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MATLAB MODELING OF ROBOTIC MANIPULATIVE MOVEMENT FOR EFFECTIVE WELDING PERFORMANCE AND PROCESS AUTOMATION

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ABSTRACT

Robots application varies widely from simple toys, office appliances, to more sophisticated industrial robots used in materials handling as well as other tasks such as arc-welding, spray painting, assembly, cutting, polishing, milling and drilling. The use of robot for welding operations can be made faster in different environments, height, and orientation as desired. Mathematical modeling of a developed mini-arc welding robot is pivotal in the automation of the arc welding processes. The model development were achieved by the use of AUTOCAD pictorial view of the mini-robot in welding, AUTODESK inventor for the simulation and MATLAB to generate the numerical model in terms of time (T) as the dependent parameter, with a number of independent parameters (Speed of weld, width of weld, depth of weld, electrode extension and power input). The welding time will enable an operator to predict the most appropriate delivery time and also enhance the customer and operator relationship.

KEYWORDS: Application, Automation. Model, Numerical, Robot and Weld

INTRODUCTION

Technological advancement in the field of science has paved the way for the invention of complex and flexible machines for the reduction of human effort during industrial processes. This invention can be found in robot and robotics.

Robotics is an aspect of technology that deals with designing, modeling, controlling of robots' application (Sorenti, 1997). Robots are reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for carrying out variety of tasks (Robot Institute of America, 1979). Most tasks carried out by humans are been replaced by robots especially automated highly accurate demanding task. Robotics service in industries has varying laws guiding their applications (Ejiko et. al., 2018). These robotic laws include the application of robots so as not to injure humanity, secondly robots should not violate a higher order law, thirdly robots should obey orders given to it by human beings, except where such orders would conflict with a higher order law, lastly that robots must protect its own existence as long as such protection does not conflict with a higher order law (Robinette & Manseur, 2001).

The modeling of robots is pivotal in the holistic design of a robust robot which focuses on development of mathematical expression to illustrate the behavior of parts in relation to one another (Das & Dulger, 2005). Simulation performance is required prior to investigation with the actual construction due to following advantages such as easy set-up, low cost, speed and convenience. Simulation is quicker than the actual robots with the parameters displayed on the computer screen (Michel, 2004). The real-time simulation performance is required before the final design can be verified. The last stage is costly and consumes time in building the prototype (Kazi et al., 2002; Sokolowski & Banks, 2009). Simulation is a designer's behavioral prediction tool use in evaluating the performance of design robots; it is also use in optimizing the path planning of the process (Ionescu, et al., 2002; Leon, 2008).

Robot welding entails the use of mechanized programmable tools to fully automate a welding process

by both performing the weld and handling the materials. Robot welding is commonly used for resistance spot welding and arc welding in high production applications, such as the automotive industry (Cantanzariti & Sega, 2006). Robot arc welding is growing at an alarming rate and it's having about 20% of industrial applications currently. The major components of arc welding robots are the manipulator, that is the mechanical unit and the controller, which acts as the robot's "brain" (Hyland, 2007). The computer controls the robot by rotating individual step motors connected to each joint (some larger arms use hydraulics or pneumatics). Unlike ordinary motors, step motors move in exact increments. This allows the computer to move the arm very precisely, repeating exactly the same movement over and over again. The robot uses motion sensors to make sure it moves just the right amount (Leeb et al., 2007; Robinette & Manseur, 2001).

An industrial robot with six joints is closely related to the human arm having seven degrees of freedom. Robotic arm's moves an end effector from place to place. Robotic arms can be fitted with different forms of end effectors that suit its application. A common end effector is a simplified version of the hand which can hold an electrode and carry out welding operations. Robotic hands often have built-in pressure sensors (for gripping robots) that maintain the right pressure in gripping a particular object. This keeps the robot from dropping or breaking whatever it's carrying (Raveendra & Parmar, 1987). Joints, sliders and links are the major components that determine the degree of freedom.

