Arc Welding Robot Automation Systems

Beom-Sahng Ryuh[1], Gordon R. Pennock [2]
[1]*Division of Mechanical Engineering, Chonbuk National University, Jeonju, Republic of Korea, 561-756*
[2]*School of Mechanical Engineering, Purdue University, West Lafayette, Indiana, 47907-1288, USA*

1. Introduction

Robot automation systems are rapidly taking the place of the human work force. One of the benefits is that this change provides the human work force with the time to spend on more creative tasks. The highest population of robots is in spot welding, spray painting, material handling, and arc welding. Spot welding and spray painting applications are mostly in the automotive industry. However, arc welding and material handling have applications in a broad range of industries, such as, automotive sub-suppliers, furniture manufacturers, and agricultural machine manufacturers.

The number of arc welding automation robot stations is growing very rapidly. The two most common stations are the GMAW (Gas Metal Arc Welding) station and the GTAW (Gas Tungsten Arc Welding) station. These two stations are the most common because they are so well suited to robot systems. Typically, a robot arc welding station is comprised of a robot, a robot controller, arc welding equipment, a work clamp and motion devices to hold work pieces accurately in position (considering heat deformation), robot motion devices to move around the robot for a larger working range and better weld positions, sensors, and safety devices. A typical arc welding robot station is illustrated in Figure 1.

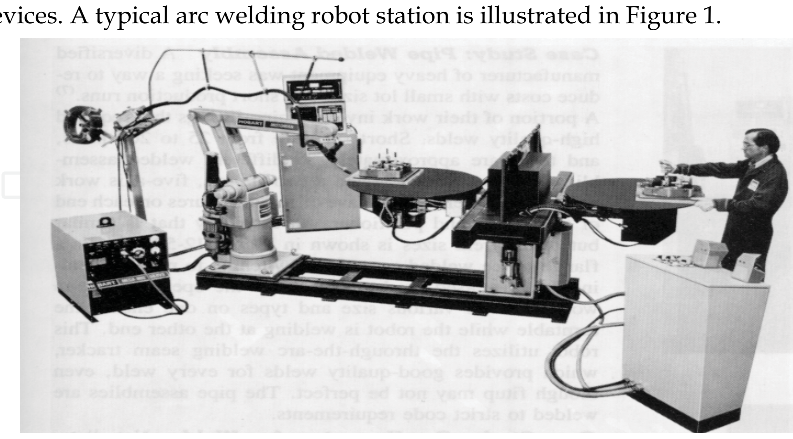

Fig. 1. A Typical Arc Welding Robot Station.

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2. A Description of the System Components

2.1 The Robot and the Controller

A robot is programmed to move the welding torch along the weld path in a given orientation. The robot is typically comprised of a large number of links and linkages, which are interconnected by gears, chains, belts, and/or screws. The majority of industrial robots are actuated by linear, pneumatic, or hydraulic actuators, and/or electric motors. Most of the high-end robots currently use AC servo motors which have replaced the use of hydraulic actuators and, more recently, DC servo motors. AC servo motors are essentially maintenance free which is very important in industrial applications.

In an arc welding robot system, the torch is attached to the wrist of the robot which has two or three axes of motion. As technology develops, however, there is less application for a robot with a two-axis wrist motion. In the case of three-axis motion, the motion is composed of yaw, pitch, and roll, similar to the human wrist. The robot has the most effective motion when the center point of the wrist is aligned with the center line of the upper arm. A robot with a three-axis lower arm and a three-axis wrist will permit the torch action that is necessary for a complicated three-dimensional welding process. The torch can satisfy all the angle requirements, such as, the work angle, the transverse angle, the travel angle, and the longitudinal angle.

Important factors, when considering manufacturing performance are the frequency of failure, the mean time between failure (MTBF), the average time for repair, and the time for robot replacement. Also, with regards to system design, important issues are the robot work envelope, the reach of the robot tip, the number of joints (i.e., the degrees of freedom), the travel velocity, and the repeatability, accuracy, and resolution of motion.

