

# Cost Effective Welding System by using AR3 Robot

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**Abstract:** *Innovations in the field of robotics and image processing have enabled robotic welding to slowly become the new standard for companies that are heavily invested in the process. However, the cost of such autonomous systems makes them accessible to only the elite; hence, without a sizeable investment, smaller companies are left behind the competition. The article describes a cost-effective solution to the process of autonomous welding through the use of a structured light set up along with an open-source robot and its design issues. A prototype of the proposed system has been developed with the results available.*

**Keyword:** *Automated Welding; AR3 Robot; vision (;)*

## 1. INTRODUCTION

Welding is a key process in this study with every product requiring one. Developing an automated manufacturing procedure for the full variance of product is an impossible task and as such for this automated welding setup we shall limit ourselves to the smaller sized products. Still, at smaller sizes having a passively automated manufacturing process would require a human to program every single of the variances found in each product which with so many is not an option. Hence, a dynamic system is required capable of automatically identifying the variances in the weld seam. As a result of this variance in the product, the weld seams location does change, and even when it doesn't change drastically no two products are ever exactly the same.

The weld of the product in question is very clearly visible meaning that it must be aesthetic but at the same time structurally strong. For this reason, TIG welding without filler will be used in this study as it is very presentable and although it is the slowest out of the welding process it produces some of the strongest welds.

This research aims to develop a cost-effective solution demonstrating the feasibility of such a system, which could lead to the investment of an industrial system.

One of the most common configuration for robotic welding consist of a 6 axis setup as their flexibility offer a greater range of operation, consequently allowing for more complex welds to be undertaken. With the increased range of operation, the robot can become a danger to any operative, and as such a number of safety precautions need to be put in place.

Fences are usually employed to surround the robot whilst sensors are placed on all entrances, which terminate any production processes if triggered by any individual entering the area whilst under production. Welding robots most commonly utilize MIG welding and although TIG welding is a possibility it can be more challenging to complete successfully. Using a robotic welder has certain advantages, but it also has some drawbacks. The initial costs involved in purchasing and setting up a robotic welding station make these systems inaccessible to smaller companies with a limited budget. Even when purchasing such a system, it comes with some caveats, as appropriately trained staff members must program it, ensure correct placement of the workpiece, and maintain it.[1]

The need for a highly reliable seam monitoring device must be included in our implementation of an automated welding station, as such one of the various implementations of seam tracking setups must be selected. Non-vision-based sensors and vision-based tracking sensors are two types of methods that have been shown to successfully detect such welding seams. Arc-sensing is the oldest and most popular non-vision-based sensor, which is capable of tracking the seam via various electrical parameters whilst accordingly adjusting the current as the distance between the work-piece and the welding torch changes.[2] However good the accuracy of non-vision-based sensing is getting; it will almost certainly be lacking in comparison to vision-based tracking sensors. Ultrasonic sensors saw some success in the 90s due to their low computational power requirements. In very basic terms, in ultrasonic sensors most of the energy emitted from the transmitter which "bounces" off a flat surface is captured by the receiver. However, if a break is

introduced to the flat surface, then part of the emitted energy will be scattered indicating the presence of a seam. Research has indicated the feasibility of such systems as seen by [3] and [4]; however, some forward-thinking researchers realized very early on that, ultrasonic sensors lack the accuracy offered by competing systems [5].

With the exponential rise in computational power throughout the years, weld seam tracking methods have moved towards other forms of contactless sensors which are widely used in industry and rely on vision. In these sensors, cameras are employed along with a laser stripe sensor in a setup based on laser triangulation otherwise referred to as a structured light setup as can be seen depicted. This is capable of offering some of the highest potential for accurate feature extraction. It is mainly related to the rich information capable of being extracted along with the previously mentioned quality of precision and relatively cheap implementation of the system. As a result, numerous studies have been conducted in which machine learning has been incorporated into the design. [6], [26], [20] and [14].

