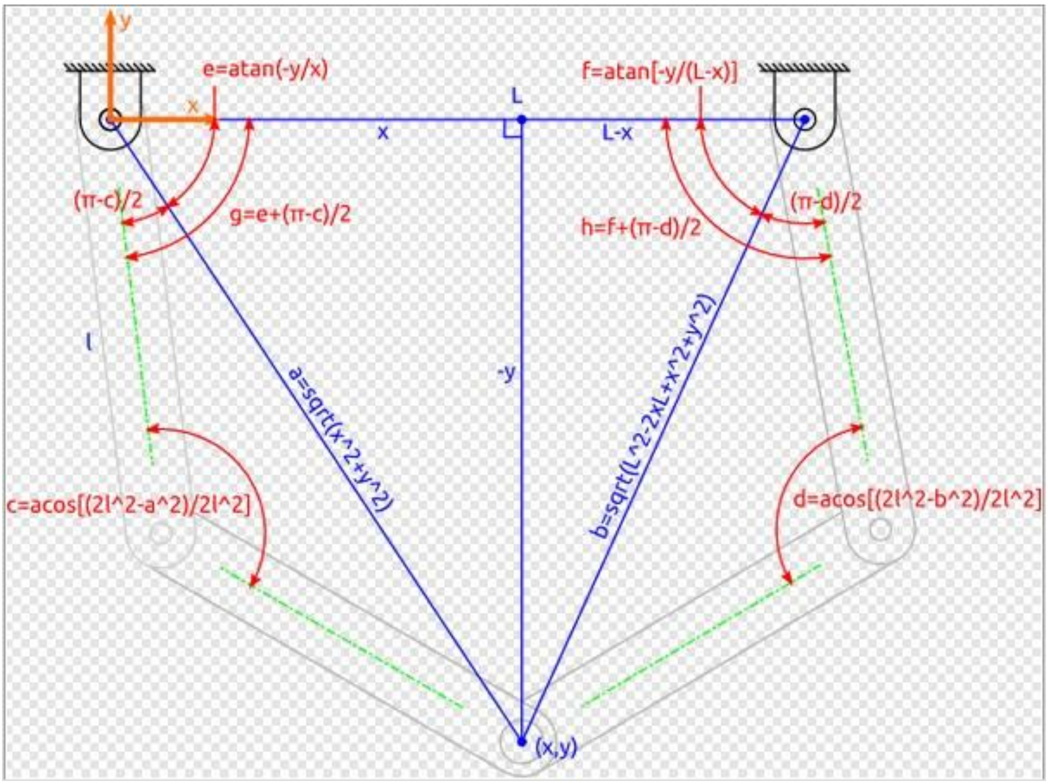

Figure 4.1. Inverse kinematics for my SCARA

So here if one is to look at the position, one may see where the end effector is supposed to be (x,y). Those coordinates are taken and plugged into the formulas and one back tracks the angles of the arms until one get to the angles needed at the point of the step motors.

Since all the arms are linked together all that has to be done is spin the step motors to the angle needed at the base and the rest of the arms will fall into position. The angle of the step motor is obtained by finding out how many step your step motor has for one full rotation. The step motor used was rated at 1.9° per step. If one needed to get an angle of 57° for one of the arms, one would divide the degrees needed by the degrees per step your motor is rated at. Thus, 57°/1.9°per step = 30 steps; this means to get an angle of 57° you have to rotate the step motor by 30 steps. A small program that would calculate the final angles was created. With this program the coordinates could just be entered in to get the angles calculated automatically.