Degree of freedom refers to the number of independent variables required to specify the configuration of the mechanical system. It is a term used to describe a robot's freedom of motion in three dimensional spaces specifically. It is also the number of independent inputs required to drive all the rigid bodies in the mechanical system (Hyland, 2007).

The point of modeling motion this way is that engineers can predict the range of motion of a complex object such as a robotic arm, and thereby assess the trade-offs between flexibility of motion versus complexity and cost.

The three degrees of freedom in the robot arm as shown in Figure 1 are the rotational traverse, the radial traverse, and the vertical traverse which are by yaw, the side-to-side movement, the roll that effect swiveling and pitch for vertical rotation (Hyland, 2007).

A robot requires a total of six degrees of freedom for maximum flexibility; most applications make use of three to five degrees. As the degree of freedom increases so also is the complexity. In this work four degree of freedom (DOFs) were applied to achieve the following movement. These movements involves moving up and down (heaving), secondly, moving left and right (swaying), thirdly tilting forward and backward (pitching) and lastly tilting side to side (rolling), which is in relation to Pennestri, et al., (2011) study.

HISTORICAL BACKGROUND

Flipping through the pages of history, studies have revealed that ancient Greece and Egypt started using the crude form of robots for accomplishing various kinds of works. With the passing time, robotics saw further developments. The design of robots became more and more sophisticated, with the increase in the capacity of the machines to do work. Humans' fascination with robots dates back to antiquity. Although the term robot was coined in 1920, inventors have been trying to build machines that mimic life since ancient times.

The Beginning: The history of robotics is connected to ancient Egypt, where priests used steam-activated mechanisms to open the doors of their temple. During the 350 BC veteran Greek mathematician named Archytas constructed a mechanical bird called 'the Pigeon', a robot powered by steam and has the ability to fly in the air. This model airplane became a milestone in the history of robotics.

Crucial Period: In the beginning of the 19th century, a number of robots were invented. The automated loom was invented by Joseph Jacquard in 1801; it was operated with the use of punched card as input device. Charles Babbage invented the 'Analytical Engine' in 1822 which was inspired by Joseph Jacquard's invention. Babbage's invention also made use of punch cards for its operation.

Modern Era of Robotics Robotics gained immense popularity in the early 1900s, which is considered the modern era of the field of robotics. The first industrial robot was invented in 1962 and named as 'Unimate'. General Motors used the robot to perform repetitive or dangerous tasks on its assembly line.

Present Day: Today, robots come in many shapes and sizes. These include simple household robots use in performing tasks such as vacuuming or mowing the lawn; toy robots for entertainment and commercial robots for performing human functions repetitively, especially the dirty or dangerous tasks, such as arc welding operation. Today's robots can walk on two legs, play the piano and ping Pong (Craig, 2004; Lawrence & Matthew, 2010).

MATERIALS AND METHOD

The system development involves generating a sketch from which the working diagram is produce base on specification of the number of links required, the types and number of joints, length, breadth and thickness of

materials to be welded and the electrode length and diameter. The robot configurations are shown in Figures 2 to 4. The comprehensive list of the components is presented in Table 1.

Operation sequence: The orientation set for the usage of the machine is based on welding a work piece set in a linear configuration parallel to the machine base. Figure 1 shows the machine having four 4 degrees of freedom, starting from one end of the workbench to the other end and back. An electric motor (stepper motor) is needed here to actuate the motion and an automatic electric controller, which is integrated within the motor component, will be used for accelerating the motor from rest to normal speed and for stopping the motor. There are two wheels at the base of the robot that enables it exhibit a translational motion on the guide rails. The step motor transmits power to the gears through the shaft that emanates from it. The gears used are spur gears and as they receive motion from the step motor, they actuate and as a result, move the link. The set of gears are enclosed or held in position by holding blocks which are positioned at opposite ends of the gears. The electrode is held in place by the tounge tops and it sticks out of them at an inclined angle which is the standard suitable for arc welding. As the robot is powered, the wheels at the base of will move along the rail being guided appropriately by the guide rail. The welding machine is enclosed within the system- just between plywood 2 and plywood 3-. The rotary platform rests on the step motor 1 which also rests on plywood 3. As the motor actuates, it enables the robot through the rotary platform to achieve a rotary motion or to rotate about the motor which encourages welding operation in a 360° range.