The controller is the brain of the robot arc welding system. This is because the controller stores the robot programming and arc welding data, and performs the necessary computations for robot control, typically by a high-speed microprocessor. The controller provides a signal to the actuators and the motors by programmed data and position, speed, and other information obtained from various sensors. The controller is now integrated to govern not only the robot but also any peripheral devices, such as manipulators. When the system is required to weld a work piece that has a complicated geometry, the simultaneous coordinated control of the integrated controller is inevitable.

Memory backup devices, such as, a floppy disc drive, are recommended for storing important data as a safeguard in the event of a break down with the controller. In the case of a power failure, or some other unforeseen event, storing the data from an absolute resolver, or encoder, in controller memory will ensure that the robot can restore the programmed position without returning to the zero configuration.

2.2 The Welding Equipment (Power Source)

The welding equipment generates power to generate the arc for welding. One of the most important characteristics is stability of power. It is recommended that the welding equipment generates a short arc with less spatter for a good welding quality even at high speeds.

The arc sensor detects the current value so that the power source can supply the correct amount of power to the wire feeder, which then controls the wire feeding speed. The wire feeder has wheel rollers to advance the wire. Some feeders have four rollers speed sensors for more accurate wire feeding by push-pull action. Also, a wire feeder with shorter length to the torch is better in terms of a response time. Therefore, a good location for the wire feeder for a robot system is at the end of the upper arm of the robot.

A slender welding gun is better for maneuverability but, in case of a collision, sufficient strength must be guaranteed. It is also necessary to ensure that the torch is equipped with shock absorption devices such as springs. It is also important to have a cooling system (a circulating water, in general) to protect the torch against heat deformation. All the connections for welding, such as, electric power, the wire, and the coolant are usually integrated into one cable unit. It is recommended that the cable unit be as short as possible for a quicker response and a better reliability.

2.3 Manipulators

A robot has a limited working range and accessibility, therefore, in many cases a manipulator has to be considered. A manipulator is a device holding the work piece and is moved around (typically with linkages) for better access and welding positions. The advantages of a manipulator include:

(1) A manipulator can easily be moved around the work piece for the best welding positions.
(2) A manipulator can reduce the variation in the lead and the lag angles of the tip.
(3) Welding can be performed in a stable flat welding position by a synchronized and simultaneous control of a robot and a manipulator.
(4) Any hard-to-reach positions can be accessed more easily.
(5) A manipulator increases the working range of a fixed floor mounted robot or an inverted robot.

In general, a robot can maintain a better flat welding position which will produce a better deposition and, thereby, reduce any repair work by the cooperation with a manipulator. This also makes possible higher welding speeds and, thereby, an increase in productivity.

There are two types of actuation systems for manipulators; namely, the indexing type system, and the servo-controlled system. The indexing type system is for economic models and is commonly actuated by pneumatic and AC motors. This type of system is usually controlled by signals for target position with constant speed. The servo-controlled type system is for speed and direction. This can be an expensive system since it has a complex structure with servo motors, worm gear reducers, and encoders or resolvers. However, the servo-controlled type system has higher accuracy and variable speed control in both directions of rotation. Errors are compensated for by feedback control.

Various types of manipulators, depending on the types of motion and the degrees of freedom that are required, are shown in Figs. 2 and 3. Several examples of rather simple one-degree-of-freedom manipulators are shown in Fig. 2.

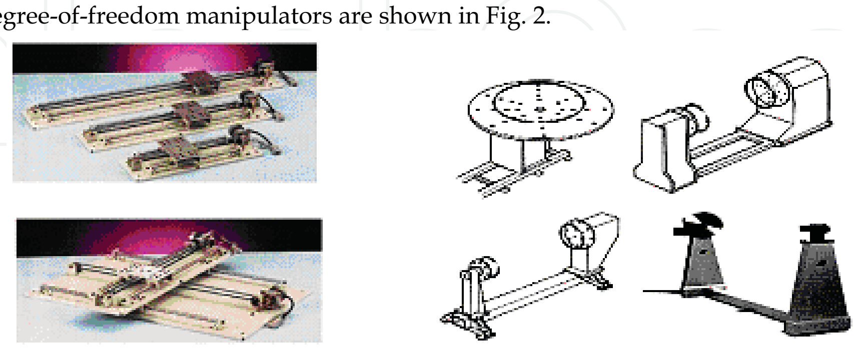


Fig. 2. Examples of One-Degree-of-Freedom Manipulators.

