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# Semi-Automatic Robot Welding for Workshops

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## Abstract



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The objective of the research was to develop semi-automatic robot welding, which can fulfill the requests of PrePipe Oy and the workshops. The reason for the research is due to a lack of qualified welders as per the company's requirement, which causes delay in the completion of projects. The studies focused on modular workstation design, risk analysis, economic analysis, programming and robotic interface. The work was commissioned by PrePipe Oy.

Data for this study was gathered from internet sources, books, online training from UR academy, interviews with Pronius Oy for the welding machine, Posicraft Oy for robot & robot communication interfaces, PrePipe Project management about work schedules, and from the Nordic welding expo 2018.

The results of this study justify the implementation of a robotic system in the company and workstations would improve the work productivity and quality with higher ROI and shorter payback period for the investments, as well as preventing health hazards for humans.



Keywords: Semi-automatic, Welding, Robot

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## Terminology

AI – Analog Input

AO – Analog Output

DI – Digital Input

DO – Digital Output

IPM – Inches per minute

m – Meter

MIG – Metal Inert Gas

NC – Numerical Control

PMC – Pulse Multi Control

ROI – Return On Investment

SS – Stainless Steel

TCP – Tool Center Point

UR – Universal Robot

WT – Wall Thickness

# 1 Introduction

This thesis has been prepared for the company PrePipe, located in Lappeenranta Finland. Specializing in welding for industrial pipe and support structures, they employ 80 employees. They have worked providing pipelines, welds, and supports for the pulp factories in Eastern Finland. They are now looking to modernize a part of their workshop utilizing a robot to weld pipes and ends for square hollow sections. This thesis is focusing on robot implementation in small scale industries for welding. Due to the shortage of professionally qualified welders in PrePipe Oy, there are project delays thereby causing some problems in accepting new projects. Additionally, they are worried about the health hazard posed to their current workers by the welding fumes.

## 1.1 Automation Background

Automation with the robot is not an old concept; the word robot being only as old as 98 years, being first coined in the 1922 (Dictionaries, 2018). The process of developing a true industrial robot had to wait awhile till 1950s when George Devol filed for a patent for a programmable manipulator. The patent, granted in 1961, coincided with the first prototype starting its work on an assembly line (Robotics.org, 2018). From there automation has progressed fast to full automation and autonomous level.

## 1.2 Welding Background

Welding is a process of joining materials and structures to make uniform connection, it can be metallic or non-metallic, with or without pressure and filler material. Welding is divided into two processes. They are fusion and pressure welding. These processes can be of mechanized in three different ways. They are mechanized welding, robotic welding, and automated welding (TWI, 2013). In mechanized welding, welding process movement is mechanized, where an operator needs to monitor during welding for parameters adjustments. In case of robotic welding, the process uses programmable weld path to weld the joints and is mainly in autonomous process for increasing production rate. The automated welding process does not require an operator to monitor its process, because loading, unloading and welding are fully automated. This process used in mass production units and various other sectors, due to the process repeatability.

Semi-automatic welding process involves using a robot to weld the workpiece where loading and unloading of the workpiece is done manually. The robot is having the flexibility of six axis movement with good precision and ability of weaving which helps in welding a complex task faster and easier. The speed of growth in robotics has been fast, with new aid of new computer technology and ministration helping push the industry forward to what it is currently. Nowadays, many large-scale industries use robots for welding processes because of their high productivity, inexpensive continuous production, consistent quality, and because it prevents humans from the harmful environment during welding. By this way PrePipe Oy can utilize their workmanship in a better way. Since there are many welding processes, this thesis mainly focuses on MIG welding process because of its freedom to automate easily, continuous feeding of solid wire increases the productivity, and pulsed welding process variant helps performing welding of pipes when fixed in a position for flawless joint.

# 2 Key things to consider for Robot Welding

PrePipe is a manufacturing unit which, mainly uses welding for different sizes of pipes, end cap for square booms and in the future is looking to adding a laser source to the robot for cutting pipes. They are also looking to try out a laser seam tracker for real time seam correction in the weldments.

## 2.1 Robot Selection

Robots play a major role in welding at automobile industries because of less manufacturing time which leads to high productivity, good consistent results, as well as performing complex welds easily. Most widely used robot manufacturers are Fanuc, KUKA, Universal Robots and Novarc. We are comparing these manufacturers according to our criteria price, reliability, maintenance, easiness of programming, and future upgradability. Some problems are analyzed before robot selection according to the requirements and they are listed below:

- Mobility of the System

  Some parts are manufactured at the company and the rest are welded at the site, so the system should be transported easily and it should be easy with the set up like a plug and play system.

- Adaptable to Modular System

  The robot tool head should be easily switchable by an automatic process after the welding process for post processing work such as grinding the surface of the welded region.

- Easy Programming

  Programming the robot should be easy and less time consuming

Considering all the factors Universal Robot UR10 was the best robot choice to fulfill the above scope. It is easy programming, can be coupled to seam tracker, has high payload for the price, a lightweight built structure, and a good reach range of 1.3 meters. The downside of the robot is the software implementation. The seam tracker which is still in progress (beta version) cannot fully rely on the features. The KUKA robot was the second option because of its easy coupling with other systems like turntables for seamless operation which makes complex weld much easier to perform and in-built seam tracking software which makes for easier implementation to the robot controller. The downsides are hard to move around, the programming is not that easy compared to universal robots and the huge price tag.

### 2.2 Qualifications or Certifications

Like a regular manual welding procedure to get qualified, the robot operator has to perform welding with a robot to get qualified by welding codes in accordance with client's requirements.

### 2.3 Risks

In manual welding there are risks to the weld quality caused by the workers themselves. While this risk can be minimized by automating the welding the manual placement of the workpieces still carries potential human errors. Some of these theoretical risk sources have been analyzed. These include risks caused by the robot, fixtures, workpiece loading, and by the mobility of the system.

#### 2.3.1 Workpiece Position Misalignment

Setting up the workpiece illustrates the offset issue, which is shown in Figure 1.

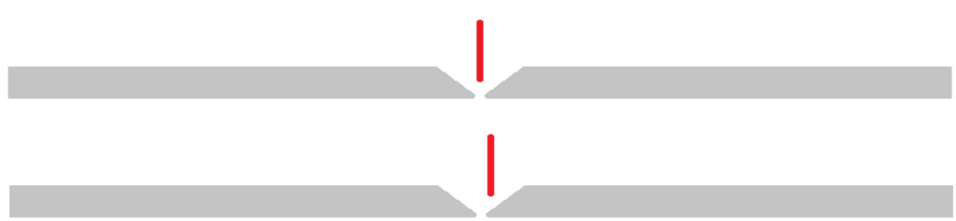

Figure 1 Welding Torch Offset.

Description: Since it is a semi-automatic welding process the workpiece loading and set up is done manually. So, there is a problem of workpiece joint edge position alignment for the welding process to carry out. Figure 1 shows the offset of the weld tip.

Prevent Measures: This can be eliminated by two ways; by pointing a laser to the edge preparation region and a pre-run can be done without powering the welding machine by finely adjusting the position during the process which is a time-consuming process but it solves the problem. The other way is by adding a laser seam tracking system (Servo Robot, 2018) so that it can compensate the offsets during the welding process which is still a beta version available for the robot.