Degree of Freedom of the Robot The degree of freedom of the robot was obtained using equation 1 as given by Grubler (2011).

$$F = \lambda(n - j - 1) + \sum f_i \quad (1)$$

Where,

F = degree of freedom,

λ = degree of freedom in space in which the mechanism functions,

n = number of links, j = number of mechanism joint,

f_i = degree of freedom permitted by each joint.

Therefore from the robot configuration, the following were obtained:

$$\lambda = 6, n = 5, j = 4 \text{ and } f_i = 1$$

$$F = 6(5 - 4 - 1) + \sum (1)$$

$$F = 4. (4 \text{ degrees of freedom})$$

The degree of freedom was verified using equation 2 as given by Khurmi, (2012)

$$F = 3(n - 1) - 2j - h \quad (2)$$

where,

h = higher pair

$$F = 3(5-1) - 2(4) - (0)$$

$$F = 12-8$$

$$F = 4. (4 \text{ degrees of freedom})$$

Graphical model: A graphical model is a probabilistic model for which a graph denotes the conditional independence structure between random variables.

Developed numerical model: Models are generated by analyzing various parameters, this involve using the

available parameters as stated by Ejiko et. al., (2009) and Oladebeye and Ejiko, (2007), a mathematical model was developed to determine the weld time in minutes. In this work, the model was generated using the following parameters:

Dependent parameter

- i. Time

Independent parameter

- i. Speed of weld
- ii. Depth of weld
- iii. Width of weld
- iv. Power required
- v. Gauge of electrode

ρ = Density in kg/mm³
 A = Weld area for a single pass in mm²
 S = Speed in mm/min
 i = Welding current in amps
 d = Diameter of electrode in mm
 L₁ = Stick out of electrode in mm
 L₂ = Weld length in mm
 T = Weld time or time required to perform the welding operation in min
 MR = Melting rate in kg/min

the melting rate is given by Singh (2010) in equation 3

$$MR = \frac{1}{10^3} 0.35 + \frac{d^2}{645} 2.08 \times 10^{-7} \left(\frac{iL_1 \times 25.4}{d^2} \right)^{1.22} \text{ kg/min} \quad (3)$$

since the melting rate is given in kg/min, a model is required to establish the time in minutes (min)

$$MR = \frac{\text{kg}}{\text{min}}$$

Recall mass (m) is in kg
 density (ρ) = $\frac{m}{v}$ (4)

$$\text{Mass (m)} = \rho V$$

Therefore, $MR = \frac{\rho V}{T} = \frac{\text{kg}}{\text{min}}$ (5)

But $V = AL_2$ (6)

Where A = Cross section of weld to be determined by weld type and thickness,

L₂ = Length of weld or weld length (Taking all dimensions for length in mm)

$$MR = \frac{\rho}{T} = \frac{\text{Weld volume} \times \text{Density}}{\text{Time}} \quad (7)$$

$$MR = \frac{\rho AL_2}{T} \quad (8)$$

But $L_2/t = \text{Speed (S) in mm/min}$

$$\frac{L_2}{T} = \frac{MR}{\rho A} \quad (9)$$

$$\frac{\text{kg}}{\text{min}} \frac{\text{mm}}{\text{mm}^3} \text{mm}^2 \quad (10)$$

So $L_2/t = \text{mm/min}$ (11)