Figure 3 shows more sophisticated manipulators for higher maneuverability, but with an associated higher cost. In selecting the best type of manipulator, it is important to consider control types, load carrying capacity, and working environment. Also, repeatability, accuracy, mechanical configuration, and degrees of freedom are important issues that should be considered.

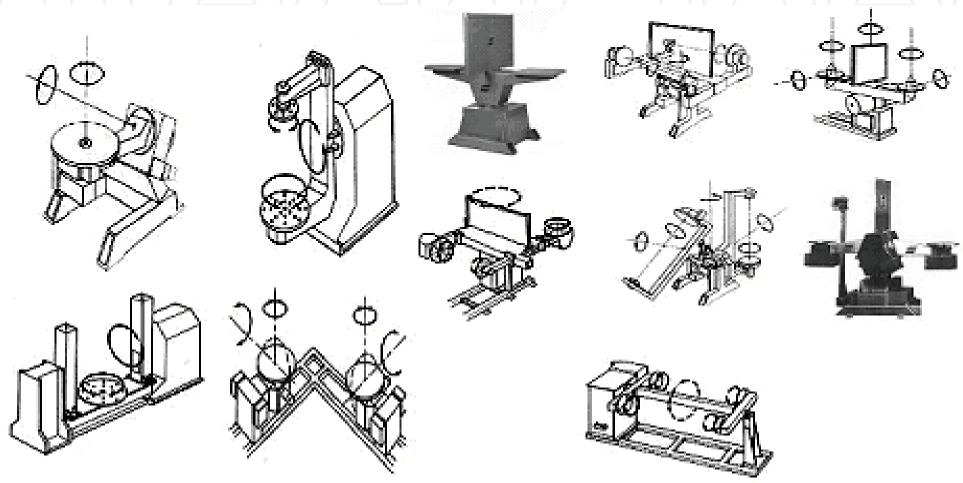


Fig. 3. Examples of More Sophisticated Manipulators.

A decision on the type of control depends on the condition of the weld that is required. In terms of the load carrying capacity, not only the mass or weight of the work piece, but also the moment caused by the off-center distance of the mass center of the work piece must be considered. For example, a work piece with a mass of 227 kg and an off-center distance of 50 mm is equivalent to a work piece with a mass of 1135 kg and an off-center distance of 10 mm. Typically, the load carrying capacity is evaluated at a distance between 76–152 mm. For purpose of illustration, Fig. 4 shows a plot of the load carrying capacity against the off-center distance of the mass center of a work piece.

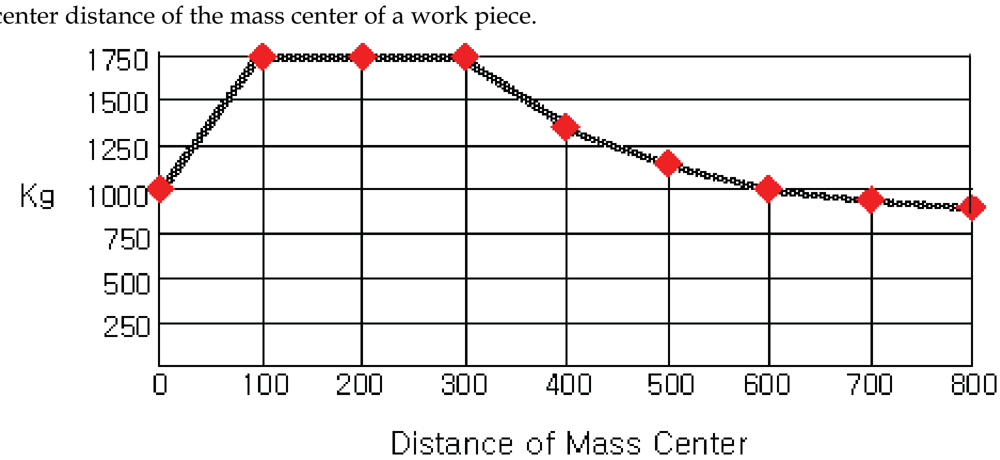


Fig. 4. A Plot of the Load Carrying Capacity.