Contingencies: Cutting and redoing the weld is the only possible solution.

### 2.3.2 Workpiece Dimensional Accuracy

Description: There is always a deviation in dimensions, because pipes cannot have perfect roundness. During welding by constant current process variant, a hole is formed due to high heat input in the section which causes a change in WT.

Solution: To overcome this problem a Fronius welding machine can be used because of its feature called PMC. It is a pulse correction function which includes penetration stabilizer and arc length stabilizer. This feature monitors the arc length, current, feed rate and adjusts the wire length without overshooting the values of the parameters as any changes during the welding process. This could be useful in welding tight corners, resulting in a sound weld (Fronius, 2014).

### 2.3.3 Equipment Malfunctions

Description: In case of any technical issues with the robot or welding equipment.

Contingencies: The local service point should be known for the equipment, having a second workstation for redundancy is a better choice or it is always safer to have a certified welder. There should be always two emergency stop switches one on the robot controller interface and another on the work table to immediately stop the action of the robot if any abnormal noise or action is noted.

### 2.3.4 On-site Workstation Assembly

Description: The distance between the workpiece table and the robot should be the same as per the program made for the welding. When setting up the robot at the site, the distance should be taken into consideration for the program to operate normally or else a new program will be required, which is time consuming.

Contingencies: A permanent scale (image shown in under design section) must be manufactured to measure the distance before making the first program so that it can be used to align the tables faster unlike using a tape to measure the distance which would involve two people and is more time consuming.

# 3 Design

The design of the work station should allow for the robot to be able to process workpieces on one table while another table is being loaded for continuous production. The mobility of the robotic system and the need to realign it with the worktables should also be taken into account in the design.

## 3.1 Workpiece Table

The idea of having two work tables would allow for faster and a more seamless operation. While table A would be being loaded, the robot can be used for welding the workpieces in table B and vice versa with a small tool switching table. The table for the workstation should be a fabrication table, as show in Figure 2. This is since different pipe sizes are being used, so the fixtures for the pipes have to be flexible. Fixturing of the workpieces would be complicated if a regular bench table was used. The size of the table should not be over 1.2 m by 1.2 m or else there will be a problem of robot’s reachability. Since the robot has to weld around the pipe like in 5G welding process the robot has to be placed in the middle of the table to allow for good reachability.

Figure 2 Fabrication Table (Siegmundtables, 2011)

Coming to the table legs, the legs should be height adjustable to account for the different pipe sizes. For bigger diameter pipes such as DN500, the weld gun should reach the top of the pipe. As the two workstations are parallel to each other, so the longer length pipes would be hard to load onto the tables because of the collision danger. By having height adjustable table legs one table could be shorter than the other which will be convenient for bigger pipes and for the longer pipes to be more easily loaded. Adding wheels to the table will be convenient for transportation and will make it easy to do the fine adjusting of the robot to table distance when moved to a new location.

## 3.2 Fabrication Table Versus Turntable

When using turntable, the programming is quite straight forward. 1G welding by pointing the weld gun to the weld region, the pipe is held on the roller and welding is done without much complications. However, the loading and unloading times are much higher and only one workpiece can be worked on at a time whereas on a fabrication table two workpieces can be done. Also, the welding speed should match with the rotational speed of the turntable which should be experimented using the formula which is given below.

Arc speed (IPM) ÷ Circumference (inches) = Revolutions per minute (Honhart, 2008)

When welding a Tee joint or a 45-degree joint it is called a branch joint. It will be a complex task to program the movement of the robot to match with the rotational speed of the turntable. This type of task can be easily achieved by using a fabrication table. In 1G welding a robot is not required because it is a stationary position without any movement.

### 3.3 Clamping and Accessories

When pipes are loaded onto the table they should be held in place. For a repeatable process with different pipe sizes having less clamping will reduce the workpiece set-up time. Stop strips are available in various lengths and they can be fixed to the end corners of the table. When pipes are loaded to the table they are aligned in the same position of different sizes for the programs made in the robot. By this way misalignment of the pipe positions can be solved and clamps hold the pipes in place. Figure 3 illustrates how the pipes can be aligned and held in place and on the right shows the alignment of different pipe sizes.

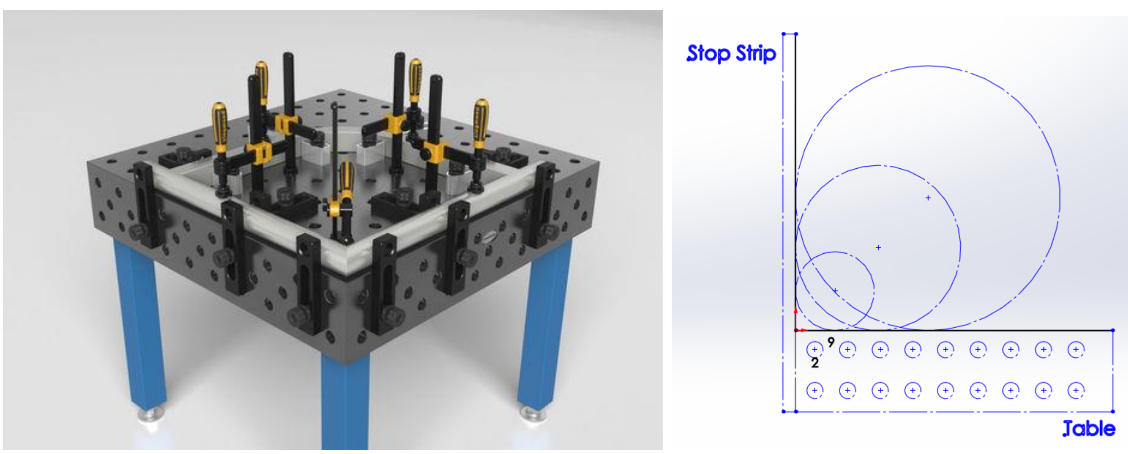


Figure 3 Pipe Alignment *(Strong Hand Tools, 2018)* and Clamping

### 3.4 Multiple Tool Head

Changing the tool head for different purposes gives a new way to utilize the robot for other purposes however, every time the tool has to be removed from the robot end and again replaced with a different tool. This is time consuming and in different applications it has to be done simultaneously then it will be a tedious process. So, to avoid this problem a plug and play tool change named SmartShift is shown in Figure 4 (Buind, 2018). It clips on/off to the robot without depending on pressure air sources. By teaching the robot the tool change position in the magazine it can work seamlessly without involving human. In case of PrePipe Oy, two tool magazines are needed, one for the welding torch and another for a grinding machine to be used for post weld cleaning.