## 2. METHODOLOGY

This research aims to develop a cost-effective solution demonstrating the feasibility of such a system, which could lead to the investment of an industrial system.

Figure 1 provides an illustration of the processes our seam detection system goes through hand comprises of: Image Capture, Image Processing, Feature Extraction, Triangulation, AR3 Controller.

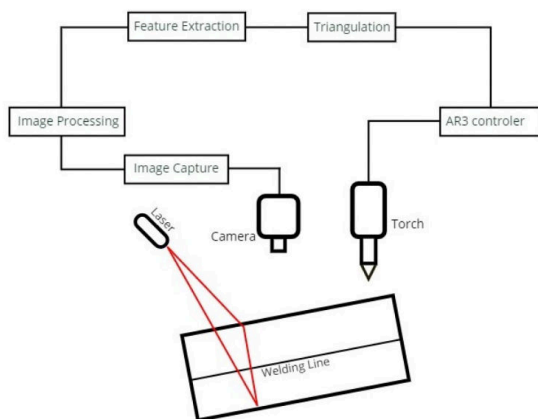


**Figure 1: Schematic of seam detecting system**

The components featured in this system consist of an off-the-shelf red laser line diode, a raspberry pi v3 camera, a 16mm telephoto lens, a red filter covering the lens, and a raspberry pi 3b+. The camera, laser, and raspberry pi 3b+ are all housed in the same enclosure with the laser and camera being situated in a particular way in reference to each other. Due to certain limitations that shall be addressed in a later stage, the housing of these components could not be attached to the end-effector along with the welding torch, however, their viewing direction is the same.

Robots come in various shapes and feature different joints as shall be seen later. However, the goal of any robot is to correctly position its end-effector through space. The term end-effector refers to the robot's final point and can be thought of as the robots fingertips in our case the tip of the welders tungsten electrode.

### 2.1 System Process

Capturing the image with the laser clearly visible is the crucial first step to this process: to accommodate for this the environment needs to be as dark as possible as any light will weaken our laser beam as well as make the stainless steel more reflective. Ensuring that the environment is "ideal" will make the image processing much easier and more reliable.

Once the client has acquired the image from the server it puts it through an image processing algorithm to acquire the point of interest which in our case is the weld seam. This process results in the acquisition of the relevant pixels coordinates (x and y), which are then passed onto the triangulation algorithm for the distance measurement. Acquiring the X, Y, and Z coordinates from this process in reference to our camera now enables us to calculate the desired position the end effector needs to be located at through the robot's forward kinematics.

### 2.2 Camera Calibration

In our case, the calibration procedure has been carried out using the open-CV library through a randomized set of images depicting a 7x9 checker-board featuring 20x20 mm squares as shown in Figure 2.

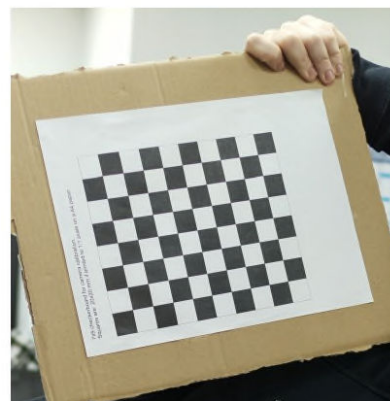


**Figure 2: Camera calibration example image**

### 2.3 Distance Measurement

The camera's center is located at our origin frame. Solving this triangulation problem requires that we know the distance from the centerline of our camera and laser denoted as  $b$ , the angle of our laser in reference to the camera denoted as  $\theta$  and the lenses focal length denoted as  $f$ . Parameters  $b$  and  $\theta$  are set in stone as these values are picked during the design of the housing, whilst  $f$  needs to be derived from our cameras intrinsic parameters which shall be identified

during the calibration process.