2.4 Sensors

Sensors collect information from the robot, peripheral devices, and process and transfer this information to a controller. In arc welding, it is critical to consider deformation from high heat input and, therefore, a closed loop control with a sensor is necessary. Also, in an automatic welding system the errors caused by manufacturing tolerances of manipulator and work pieces have to be considered. Various types of sensors for robot arc welding Stations are available, see Table 1, and the right type must be chosen depending on the application.

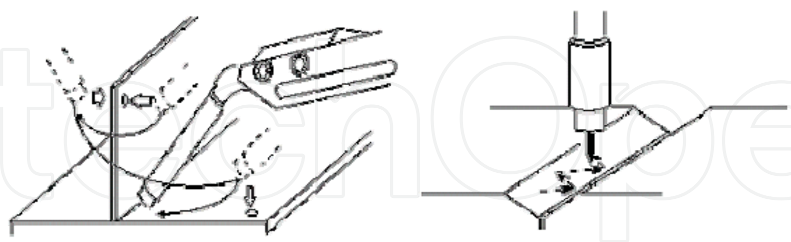
Sensor type	Sensors
Contact type (Weld seam tracking)	Mechanical Type - Roller Spring. Electromechanical type: 1) Two probes across the seam line. 2) A probe in the seam line. Electric control type with probe.
Non-contact type (Various Purposes)	A. Physical type: 1) Acoustic – arc length control. 2) Capacitance – distance control. 3) Eddy current –seam tracking. 4) Induction – seam tracking. 5) Infrared radiation – penetration control. 6) Ultrasonic – penetration and weld quality. 7) Magnetic – detecting electromagnetic field. B. Through-the-arc type: 1) Arc length control (arc voltage). 2) Weaving with electric measurement (GTAW, GMAW). C. Optical/vision (image capture and process): 1) Vision sensors. 2) Laser sensors. 3) Opto-electric sensors.

Table 1. Various Types of Sensors for Robot Arc Welding Stations.

As illustrated in Table 1, and shown in Fig. 5, there are two types of sensors; namely, a contact type sensor and a non-contact type sensor.

A contact type sensor. Figure 5(a) shows a contact type sensor. A gas nozzle, or a finger, is used as a probe to detect contact with the work piece. The nozzle senses the existence, location, and orientation, and, thereby, the location of the weld seam. A contact type sensor is less expensive and easier to use than a non-contact type sensor. However, this type of sensor can not be used for butt joints and thin lap joints.

A non-contact type sensor. Figure 5(b) shows a non-contact type sensor referred to as a through-the-arc sensor. This sensor detects changes of welding parameters while the torch is weaving during the arc welding process. The sensor may be used for tee joints, U and V grooves, or lap joints over a certain thickness. This type of sensor is appropriate for welding of bigger pieces with weaving when penetration control is not necessary. However, it is not applicable to materials such as aluminum.



(a) A Contact Type Sensor. (b) A Non-Contact Type Sensor.

Fig. 5. Two Types of Sensors.

Optical systems for guiding a weld seam. Figure 6 shows a system that will detect an upcoming weld joint. This sensor may be used for grooves such as V and J, lap joints, fillet joints, butt joints, or corner joints. However, since it is located near the torch there is a limitation in access.

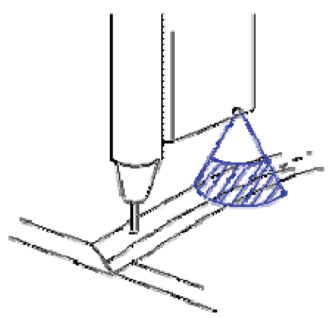


Fig. 6. Optical System for Guiding a Weld Seam.

The system in Fig. 7 is used for detecting minor changes of the joints that lie ahead. This system can be used for thin welds and at high speeds. The system is good for lap, fillet, or butt joints. However, it is important to note that there is the possibility of a collision with the work piece.