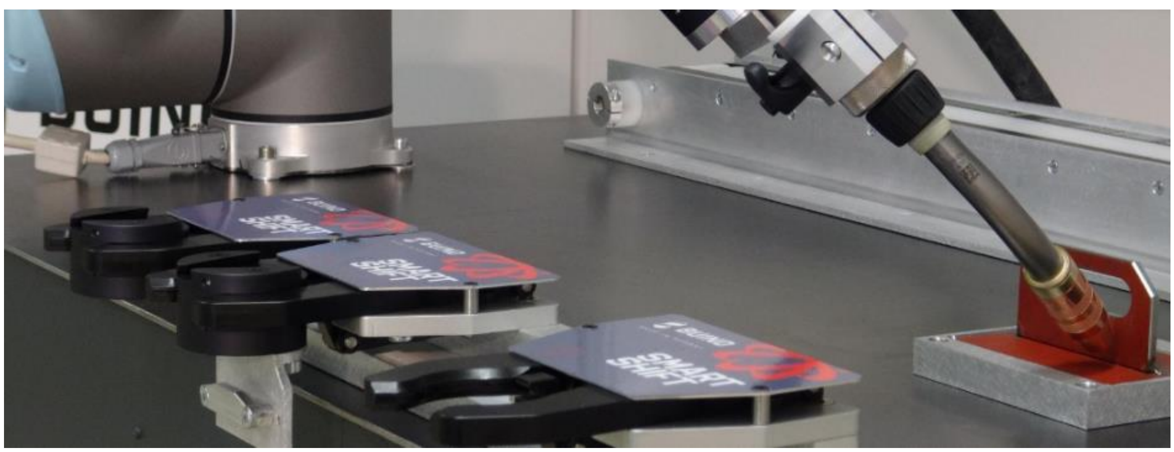


Figure 4 SmartShift for Changing Tools *(Buind, 2018)*

### 3.5 Robot Fixtures

The robot needs to be mounted in a steady fixture to get the best result in the welded joints. The fixture should be short and compact for easy assembly of the robot and should not limit or obstruct the movement of the robot. Having a separate robot table allows the user to move the robot to a place when the workpiece cannot be moved to the fabrication table. Three models were created and tested in RoboDK software for collision tests, where it was colliding with table's surface because it has to move from 45˚ to 315˚. The final model is shown in the image below in Figure 5.

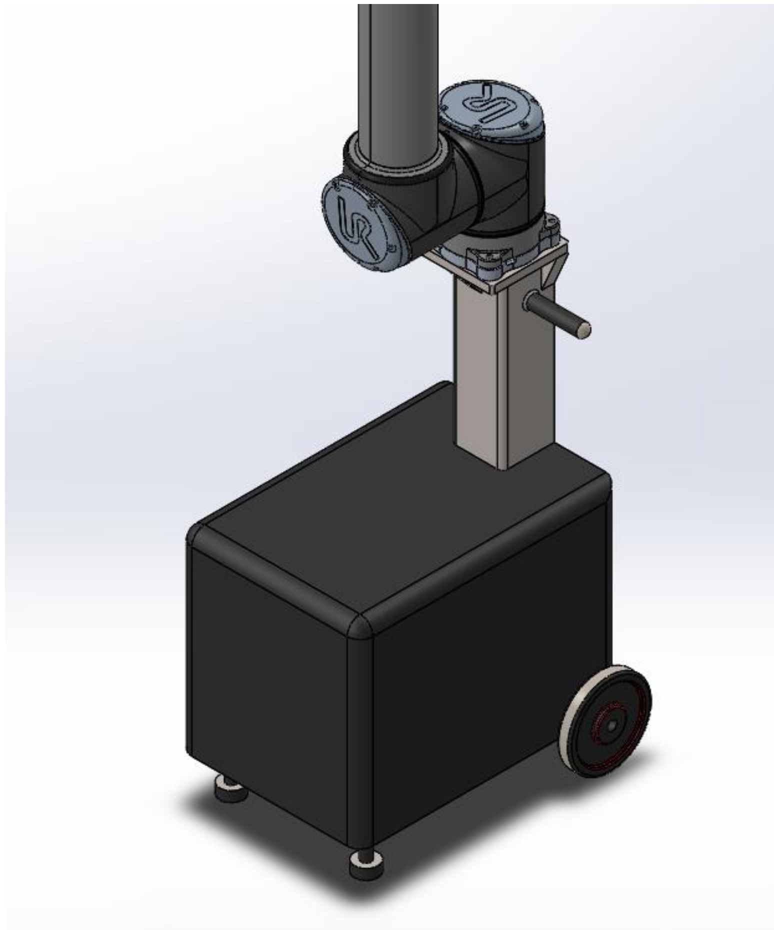

Figure 5 Robot Table

The model has been constructed in a way that the robot can work 360˚ without any obstruction. A storage compartment is placed below the robot mount which serves for two purposes: as an enclosure to protect the robot controller from dust and dirt and as weight compensation to balance the robot. It has wheels and a handle for easy transportation.

The robot's reachability can be increased by increasing the angle of the mounting base. As the angle becomes bigger the reachability increases. The angled mounted robot idea was inspired from dual arm robots which are top mounted and used for assembling things in industries (SwRI ROS-Industrial team, 2015). Figure 6 illustrates the result of a 0˚ mount and a 30˚ robot mount.