The the XZ plane has been used to figure out the X distance. the equations are following:

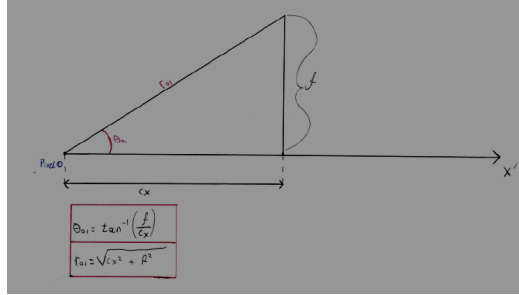


Figure 3: XZ for finding  $\theta_{01}$

By using Figure 3 above the  $\theta_{01}$  can be found as following equation.

$$\theta_{01} = \tan^{-1} \left( \frac{f}{C_x} \right)$$

And

$$r_{01} = \sqrt{C_x^2 + f^2}$$

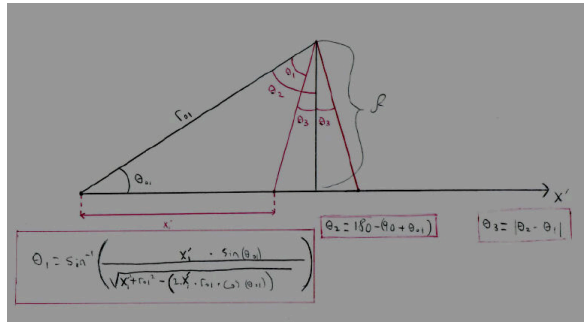


Figure 4: XZ to find  $\theta_1$  to  $\theta_3$

According to Figure 4 the equations of  $\theta_1$  to  $\theta_3$  can be found as following:

$$\theta_1 = \sin^{-1} \left( \frac{x'_1 \sin(\theta_{01})}{\sqrt{x_1'^2 + r_{01}^2 - (2x_1' r_{01} \cos(\theta_{01}))}} \right)$$

$$\theta_2 = 180 - (90 + \theta_{01})$$

$$\theta_3 = |\theta_2 - \theta_1|$$

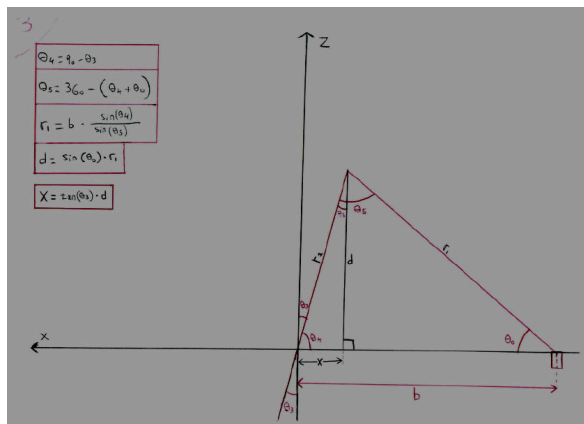


Figure 5: XZ to find X distance

The rest of the joint angles and X distance can be found from Figure 5 are following:

$$\theta_4 = 90 - \theta_3$$

$$\theta_5 = 360 - (\theta_4 + \theta_0)$$

$$r_1 = b \frac{\sin(\theta_4)}{\sin(\theta_5)}$$

$$d = \sin(\theta_0) \cdot r_1$$

$$X = \tan(\theta_3) d$$

For YZ triangulation depiction as shown in Figure 6 the equation for the Y will be:

$$Y = \tan(\theta_{5y}) d$$

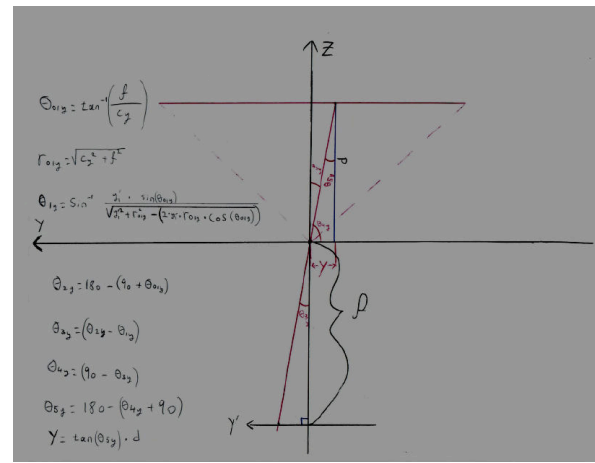


Figure 6: YZ to find Y distance

## 2.4 Image Processing

The identification of x and y pixel value is required in order to translate map the robot coordinate system to the camera coordinate system. A depiction of the image acquired from the camera can be seen in Figure 7. The red colour of the image has been enhanced as it has gone through the red filter found in front of the lens; this filter makes the red colours.