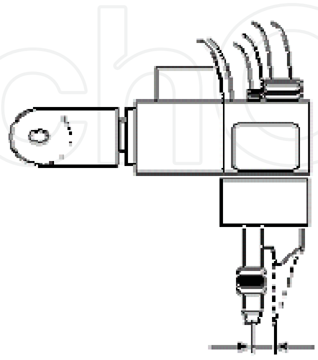


Fig. 7. A Sensor for Detecting Minor Changes of Upcoming Joints.

2.5 Track, Gantry, Column, and Peripheral Equipment

When a work piece is too large for the robot workspace, or a robot cannot reach some welding points, peripheral devices such as a track, a gantry, or a column should be considered. These devices have advantages of expanded work space, flexibility, and increased productivity. Also, it is possible that a robot may work on a multiple of work pieces and, thereby, increase the arc time. For efficient use of these devices, it is advantageous to provide all the axes of the system (including the robot and peripheral devices) with simultaneous or synchronized control function. The standardized and modularized system may be chosen based on load carrying capacity, stability, accuracy and repeatability, and the maximum number of axes that the controller can handle. However, the productivity proven by practice is the most important criteria.

A Track. To increase the working range, the robot is mounted on a track as shown in Fig. 8. The track also this provides flexibility for the future consideration of the size of the work piece. In addition, a track is useful when the breadth of the pieces is less than 1 meter and a travel distance greater than 1.5 meter is required. Most common work pieces for track application are automotive panels, rear axles, tractor frames, bed and furniture frames, window frames, container doors, and computer racks. For increased arc time and productivity, the concept of one robot with multiple work stations is used. This is also illustrated in Fig. 8.

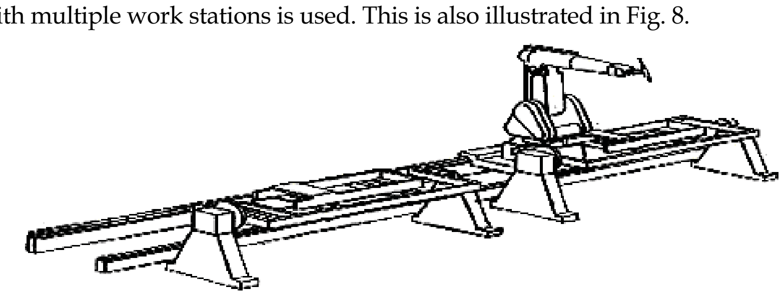


Fig. 8. A Robot Mounted on a Track.

A Gantry. A gantry is a steel structure where the robot is suspended and inverted. Using a gantry, a robot can weld work pieces of different sizes. A very large work piece can be welded with multiple robots suspended on a single gantry or multiple gantries. Figure 9 shows two robots suspended from a gantry (i.e., a grinding robot and a welding robot) working on a double station manipulator.

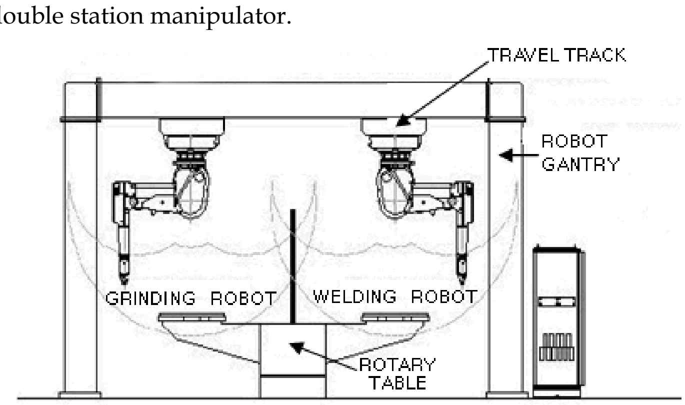


Fig. 9. Two Robots Suspended from a Gantry.

A Column. A column is developed from the concept of modularization. While the track moves in a single horizontal direction, the column may fix the robot or move the robot in a vertical direction and a horizontal direction. A column occupies less space in the plant and makes possible efficient utilization of the space. Also, the wirings of welding wire, power and signal cables may be placed in a duct inside the column to avoid unnecessary exposure. As shown in Fig. 10, a robot suspended from a column may have better accessibility and weld position than a floor mounted robot. There are stationary (fixed), traveling, rotary, and rotary/traveling types of columns.