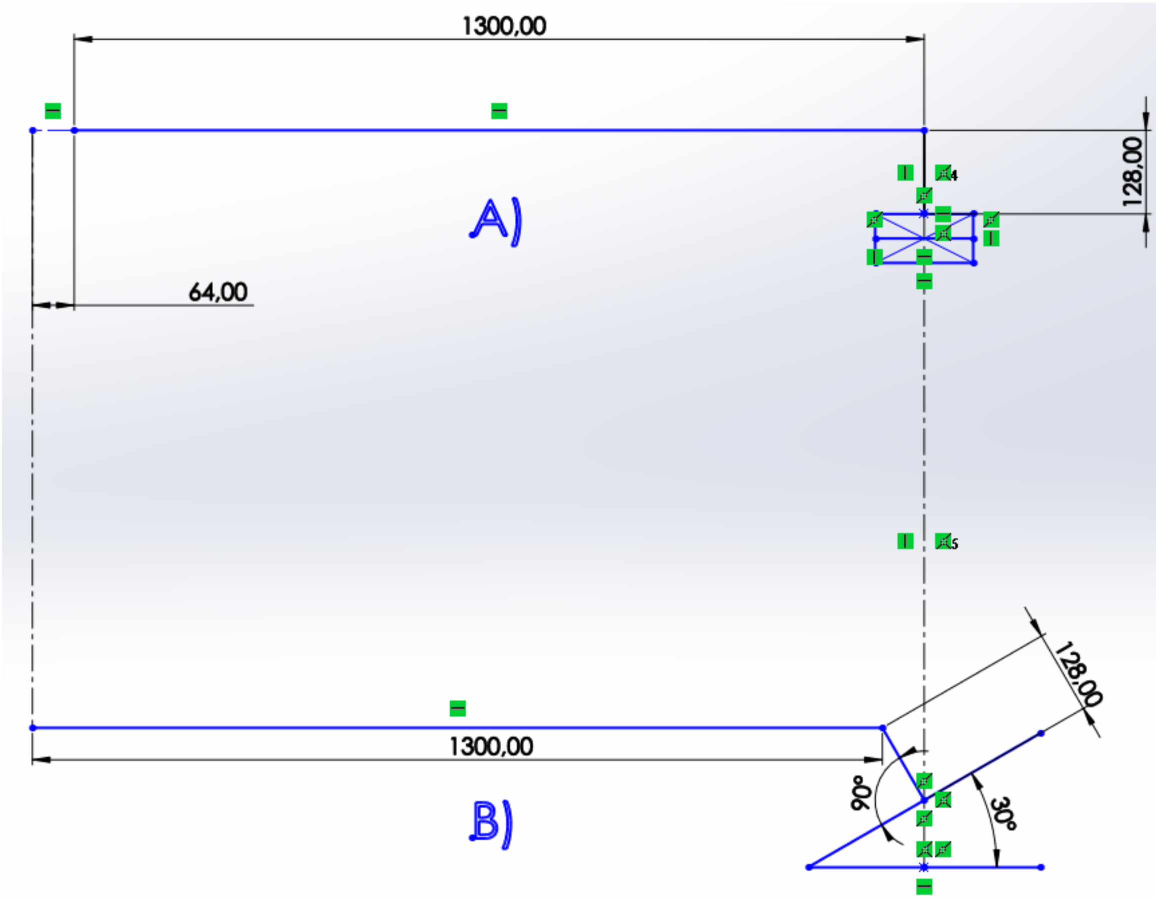


Figure 6 Angled Robot Mount

From Figure 6 the distance 128 mm is from the bottom to the base center point and 1300 mm is the reach distance which is shown in A and B. In the B part of the image the base is mounted to angle of 30˚ which increases the reach by 64 mm when the angle was increased to 45˚ the reach distance increases approximately by 100 mm. Higher the mounting degree, the reach distance is increased proportionally. The increase of the reach was not huge in numbers, but it can be used in some special cases where the extra reachability is needed.

### 3.6 Workstation Aligner

Workstation aligner refers to a self-made device used to set-up the tables in their coordinate system according to the programs made. This aids the process repeatability when the systems are transported to a new location. This eliminates the need in making of new programs for a different pipe configuration. The process of the aligner takes time, but it is faster compared to making a new set of programs. The image in Figure 7 shows the aligner equipment.

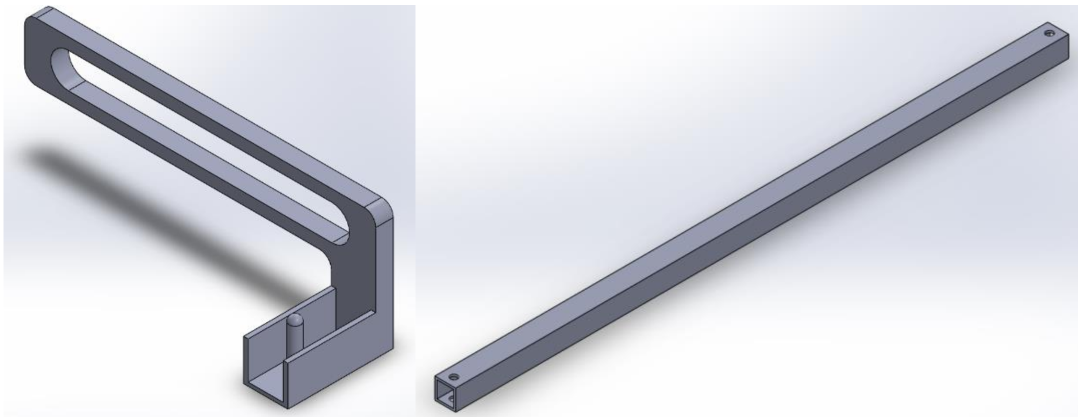

Figure 7 Table Aligner Clamp and Scale

The aligner assembly consists of a clamp and a scale. The clamp on the left image is bolted to the table and the scale is placed on the clamp and the robot, aligning the protruding pins on the clamp and the robot table. The side wall in the clamp points the scale straight by restricting angular deviation while set up and pins prevent the back and forth movement of the scale. By this way the workstation can be set up quickly. Another thing that affects apart from aligning the tables is the flatness of the surface that is where the table height adjuster comes in handy to finely adjust the flatness using a horizon leveler device. The image below shows the mounting of the clamp to the table in Figure 8 and aligning in Figure 9.

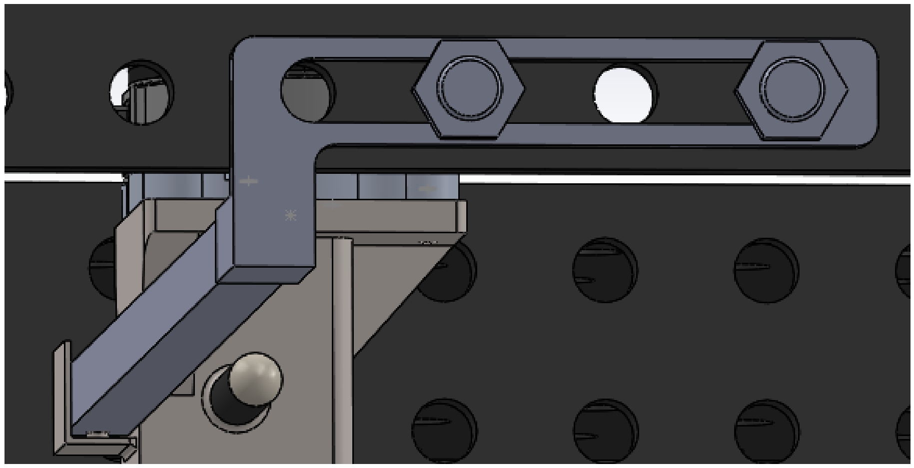

Figure 8 Clamp Mounted to the Table

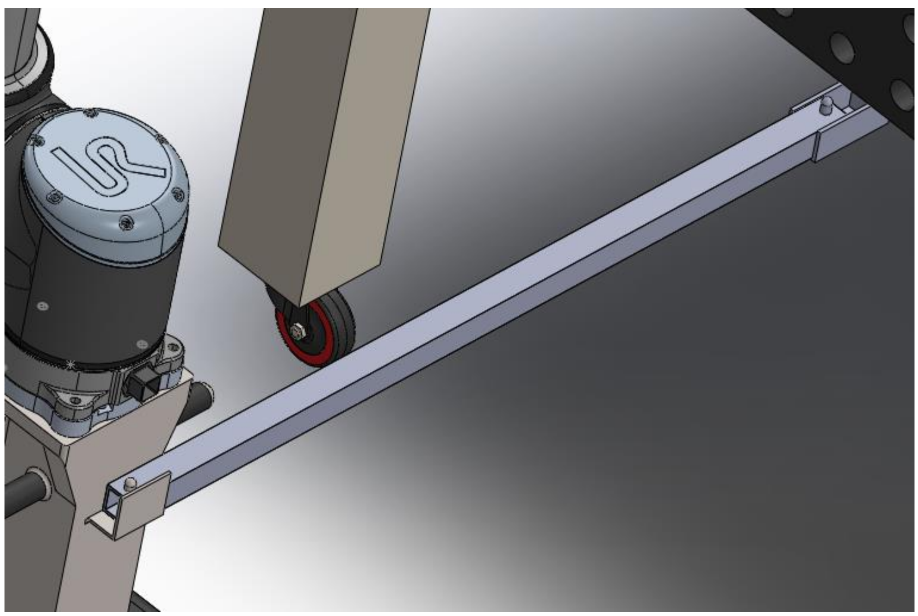

Figure 9 Scale Mounted to the Work Table and Robot Table

## 3.7 Robot Protection

Since the robot will work in environmental conditions where it is exposed to welding and grinding, it is very prone to get damaged so as an investment it must be protected. For example, In MIG welding weld spatters are more likely to happen so there is possibility that some spatter may fall on the robot body. To avoid damages, arm sleeves (Universal Robots, 2018) are used to protect the robot and ensure a longer operational life.