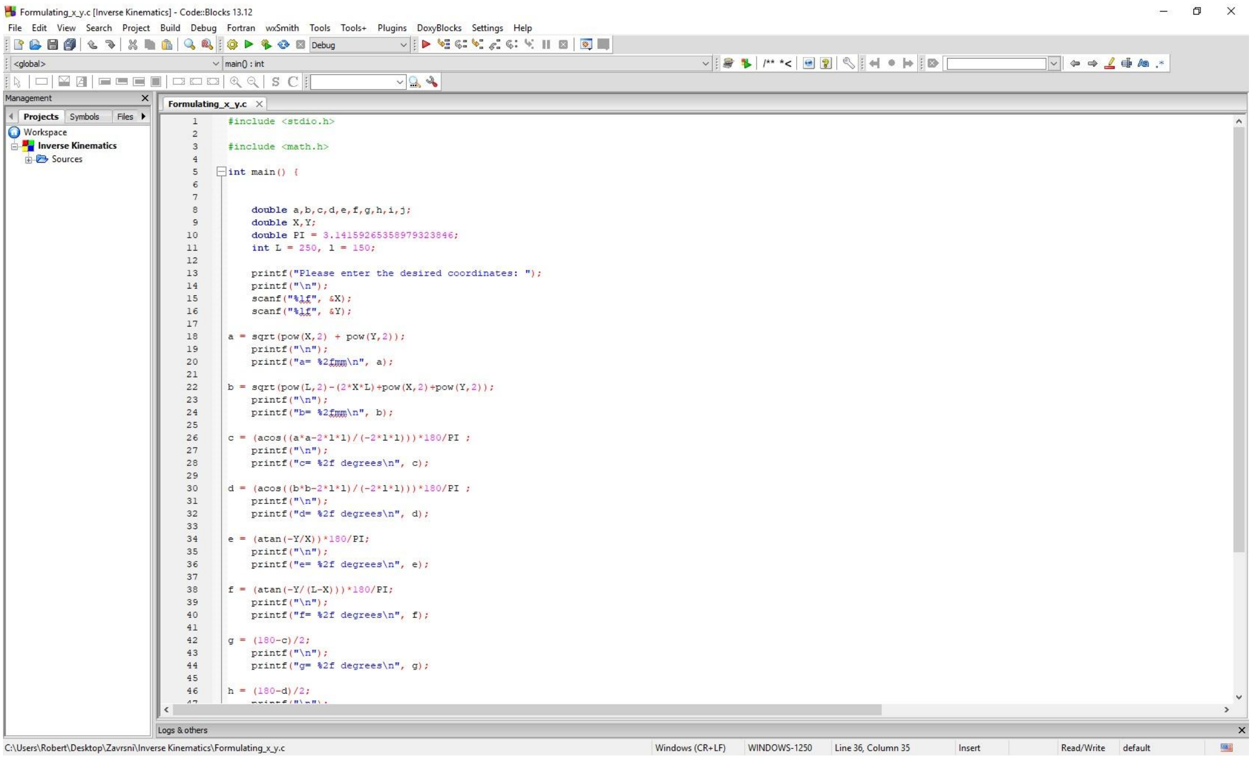

Figure 4.2. Program for calculating angles for SCARA robot

Using this program there is the possibility of testing to make sure the formulas were correct. Choose a point on the work area and put the coordinates in the program and you would get the angles needed. Manually move the arms and measure out the angle needed, and doing this multiple times you would be able to see if the formulas were correct or not.

Since the formulas were correct programming in ATMEL studio was the next step and to get the robot to finally move on its own. Two points on the work area were chosen that the arms would pick and place the metal balls on. The program was set up in a way where one could see all the movements of the robot while the robot picked the metal balls up and basically switched their positions. This way actions could be looped and have the robot constantly repeat these actions over and over again.