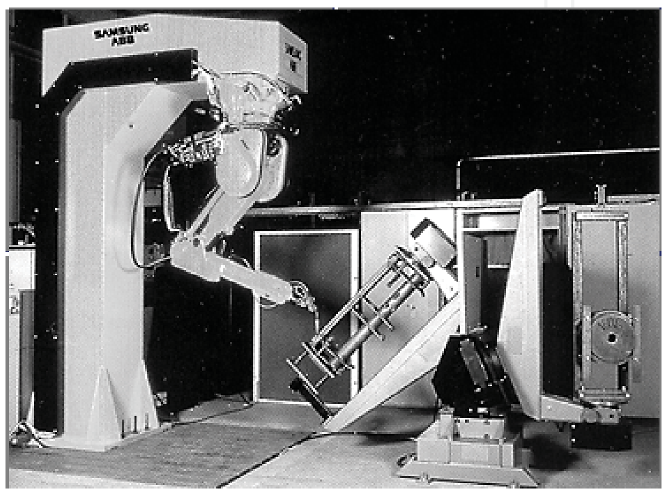


Fig. 10. A Robot Suspended from a Column.

Welding Fixtures. Manufacturing a welding fixture requires experience and know-how. A designer should have a profound knowledge of tolerances of work pieces before and after welding. Also, a designer should obtain information from experienced welding experts. The geometry of a fixture is based upon the geometry of the work piece and the clamping device of the manipulator. The fixture should guarantee a good welding position and should be protected against heat, smoke, and spatter. Figure 11 shows an example of a welding fixture.

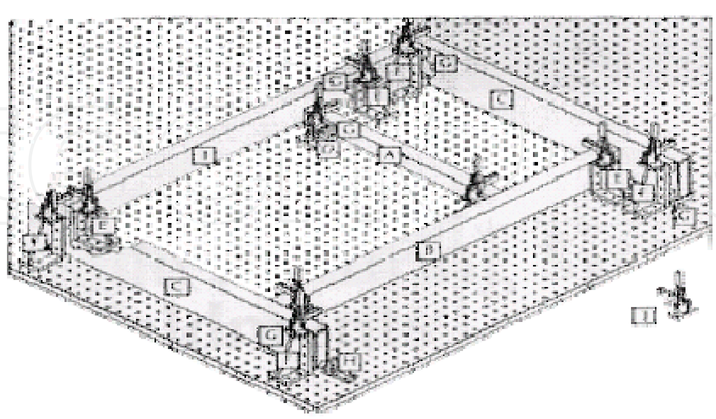


Fig. 11. An Example of a Welding Fixture.

2.6 Safety
An arc welding robot system should be on a firm foundation so that any vibrations will not produce a shaking effect on the system. Also, the emergency switch button (with colors of yellow and red) should be located at a position that is easily accessible. The switch should stop the robot without shutting off the power. There should also be a safety fence to protect the work force from spatter and arc flash. Figure 12 shows a complete system of a safety fence.

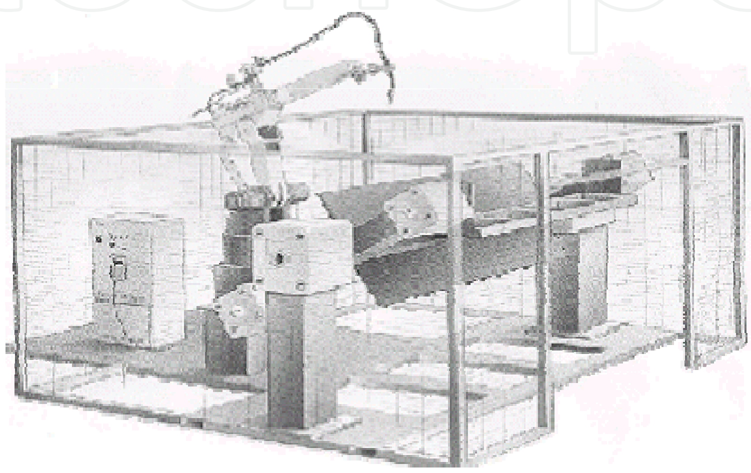


Fig. 12. A Complete System of a Safety Fence.