### 3.8 Overall Design of the Workstation

Figure 10 illustrates a final design of the work space that fulfills the set design criteria. It features the two-fabrication table design with a space for tool changing and alignment for the robot system.

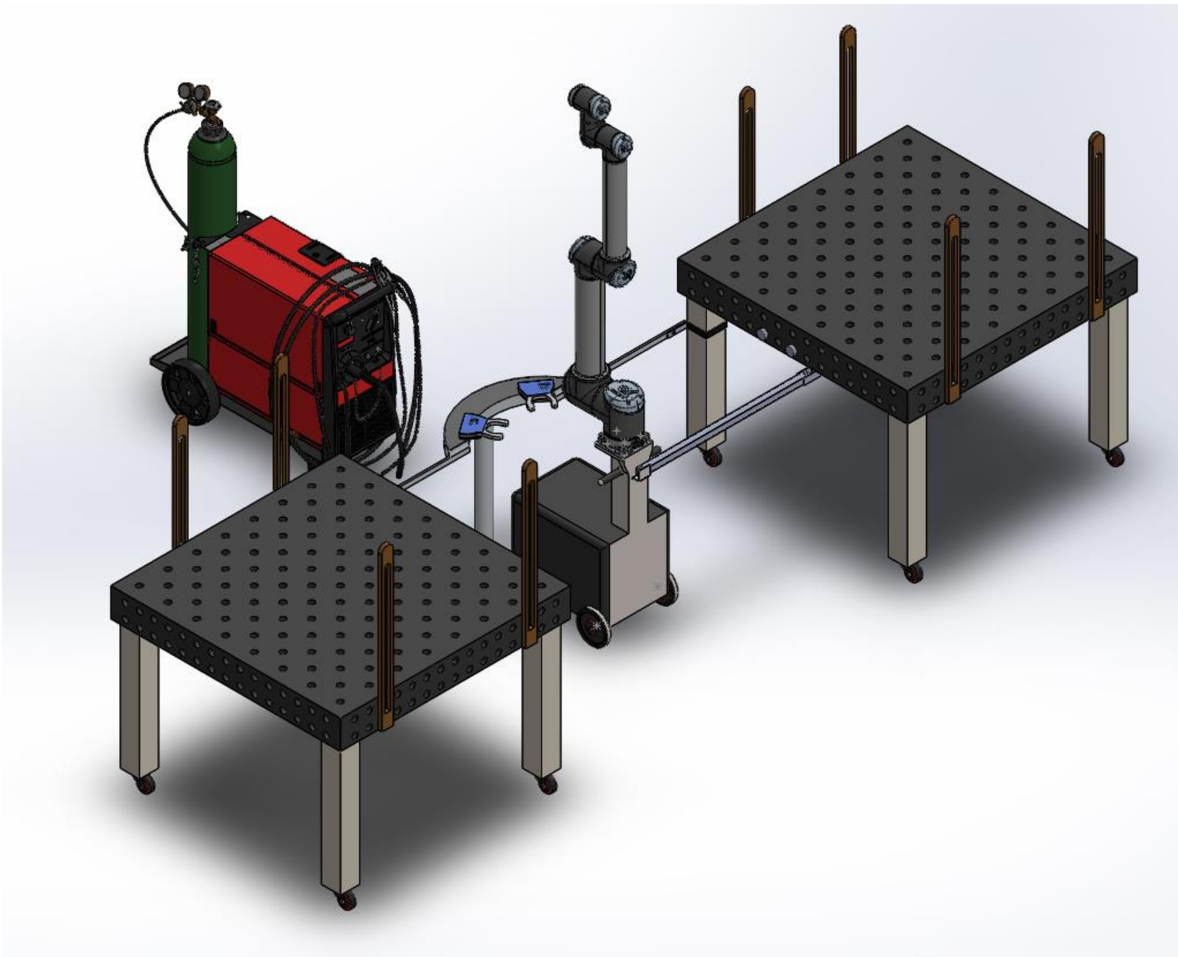

Figure 10 Work Station Design

# 4 Investment Evaluation

**Investment Costs**

| | |
|---|---|
| Universal Robot UR10 | 36000€ |
| Table and accessories | 8000€ |
| Welding machine with robot interface accessories | 14500€ |
| System Cost | 58500€ |

**Welder Wages**

Early payment for a welder 35360€

Including employee benefits and supplementary expenses

(17€/hr, 8hrs/day, 5 days/week for 52 weeks)

Robot replaces two welders so savings from welders 70720€

A case study has been conducted in Prepipe where twenty joints of DN500 pipes was prepared and welded in a week by a welder. Joint preparation (tack weld) consumed two working days and remaining three days, welding has been carried out (Myllys, 2018). When using a robot, welding can be completed in a day or day and half, saving one or two working days in a week. On average saving twelve hours in a week approximating 500-700 hours can be saved annually. This time saving result can be achieved because robot can make a complete 360˚ weld in a single run unlike manual welding, pipes are loaded to the roller and the pipes are welded in two or four sections to complete the whole pipe, the sections depends on the accessibility of the welder and resource savings calculation are shown below.

Average Time Saved annually = 12 hrs/week * 52 weeks = 624 hrs

Average Money Saved annually = 624 hrs * 17€/hr = 10608€

Which is 30% of the annual working hours and the salary of a welder.

For calculating the payback period and return on investment, Raye from California Polytechnic State University has derived robot investment formula for companies, which is given below.

$$P = \frac{C}{W + I + D - (M+S)}$$ (Raye, 2015)

$$ROI = 100 * [\frac{W + I + D - (\frac{C}{N} + M + S)}{C}]$$ (Raye, 2015)

D = C / N (Raye, 2015)

Where,

| | |
|---|---|
| P = Payback Period (year) | ROI = Return On Investment (%) |
| C = System Cost (€) | W = Wages Saved (€) |
| N = Life of Robot (year) | S = Robot Operator Cost (€) |
| D = Depreciation (€/year) | I = Robot Savings (€) |
| M = Maintenance Cost (€) | |

Rated life for the robot is 40000 hrs operated with a full payload and speed.

D = 58500 / 5 = 11700 €/year

$$P = \frac{58500}{70720+10608+11700-(2000+35360)} = 1.05 \text{ years}$$

$$\mathrm{ROI} = 100 * \frac{70720+10608+11700-(11700+2000+35360)}{58500} = 75.16\%$$

The approximated payback period is around 1.05 years and 75.2 percent of ROI, these results help the company in making investment decisions.

# 5 Programming

There are two types of traditional robot programming methods, which are Pendant teach programming and Offline programming (Motoman, 2014). The Pendant teach programming method has three types of jogging functions which are tool, world, and joint modes. The Tool mode holds the position of tool's angle and then moves the x, y and z axis. Robot also known as xyz coordinates or world mode ignores the tool angle position and moves it in the x, y and z axis. The joint mode allows the user to move each joint individually. Other parameters are manually selected according to the users' configuration.