But we are looking for time in minutes therefore,
 from $L_2/t = \frac{MR}{\rho A}$

$$\frac{MR}{\rho A} = \frac{10^{-3} \left[0.35 + \frac{d^2}{645} + 2.08 \times 10^{-7} \left(\frac{iL_1 \times 25.4}{d^2} \right)^{1.22} \right]}{\rho A} \quad (12)$$

Therefore, $MRT = \rho AL_2$, where

$$T = \frac{\rho AL_2}{MR}$$

$$T = \frac{\rho AL_2}{10^{-3} \left[0.35 + \frac{d^2}{645} + 2.08 \times 10^{-7} \left(\frac{iL_1 \times 25.4}{d^2} \right)^{1.22} \right]} \quad (13)$$

$$T = \frac{\text{kg}}{\text{mm}^3} \text{mm}^2 \text{mm} \div \frac{\text{kg}}{\text{min}}$$

$$T = \text{min}$$

where T is the time required to perform the welding operation in minutes,

A is the cross section of weld to be determined by weld depth and width,

ρ is the density of mild steel = 7860kgm⁻³ and d is the diameter of electrode.

L₂ = weld length, d = diameter of electrode,

L₁ = electrode length and i = welding current

Autodesk Inventor Analysis

Autodesk inventor is a 3D solid modeling program designed for rapid prototyping applications used in the design, visualization and simulations of products. It uses shape manager, their proprietary geometric modeling kernel. Inventor includes an integrated motion simulation and assembly stress analysis environment. Users can input driving loads, friction characteristics, and dynamic components, and then run dynamic simulation tests to see how a product will work under real- world condition.

Finite Element Analysis (FEA) lets users validate component design, by testing how parts perform under loads (using actual load information, instead of estimates). It also helps users modify design parameters from within the assembly stress environment and compare various design options, then update the 3D model, with the optimized parameters.

This software was utilized in this project to help design the robot and generate the mathematical model while the MATLAB software was used to validate the generate model.

RESULTS AND DISCUSSION

Based on the working drawing and the simulation graphics, some data were obtained and then used in the computation of the required numerical model which is based on the melting rate of the electrode as discussed by Khannah (2010). The model generated is represented by equation 13: The developed model was subjected to MATLAB analysis and the model was validated.

Using MATLAB, we were able to obtain the value of weld time (t) in minutes as well as the weld speed for different material thickness and weld length along with other parameters such as diameter of electrode (mm), length of electrode (mm), weld cross sectional area (mm²), and the weld current (i) amps as shown in Figures 5 and 6.

The material thickness and weld length are imputed, and by using auto computation, the program will select the correct diameter of electrode, the correct length of electrode, the correct weld cross sectional area, and the correct weld current (i) in amps; and with these parameters imputed, it will generate the weld speed (S) in mm/min and the weld time (t) in minutes.

The interface in Figure 6 was utilized to determine the time taken for completion of welding materials of different thickness and length and presented in Table 2.

The weld time and speed can also be generated by manually imputing the following parameters and the parameters are: the material thickness (mm), the weld length (mm), the diameter of electrode (mm), the length of electrode (mm), the weld cross sectional area (mm²)

and the weld current (i) in amps. The correct value for each of the following parameters can be obtained from the table below, if they are to be entered manually. After these parameters have been imputed, then the weld time along with the weld speed will be generated by the program.

The model developed is a function of time against other variables (density of metal (ρ), area of weld (A), weld length (L_2), electrode diameter (d), current (A) and the electrode stick out (L_1).

The result shows that decrease in welding time is favored by decrease in density, weld area, length with a corresponding increase in the electrode diameter, stick out and the welding current. Otherwise the weld time increases.