For safety, the robot operator should have a rigorous training on robot speed, working range, emergency stopping, and functions of teach pendant. The training should also provide the operator with the opportunity to become familiar with the robot system.
While designing the robot system, sufficient time for system modification and operator training is indispensable. Also, obstacles inside the working area of the operator should be eliminated and the system should be designed so that the welding is perfomed at a safe distance from the operator. For this purpose, a manipulator should be designed with dual stations with safeguards so that the operator can work safely on loading and unloading. This will also increase productivity.
After the system is designed, installed, and tested, all the detailed information in the design process should be documented and transferred to the operator.

3. Important Functions of an Arc Welding Robot

3.1 The Robot Program
(A) Programming Method. First generation robots were programmed by manual operation. However, in modern technology, there are four common methods for robot programming; namely:
(i) Programming by a Teach Pendant. The operator uses a dedicated teach pendant for robot teaching and program editing. Teaching is carried out for the tool center point (TCP) and the LCD display panel is adopted for menu guide. It is easy to use but restricted in application and extension. A teach pendant (such as the one shown in Fig. 13) is the most popular device in robot programming

Fig. 13. A Robot Teach Pendant.

(ii) Programming by Manual Lead-Through. A well trained welding expert will hold the holder near the torch and program by manual lead-through. This was common in first generation robots, however, in modern technology, this is only used for spray painting robots.
(iii) Programming by a Robot Language. The robot is programmed by a program language using a monitor and a keyboard. There exist several command, motion, and operation level languages. Commonly used robots can take advantage of a broad range of motion level languages. The operation level language only describes the final goal of the process, and the sequence of motion and data are generated automatically. This programming method still remains very much in the research stage.
(iv) Programming by a Simulator. A graphic simulation is performed and it is translated into the language of the robot. This is also referred to as off-line programming.
(B) Welding Data. Welding data is special data of parameters that are used for the welding process. The welding data is composed of start data, main data, end data, and weaving data. Figure 14 shows an example of welding data.

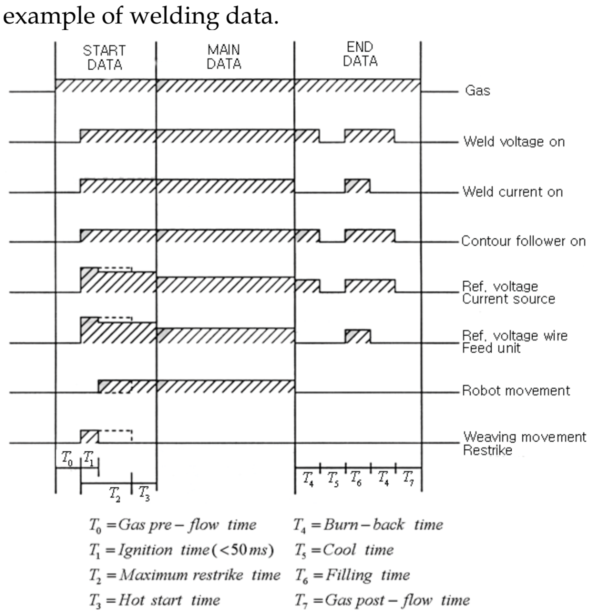


Fig. 14. An Example of Welding Data.

Start data. Start data generates arc start data and stabilizes electric power. Start data contains the following parameters:

- Ignition voltage and current.
- Gas preflow time. The time between shield gas flow and arc start.
- Hot start voltage and current: To stabilize the arc in the first stage.
- Restrike amplitude: Minor change in the position of the torch to start the are.
- Restrike cross time: Time to stay in the restrike position.
- Arc welding start maximum time. The robot stops the process if the arc does not start in this time interval.

Main data. Main data contains the following parameters for the actual welding process:

- Welding voltage.
- Welding current.
- Welding speed.

For higher productivity, the welding speed should be increased to the maximum value. Therefore, a new system should be put through a number of tryouts until the parameters for maximum speed are determined. The above three parameters have interrelations with each other.