Offline programmings are made with computers. There are two ways of programming. Using robot simulator software like, for example, RoboDK the robot workstation model can be imported. Welding path code is generated and then imported to the robot for welding. Another way of offline programming is by capturing the welding path or coordinates by using a measuring arm and then uploading to the computer for generating the welding path program. The generated codes are uploaded to the robot. (Owen-Hill, 2016)

One of the biggest disadvantages of these approaches to programming is time consuming methods. Even a simple program consumes more time then when compared to teach by demonstration method. Some advantages of these programmings are used for painting, it has the ability of assigning values like 10.5 centimeters, so the tool can move accurately the distance for applying another layer.

Universal Robots uses their own programming language called URScript (Universal Robots, 2015). Users mainly use teach by demonstration method because of its easiness. The teach by demonstration method is also known by kinetiq teaching from manufacturer Motoman. This method takes the next step in robot programming, the robot operator can move the robot arm to teach the coordinate points which gives the freedom of making complex tasks simpler and for more accuracy they can switch to traditional methods. The graphical user interface (pendant) is simple and easy to understand for programming.

### 5.1 TCP Installation

TCP is usually zero in the center of the flange. In many robots, TCP is measured manually in x, y and z axis and dialed to the settings. In UR10, the TCP can be entered manually or semi-automatically calibrated, by pointing the tool tip to the same location from three different angles. *Figure 11* below illustrates the process.

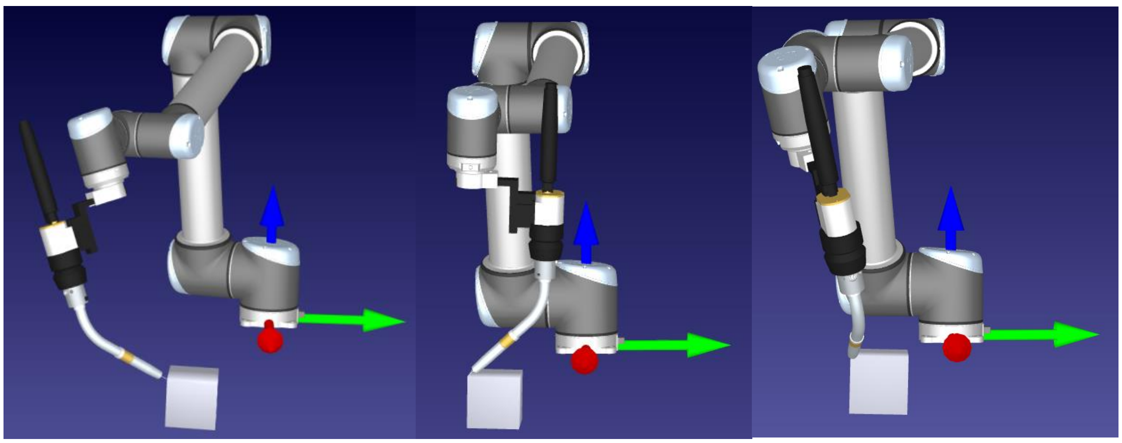

Figure 11 TCP Illustration

From the images, the welding torch tip is pointed to one corner of the cube which is shown on the left side of the figure and other two images show the torch is pointed to the same location but in different angles (Universal Robots, 2015, pp. II-23 to 25).

### 5.2 Types of Moves

To program the waypoints, the move command is used. There are three types of movement, Move J, Move P, and Move L (Universal Robots, 2015, pp. II-48 & 49). Joint move or Move J is a non-linear move from one point to another. It can be used when the TCP movement is not important, and the speed is not constant throughout the path. Linear move or Move L makes a linear move of the TCP to the specified waypoint where TCP speed is constant throughout the move which will be useful in painting. Process move or Move P is similar to linear move but incorporates a circular move with a linear way path. One command of Move P can only make a 180˚ arc. To make a complete circle (360˚) two circle moves are made which is explained in a later part of the demo program. The speed of the TCP is constant, and it can only make blend radius and cannot make a sharp edge turn. Blend radius can be adjusted according to the user preferences. This move can be used for welding and gluing (UR Academy, 2018).

### 5.3 Demo Program

To make a circular way path for pipe welding, process move (move p) was used, a three-point way path should be defined. They are start, via and end points. *Figure 12*a) shows the start point of the way path. 12b) is the via point and should be defined in the middle of the start and end points. 12c) is the end point of the way path. The same procedure has been followed for the other half of the pipe to complete a circle.

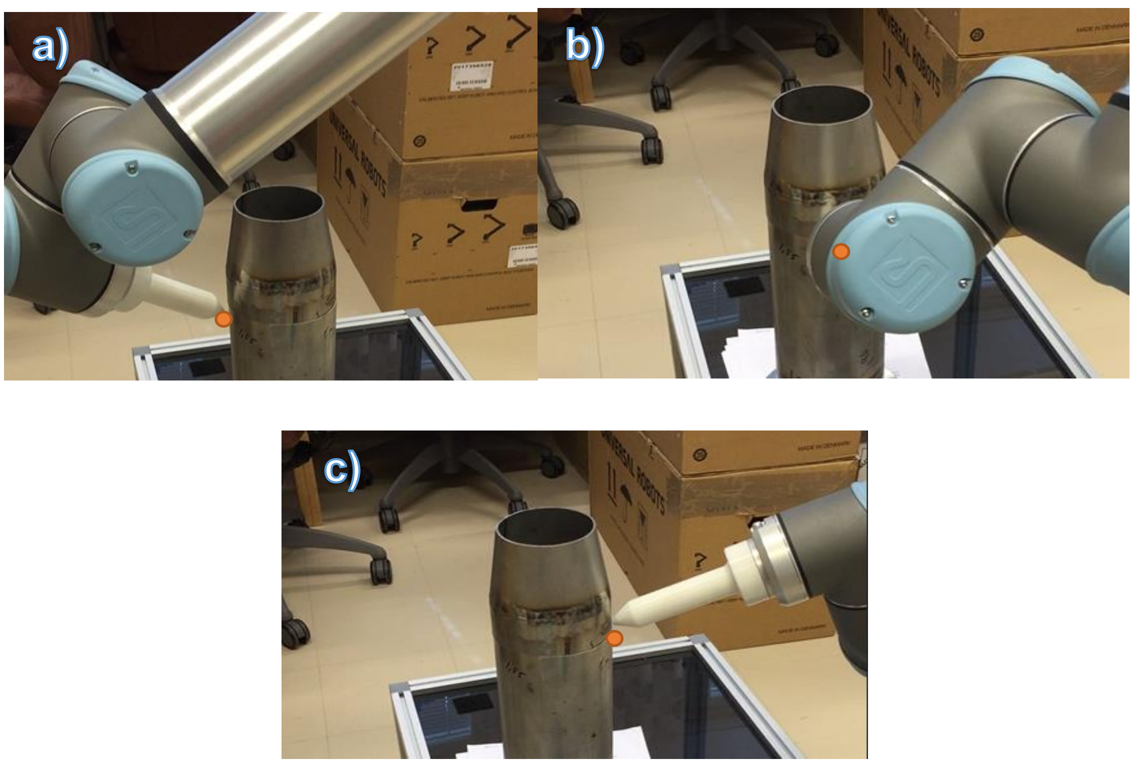


Figure 12 Circular Move Illustration

An experiment was also conducted to make a complete 360˚ run in a single program, by using the same start and end points but the via point was selected on the opposite side of the start and end points. For example, from the images, start and end points are shown in the image a) and via point in image c). The program could not be executed correctly. Instead of a horizontal circular move it was making vertical circular move. From the experiment it was concluded that, to make a complete circle at least of two circular moves should be programmed. *Figure* 13 shows the program which was executed.