Using the MATLAB program, the Table 2 is computed as a variation of the modelling parameters with the welding time. The effect of the weld length on the time taken to complete the welding operation was studied by assuming constants for other modeling parameters while taking the weld length variable against the speed and time of weld as shown in Table 2 and Figure 6. The result shows that the welding speed is independent of the weld length but dependent on the electrode diameter, area, and current. The following constants are assumed.

$$\begin{aligned} t &= 4\text{mm} \\ I &= 40\text{amps} \\ L_1 &= 250\text{mm} \\ d &= 1.2\text{mm} \\ A &= 10\text{mm}^2 \end{aligned}$$

The graph shows that the time is a function of length of weld and this is shown as a linear graph in Figure 6. It can also be deduced, that as any of the parameters changes, so also does the time, therefore welding time is factor of these parameters as shown in Table 3.

To validate the model, the following parameters were imputed into equation 13 and the value of time obtained was compared to that generated by the MATLAB programme. The model results for materials of various specifications are presented in Table 4.

where, $T_{s,s}$ denotes the time obtained from using the model and $S.S$ denotes the sample solution.

Comparing the resulting welding time from the sample calculation in Table 4 and the result obtained from the MatLab programme in Table 3, it is clear that both welding time T and $T_{s,s}$ are the same which validates the correlation between the MatLab programme and the developed model.

CONCLUSIONS

This model has been developed and successfully analyzed using the Autodesk inventor analysis and validated using the MATLAB software. The model is analyzed reference to material factors such as the stress combination and reliable factor of safety holding true for a mini-welding robot for welding with four degrees of freedom in determining the most appropriate welding time involving a work piece across any distance. The developed model is also useful for welding time estimation, that is, of help in planning, managing, financing and upgrading our welding industries. The implementation of the model will enhance utilization of available resources and welding machines

that will establish good interrelationship between customers request, operators' available time. Educational institutions where practical are conducted giving preferences to the number of student per department can effectively plan their workshop activities through scheduling with the model.

RECOMMENDATIONS

The model is based on four degree of freedom; effort should be made to develop model on more degree of freedom considering more input parameters as variables. The model is suitable for small, medium and large scale welding industries for effective operational service. The model should be made more robust to accommodate different material and give results varieties of parameter during operation such as welding depth, speed and amount of electrode used.

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Figure 1: Concept of degree of freedom(Hyland, 2007).