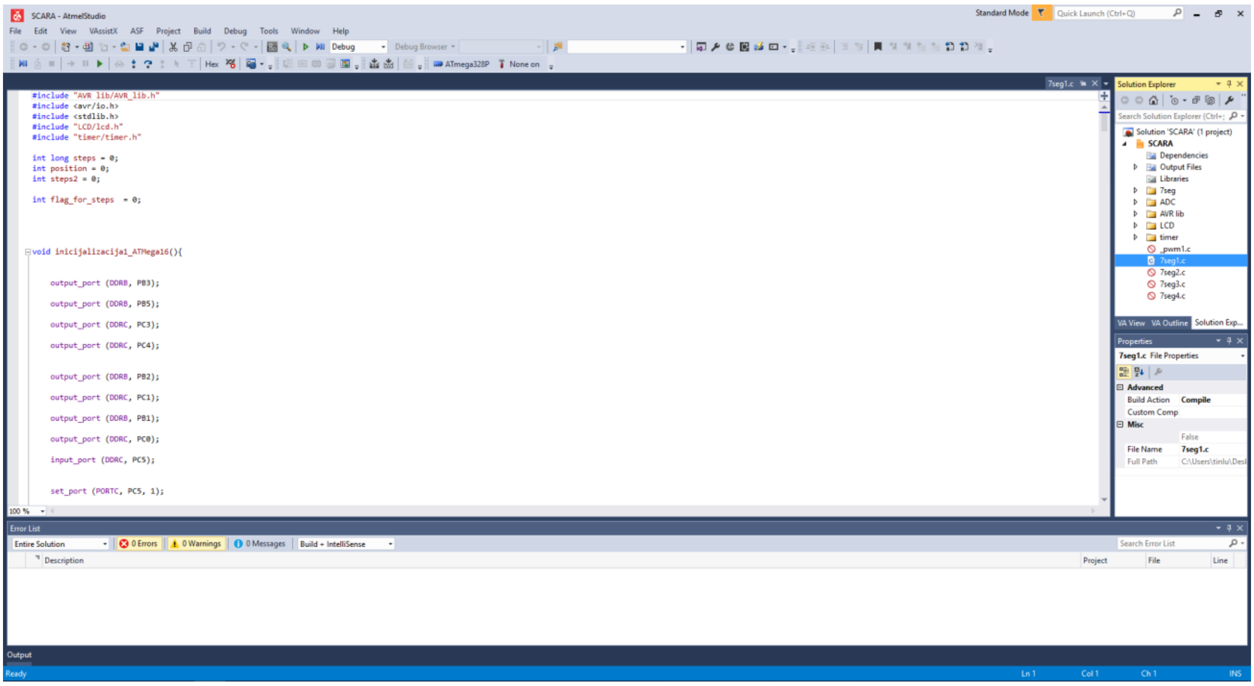

Figure 4.3. Programming in ATMEL studio

5. Conclusion

The parallel SCARA is a very versatile robot which can be used in many places in industry. Most commonly used as a pick and place robot for electrical components. It is very cost efficient while being very accurate and fast. In this thesis you saw the basic way of building a SCARA, wiring one and programming one. One can also see that they can be adapted in many ways in terms of work area, end effector and type of object need to be picked and placed.

This is just one of many types of robots used in industry and in no way is the SCARA robot the best and only choice. Much thought is needed when selecting the robot that is right for you and the work that you need to be done. Each type of robot has its plusses and minuses and each type is specifically selected for certain types of work. This thesis simply opened your eyes to one of many types of robots. However, all types of robots should be looked at and analyzed when going into robotics.

Literature

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Abstract

Title: Design and Control of a Parallel SCARA Robot

This thesis describes the way the SCARA robot was designed and programmed. The final thesis shows all the steps taken from building all the parts, to wiring the electrical components and lastly programming the actual robot to move. Inverse kinematics was used to calculate the required angles for positioning the end effector so that the solenoid can pick and place the metal balls around the work area.

Key words: SCARA robot, Inverse kinematics, end effector, pick and place

Sažetak

Naslov: Projektiranje i upravljanje paralelnog SCARA robota

U ovom završnom radu opisna je izrada i programiranje SCARA robota. Završni rad prikazuje izradu svih dijelova paralelnog SCARA robota, ožičenje elektroničkih komponenti te programiranje gibanja robota. Inverzna kinematika korištena je za izračunavanje potrebnih kutova za pozicioniranje alata robota kako bi elektromagnet mogao pokupiti i premjestiti metalnu kuglu u radnom prostoru robota.

Key words: SCARA robot, inverzna kinematika, alat robota, pick & place

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