Figure 13 Executed Program

From the tree program view, the waypoint_1 is the home position. The second move P is including a circle move for the first half waypoint of the pipe (semi-circle), where waypoint_2 is the start point. The last move p is the second half waypoint of the pipe, where waypoint_3 is the same position of the endpoint_1 to continue the loop from the previous move. In this way a complete 360˚ weld path can be achieved.

### 5.4 Technical Problems Faced During Programming

During programming a couple of technical problems were noted. Parallel wrists, the robot cannot execute the program if any of its programmed way point is positioned when the robot wrist 1(J3) and wrist 3(J5) are parallel as shown in *Figure 14*.

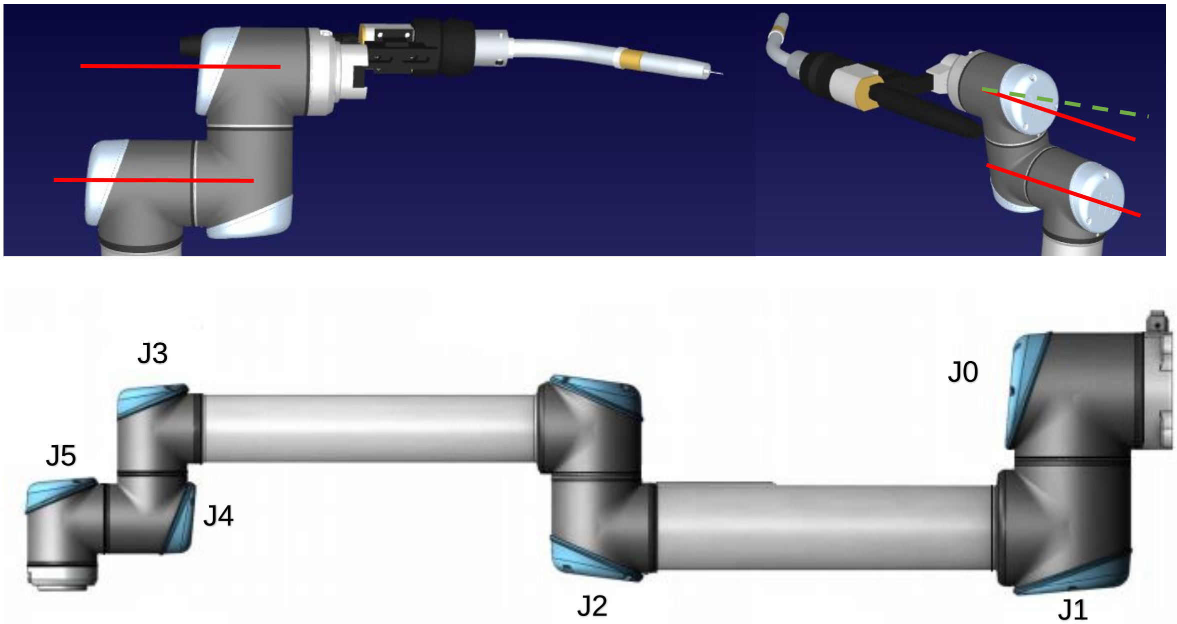


Figure 14 Robot Parallel Joint and Arm Configuration *(Universal Robot, 2016, p. 17)*

This problem can be resolved by positioning wrist 3 with a slight offset from wrist 1 which is shown in the right image in *Figure 14* with green lines.

TCP constraint was another problem. When the TCP constrain is enabled the program runs for few seconds and fails to execute it completely with a motor violation error message. The same program was performed again with disabling the constraint, now it works seamlessly with minor deviation in the TCP angle. The small numerical deviation was noted when it was simulated with the robot interface.

# 6 Welding System and Robotic Interface

For the welding machine, Fronius TPS 320i was chosen because of its advanced features incorporated with it that resolves the problem of welding thin materials. The TPS 320i has the capability to support communication between itself and the robot through Modbus fieldbus protocol. This is already preexisting hardware in PrePipe and was requested to be integrated.

## 6.1 Welder and Welder Supplementary

In PrePipe, pipes of DN 15 to 500 configurations are welded, the thickness can vary from 2 mm to 15 mm. The welder should be configured with the PMC feature, the features include penetration stabilizer and arc length stabilizer (Hummer, 2016). Penetration of the weld is mainly determined by the welding current. When the torch is too close or too far from the workpiece the penetration increases or decreases with overshooting the values of the parameters. This causes a poor weld. To overcome this problem the penetration stabilizer automatically stabilizes the penetration by adjusting the speed of the filler wire to maintain constant current throughout the weld. This way the lack of penetration and burn through problems can be controlled (Fronius , 2013). *Figure 1* shows that the welding current and penetration is constant throughout the process even though the stick out distance varies. The results are on the images on the right, where I[A] refer to current and, Vd[m/min] refers to speed of the wire.


Figure 15 Penetration Stabilizer Enabled *(Fronius , 2013)*

Welding in corners can be easily performed with less heat input to the material. Since the pipes material is austenitic stainless-steel, less heat input in to the material is safer since austenitic SS is more prone to sensitization. Sensitization is an intergranular corrosion in heat affected zone due to the precipitation of chromium carbide at grain boundaries which causes corrosion to the welded region over time (Lincoln Electric, 2003, p. 4) (SSINA, 2008).

*15* shows the disabled penetration stabilizer, from the weld result on the image on the right, 2, shows the lack of penetration. The left image, as the torch distance is increased, there is a significant drop in the current which causes change in penetration of the weld.


Figure 16 Penetration Stabilizer Disabled *(Fronius , 2013)*

Arc length stabilizer is an automatic correction function that maintains arc length throughout the process regardless of the change in torch position and thickness of the workpiece (Wiliamson, 2017, p. 11). Arc length is directly related to the voltage, shorter arc reduces the voltage and duration of the arc by providing reliable droplet transfer which minimizes the bonding defects and spatters (Robotics Online, 2014). With the combination of the arc length and the penetration stabilizer consistent quality welds can be achieved.

For the welding supplementary, TPS 320i welder can be configured with wire feed unit WF 25i R/4R/G/W/FSC, which can feed wire at the speed of 1 to 25 m/min and takes the wire diameter of 0.8 to 2.4 mm (Fronius, 2014, p. 32). With a MHP 700i ML M/W/FSC/3.5 m hose kit and a MTB 400i ML/W/45˚/L168/H77 torch this would complete the welder set up.

In robotic MIG welding, the hoses should be properly guided because of the robot’s arm movements. The hoses could get twisted which causes gas flow restriction which leads to porosity in the weldments (WeldReality, 2009).