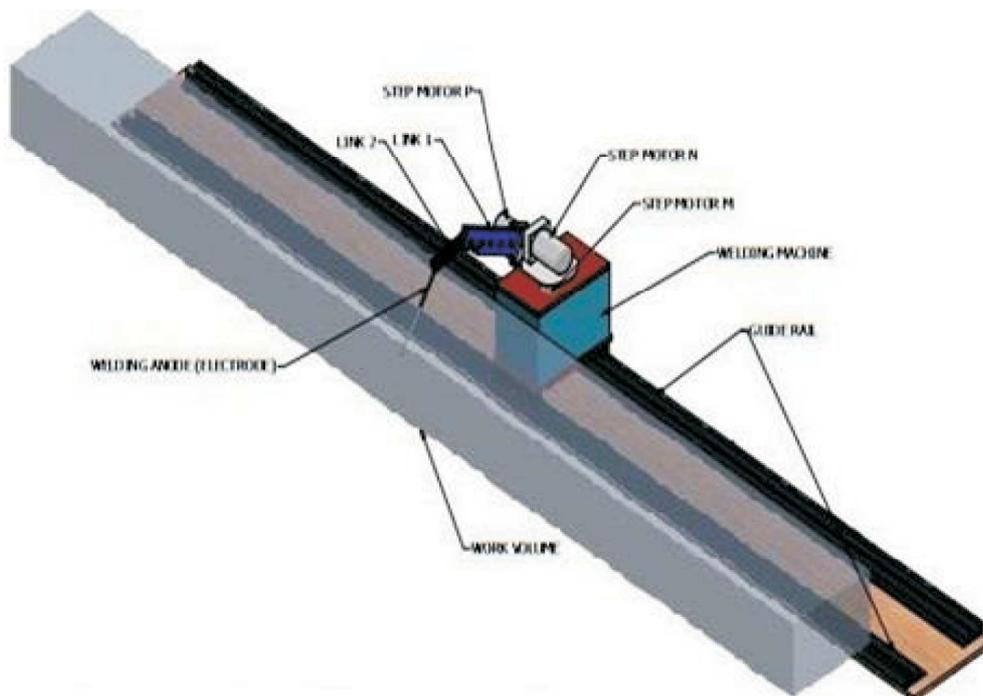


Figure 2: Isometric view of the entire machine with work volume

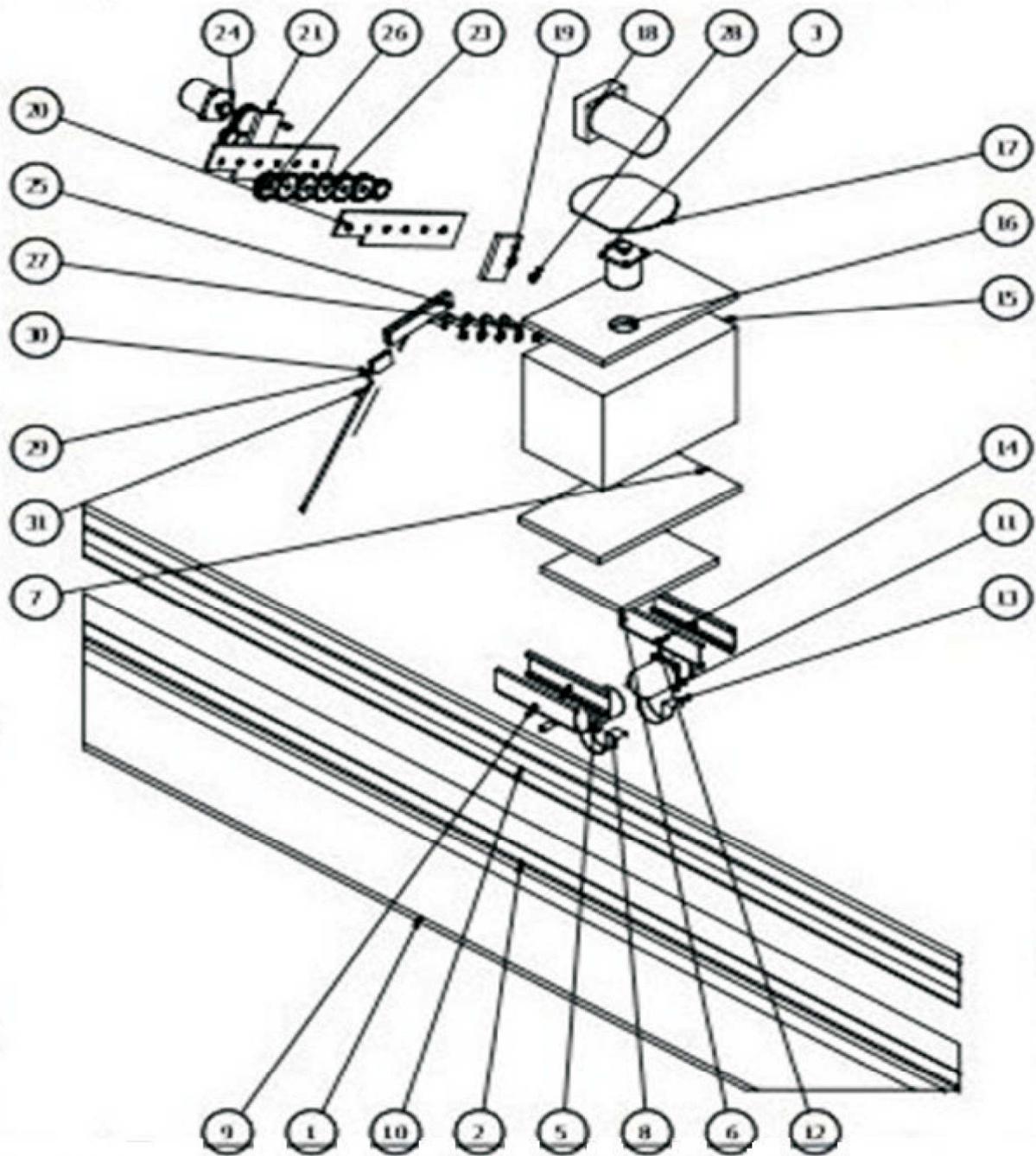


Figure 3: Exploded view of the Robot

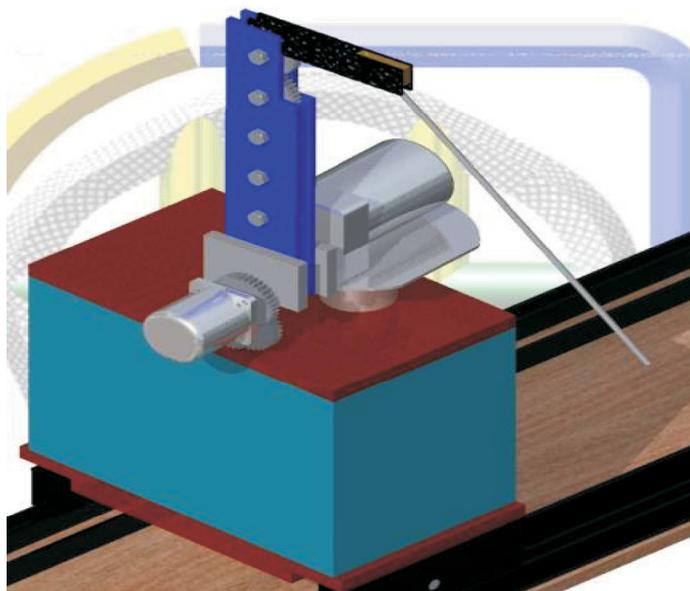


Figure 4: Isometric view of the robot

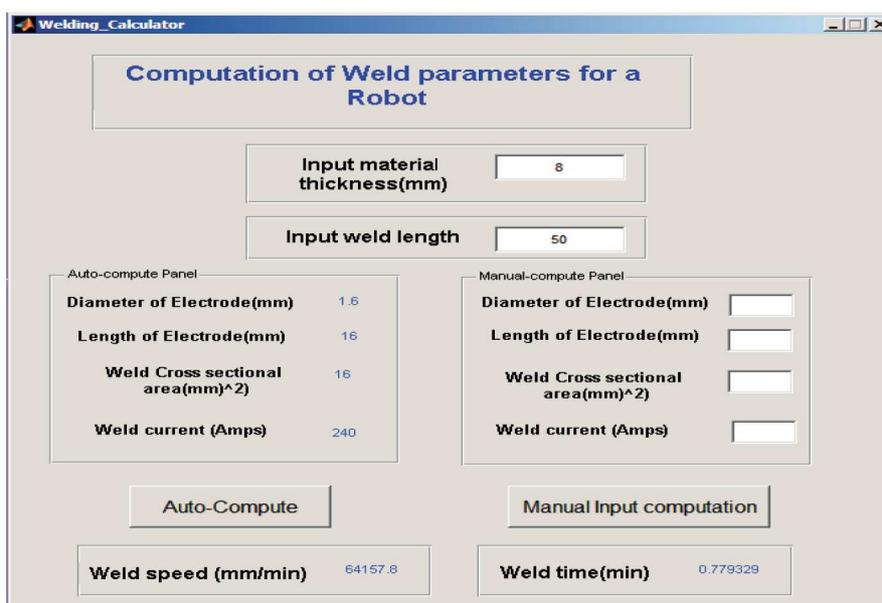


Figure 5: Verification of Numerical Model Using Matlab Form 5 Interface

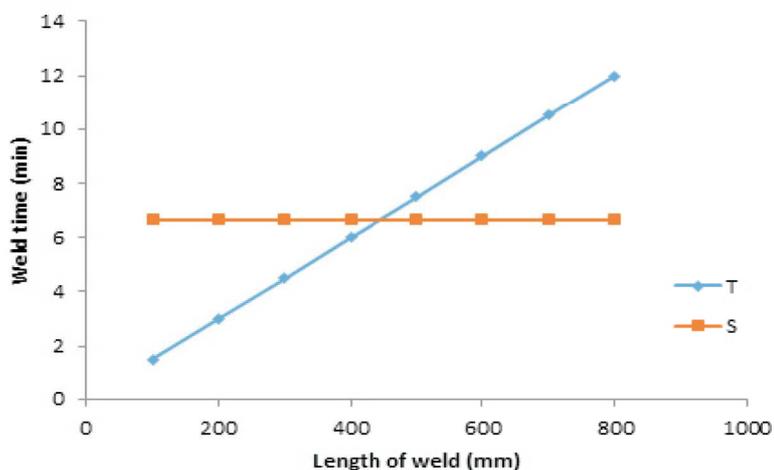


Figure 6: Weld length against welding time.

Table 1: List of the Robotic Arm Components

S/N	PART DESCRIPTION	S/N	PART DESCRIPTION	S/N	PART DESCRIPTION
1	BOTTOM PLATFORM	11	STEP MOTOR 1MIR	21	HOLDER BLOCK 2
2	GUIDE RAIL	12	WHEEL MIR	22	ASSEMBLY 3
3	STEP MOTOR 1	13	CLAMP 1MIR	23	SPUR GEAR 1