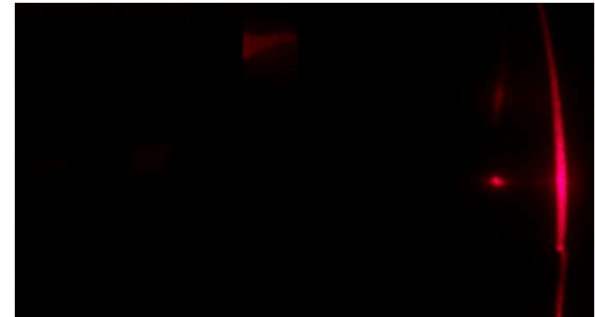


Figure 7: Seem Image captured from Camera

It might not be clear at first glance, but the laser line features a minor but abrupt change in the x-direction towards the bottom of the laser line, hence that is the point of interest. What is clearly visible however are all the specks of red light which is a result of the stainless steel highly reflective surface and as such

our first task is to remove them. Figure 8 shows that the red channel image has been converted to the grayscale image in order to reduce the computational cost. It is further converted to binary image. The irrelevant regions are also further eliminated.

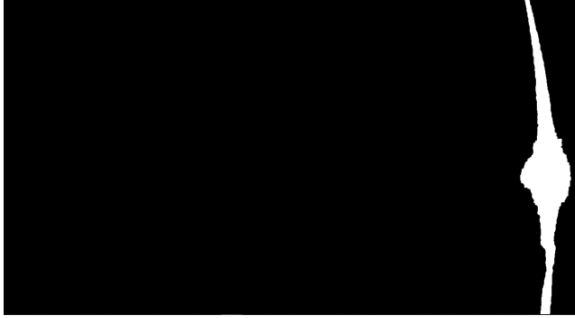


**Figure 8: Binary of grayscale image**

After removing the irrelevant regions there is clearly another problem, being that our laser line does not resemble a thin line anymore as there is a bulbous area located towards the center of the image. Going back to Figure 7 we can clearly see that in that region there is a lot of glare, this again comes as a result of the stainless steel reflective nature. An easy fix would be to decrease the amount of light entering the lens through its adjustable aperture; however, this is not a great solution as if an increase in light is introduced then we will see the return of this bulbous region. All problems aside, the region we are interested in is still clearly depicted but this region spans over many pixels. To narrow down the available pixels we utilise a thinning or skeletonization algorithm as it is sometimes called which should create a thin singular line allowing us to pinpoint our point of interest easily and accurately. The results of this process can be seen in Figure 9.

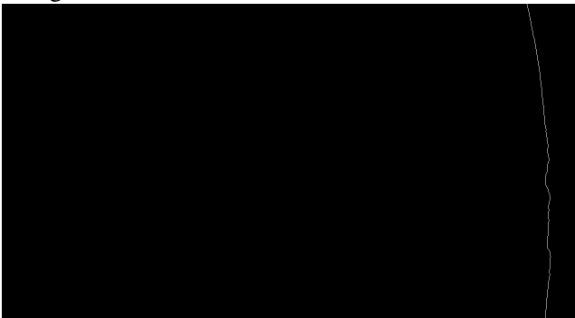


**Figure 9: Skeletonization**

The last step is to detect the point of interest is achieved through a customized function which in very simple terms find the most abrupt/steep slope featured in the line by comparing each pixel's location to each other. For illustration purposes, the x and y pixels derived from this process are marked onto the original image as can be seen in.