### 6.2 Robotic Interface

A robotic interface connects the robot to the welding machine (welder) so that the parameters can be adjusted, and other functions can be controlled from robot the interface by the user. Communication can be established in two ways by standard I/O and Fieldbus (Fronius, 2010) (Fronius, 2012, pp. 27-29). Fieldbus Interface is used because of its flexibility, all the signals are on bus, whereas in standard every signal must be wired individually. There is a wide choice of fieldbus, in which Modbus protocol is used (Fronius: Williamson, 2013, p. 12). Universal robot can be easily set up for MODBUS TCP communication. Modbus communication system uses a Master/Slave or Client/Server technique, where the server receives the requested information from the client, processes it, and returns to the client. If the server is unable or cannot perform the requested process it sends a message back to the client with the error message through Modbus protocol (Acromag, 2005, p. 3). In Robotic interface, the robot is used as the client and the welder as the server, so the user can take control of the welding machine and the robot movement from the touch display of the robot. Two items are needed to pair the welder to the robot, RI FB Inside/I /IK Standard Fieldbus Interface and RI MOD/I CC ModBus 2P from Fronius (Kirmanen, 2018). Table *I* shows the signals that can be assigned for the user's requirement are shown.Table *I*, the signals that can be assigned for the user's requirement are shown.Table *I*, the signals that can be assigned for the user's requirement are shown.

Table I.

| Signal Type | Signal | Description |
|---|---|---|
| DI | Arc ON | To start the welding process. Depends on three signals. Starts the process when there is no error in source error reset, robot ready and power supply ready is in ON condition. |
| DI | Gas Test | To test and correct the pressure regulator. |
| DI | Robot Ready | It is an emergency stop feature that disables the welding process. Can be configured to the pre-existing emergency button on the robot pendant. |
| DI | Source Error Reset | The errors on the power source is cleared when the signal is passed. |

| | | |
|---|---|---|
| DI | Wire retract | Wire retract feeds the wire without starting the welding process. |
| DI | Blow Through | Pressurized air is blown through the nozzle for cleaning. |
| DI | Torch Collision | When torch is collided, the power source is shut off to stop the welding process. |
| DI | Welding Simulation | This feature allows the welding to be stimulated in the weld path without arc, wire feed and gas flow. |
| DO | Arc Stable | Maintains a stable arc throughout the welding process. |
| DO | Power Supply Ready | This feature is enabled when the robot is ready and source error reset has a green signal. |
| AI | Arc Length Correction | Changes the voltage from the power source in a range of 0V to 10V. Where 5V is the actual voltage, 0V reduces the actual voltage by 30%, and 10V increases the actual voltage by 30%. |
| AI | Welding Power | Controls one of the three parameters. It changes the other two automatically. The parameters are wire feed speed, welding current, and material thickness. Changes of the parameters values range from 0V to 10V. |
| AI | Pulse Correction | It controls the force of the droplet detachment in the range of 0V to 10V. |
| AO | Actual Welding Voltage | Reference voltage set in the power source |
| AO | Actual Welding Current | Reference current set in the power source |

(Fronius: Williamson, 2013, p. 14)

# 7 Robot Over Orbital Welding

Robot welding was chosen over the orbital welding because of the lack of consistent results achieved from the orbital. PrePipe have done several tests with Orbimatic 165 CA with an Orbiweld TP600 open weld head. Like with other orbital welding the head is incorporated with TIG process. Due to ovality and change in the wall thickness in the pipe, high heat input causes holes in the pipe sections where the wall thickness changes. The *Figure 1*7 shows successful results on the left and center and a failed blow through hole on the right.

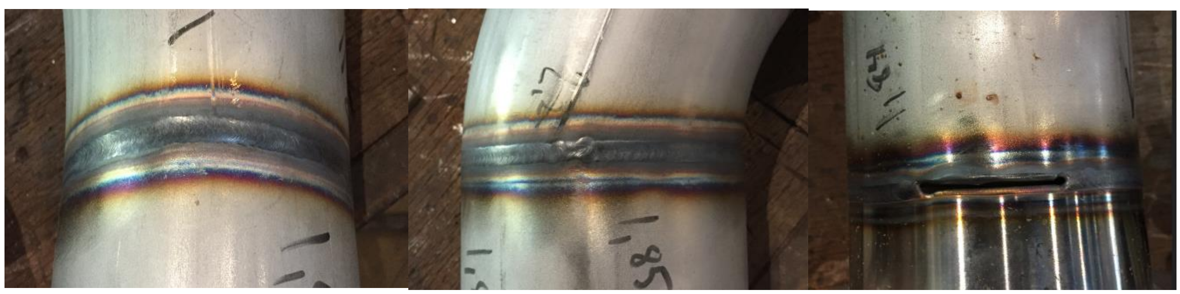

Figure 17 Results of Orbital Welding

Orbital welding has a quick set up time and is more portable than robotic but different configurations of the weld head are needed for varying pipe sizes. Since PrePipe has difficulties working with orbital welding by getting inconsistent weld results, PrePipe is looking for another alternative solution to overcome. A robot with Fronius welder can solve this issue and provide reliable quality of welds. Compared to the orbital welding process the semi-automatic robotic welding has more advantages over it. Listed they are that: two pipes can be welded in a single loading set up, robot tools can be switched for other processes without human involvement, and the welding torch can be removed from the robot for manual welding. To conclude, advanced orbital welding with arc control systems can be used but flexibility of the robot welding cannot be matched with orbital welder.

# 8 Summary and Conclusion

The main goal set for this thesis by PrePipe was to develop and justify introducing a robotic semi-automatic welding process into their company. Through discussions this main goal was refined into smaller more tangible objectives. The integration of their pre-existing welding hardware, the ability to work around the robot while it is in operation, and future upgradability with different tools was raised then. Over all, we have achieved these objectives and goals in our recommendations, designs, and analysis brought up in this thesis.

For the reasons brought up in the sections before the selection of the Universal Robots UR10 can be justified due to its flexibility and cost efficiency. The workstation is a useful addition to the work processes even without the addition of the robot. Adding more table space with the possibility to clamp many different size pipes and workpieces will also aid the welders during manual welding. According to the economic analysis, with a good projected ROI of 75,16% and payback time of only 1,05 years, with higher percentage of ROI and shorter payback time it could be a good investment. The calculations are based on well-educated estimations of pay and work time. The true worked hours are more flexible with the possibility of unexpected break downs and the pay of the welders also changes on a yearly basis as their training and workmanship improves. Over all the calculations do well enough job of modeling reality to be useful as investment guides. The robot will also result in increased cash flow. By freeing the welders and gaining back approximately 30% of working hours annually this helps the company take on more projects. By the robot implementation health hazards to the welders can be minimized by not subjecting them to the harmful welding fumes.

In addition to the risks that we have analyzed there are still many other factors from the robot or workshop environment that may influence the operation of the welding process.

# 9 Future Work

Most of the current work has been theory based and preparing for the future practical tests. The next steps are to do trial runs with the equipment to find out problems and help redesign the package. There is also work in gaining qualifications and certifications to use the robot’s welds in projects. The operators also need to be training and experience to ensure better workmanship. Welding programs for the robot should also be made.

While the idea of multiple tool heads has been brought up there is still more work to integrate them into the system. There is discussion of implementing a laser source to the tool head to cut pipes. Currently a local laser cutting company is doing this work. The shipping times add a whole week to the start of the welding process causing delays. Human safety considerations are also a point that will need to be thought of while working to integrate it into the current system.

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