4	WHEEL 1	14	SLIDER MIR	24	SPUR GEAR 2
5	WHEEL 2	15	WELDING MACHINE	25	LINK 2
6	PLYWOOD 1	16	PLYWOOD 3	26	SPUR GEAR HOLE
7	PLYWOOD 2	17	ROTARY PLATFORM	27	AREA MIR 2.15_MH*1.25*30
8	CLAMP 1	18	STEP MOTOR 2	28	ISO 4035 MB
9	SLIDER	19	HOLDER BLOCK	29	TOUNGE TOP 1
10	GUIDE RAIL MIR	20	LINK 1	30	TOUNGE TOP 2
				31	ELECTRODE

Table 2: Variation of Welding Time with Weld Length

Length of weld(mm)	100	200	300	400	500	600	700	800
Time (min)	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0
Speed(mm/min)	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66

Table 3: Variability of Independent Parameter with Weld Time

Material thickness t (mm)	Weld length L ₂ (mm)	Electrode diameter d(mm)	Electrode stickout L ₁ (mm)	Area of weld A(mm ²)	Welding current i (amps)	Welding time T(mins)
0.5	10	0.6	6.0	1	50	0.019955
1.5	20	1.0	9.0	3	95	0.116042
3.0	30	1.2	12.0	6	120	0.287564
5.0	40	1.6	16.0	10	240	0.389664
7.5	40	1.6	16.0	15	240	0.584497
8.0	50	1.6	16.0	16	240	0.779329
9.0	60	2.0	10.0	18	350	2.030650
12.0	70	2.0	10.0	24	350	3.158800
15.0	80	2.4	22.5	30	500	1.694270
17.0	90	2.4	22.5	34	500	2.160190

Table 4: Time (T_{s,s}) Obtained from the Developed Model Application

S.S	t	L ₂	d	L ₁	A	i	T _{s,s} (mins)
1	1.5	20	1	9	3	95	0.116039
2	3	30	1.2	12	6	120	0.287561
3	5	40	1.6	16	10	240	0.389660
4	7.5	40	1.6	16	15	240	0.584495
5	8	50	1.6	16	16	240	0.779330

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