**Figure 10: Marked pixel on original image**

## 2.5 Robot Kinematics

The kinematics developed by the designer of this robot are reflective of its total rotary joints being 6 degrees of freedom (6DOF) with the addition of an optional extra coordinate frame for the tool. The problem was identified when the camera's coordinate system was calculated with respect to the robot's kinematics. The problem then identified in the design of the AR3 robot as numerous mathematical mistakes have been made throughout the process. This seems to have worked in the provided Anin software [7] indeed move the robot as expected but it makes the process of adding the end-effector and camera coordinate system proves the model not agreeing with the physical kinematics.

The first mistake is one of the fundamental engineering concepts which is the importance of a correctly drawn free body diagram. This becomes most apparent in this case as the robot's wire diagram developed by the designer is wrong. In figure the wire diagram is depicted. When applying each of the coordinate frames the designer must ensure that they all adhere to the same right-hand rule; this is not the case with coordinate system 3 as for it to be correct axis  $y_3$  should be the same as  $y_0$ .

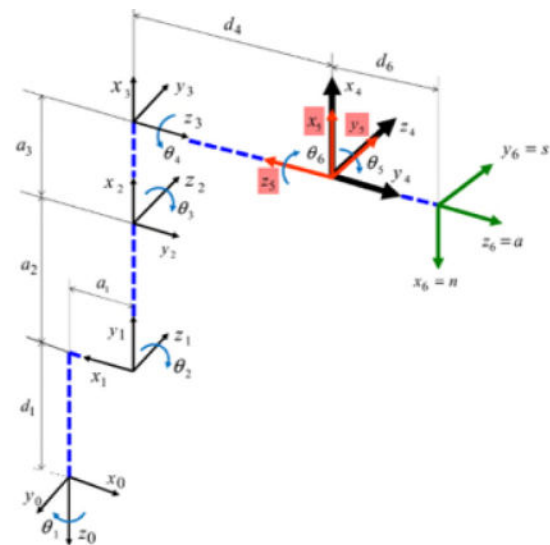


**Figure 11: Anin 6DoF Wire Diagram[7]**

This has ripple effect of problems in DH table and the inverse kinematics which has been solved during this

project. The wire diagram has been redrawn by considering camera location to solve its kinematics for that particular pose. [8] The way our camera has been placed onto the arm as shown in Figure 12 means that any movement around J4 would result in our camera not being aligned with the weld seam anymore, as such any rotation around J4 is undesired. Additionally, the way the torch holder has been designed makes the tip of the welding torch (end-effector) pass through the centre line of J6. So, excluding the undesired rotation around J4 and J6 as its rotation does not make a difference results in only 4DOF.



**Figure 12: Housing placement for camera - AR3**

The wire diagram has been designed for our customized problem as shown in Figure 13.

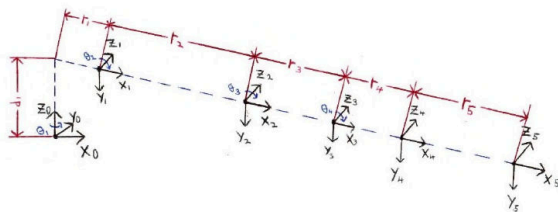


**Figure 13: Custom 4DOF wire diagram**

Following is the DH table for the customized wire diagram:

|   | $\theta$ | $a$ | $r$   | $d$   |
|---|----------|-----|-------|-------|
| 1 | 0        | -90 | $r_1$ | $d_1$ |
| 2 | 0        | 0   | $r_2$ | 0     |
| 3 | 0        | 0   | $r_3$ | 0     |
| 4 | 0        | 0   | $r_4$ | 0     |
| 5 | 0        | 0   | $r_5$ | 0     |

The rotation around each axis can be figured out using the homogeneous transformation matrix based on the

DH table above. The equations of rotations around axis is following:

$$R_x = \text{atan2} \left( \frac{H(3,2)}{\cos(R_y)}, \frac{H(3,3)}{\cos(R_y)} \right)$$

$$R_y = \text{atan2}(-H(3,1), \sqrt{H(1,1)^2 + H(2,1)^2})$$

$$R_z = \text{atan2} \left( \frac{H(2,1)}{\cos(R_y)}, \frac{H(1,1)}{\cos(R_y)} \right)$$

The system setup is shown below in Figure 14.

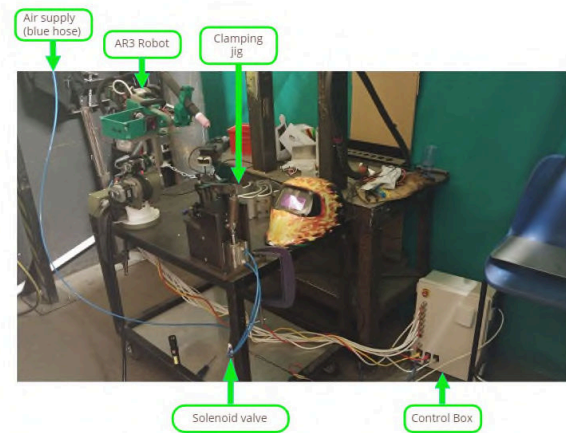


**Figure 14: Welding Cell Setup**

### 3. Results and Discussion

Multiple test rounds have been carried out to weld the part and each round helps to identify multiple problems from shielding to the heat control. Following are the settings for each tests:

| Test | Amperage (Welder power) | Robot Speed (Percentage of total speed) |
|------|-------------------------|-----------------------------------------|
| 1    | 40                      | 0.9%                                    |
| 2    | 40                      | 0.9%                                    |
| 3    | 40                      | 0.9%                                    |
| 4    | 40                      | 0.4%                                    |
| 5    | 60                      | 0.4%                                    |
| 6    | 60                      | 0.2%                                    |
| 7    | 60                      | 0.2%                                    |

One selected test from number 6 has been shown in Figure 15. This test only saw a minor decrease in the robot's speed. Yet another successful complete pass from the robot over the weld seam and had there been a little more heat we would have seen a better weld.

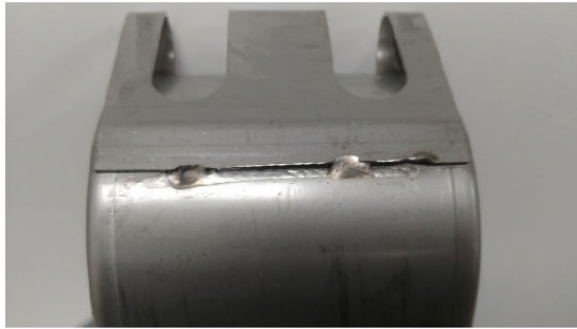


**Figure 15: Sixth Weld Test**

In the tests conducted it has been observed that the weld pool formed in some places, however, it failed to be carried along. This has been previously mentioned and comes as a result of the tungsten tip featuring 0 degrees of angulation in reference to the weld pool. To fix this the orientation of the end effector must be revisited in the kinematics so that an angle of about 30 degrees is achieved. This would help to direct the weld pool along the weld seam.

Another worthy point of discussion is the backlash introduced to the effector as a result of the poorly tensioned J5 belt. To account for this a rotation of -12 degrees is applied to the moves of joint J5. This number has been identified via testing and although it does work, the J5 belt tensioner must be redesigned to eliminate any backlash.

#### 4. CONCLUSION

Since no previously conducted research using the open-source AR3 robot which addressed its flaws was found, there was no procedure on how to deal with these problems. This resulted in a large amount of time being put into trying to decipher the inner workings of the robot so that these problems were understood, from which we could then judge if they were solvable or not, in our given time frame. Having said that, although the problems of this robot are not an easy fix they can be solved, at which point it could make for a very well designed robot, considering it is open-source.

This research study proves the workable weld system that can be developed and designed at minimal cost by using the open-source technology.

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