End data. At the end of the welding process there are craters, or cracks, that may be the cause of welding defects. Therefore, several parameters for appropriate finish are required. These parameters include:

- End voltage and current.
- Gas postflow time.
- Burnback time.
- Cool time.
- Fill time.

Weaving data. A large work piece, to be welded with large penetration repetitive welding, demands a long time and requies a motion plan to the weld start position. Carrying out this type of welding in one pass is possible due to weaving. Weaving has various patterns such as zig-zag, V-shape, triangular, and wrist weaving as shown in Fig. 15. Wrist weaving uses only the sixth-axis of the robot and enables weaving in a narrow space where weaving with the lower arms of the robot is impossible. Also, it is useful when high frequency weaving is necessary. However, there is an error in the weaving height, as shown in Fig. 15. Therefore, small amplitude weaving is recommended.

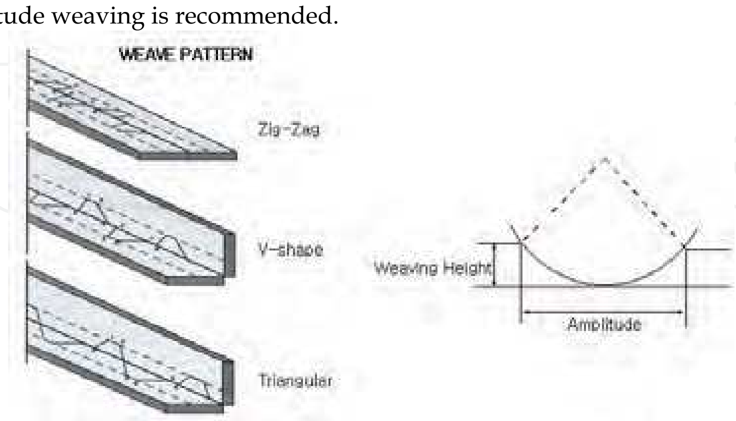


Fig. 15. Zig-Zag, V-Shape, Triangular, and Wrist Weaving.

3.2 Coordinates and Interpolation

(A) Coordinates. Typically, there are five types of coordinate systems in robotics; namely:

- A World coordinate system.
- A Base coordinate system.
- A Hand coordinate system (a mechanical interface coordinate system).
- A Tool coordinate system.
- A Goal coordinate system.

These five types of coordinate systems for a typical robot are illustrated in Fig. 16.

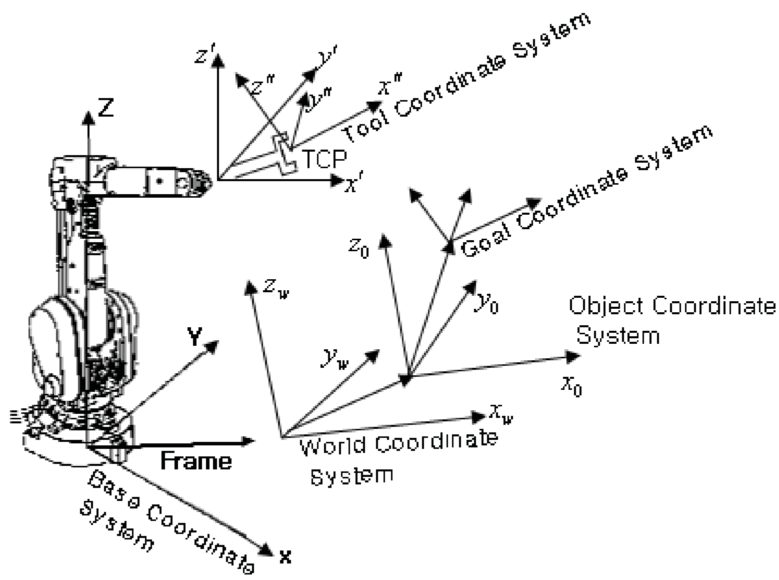


Fig. 16. The Five Types of Coordinate Systems.

The world coordinate system is the reference coordinate system for the other four types of coordinates. The world coordinate system relates the coordinate systems in a work cell where robots and other peripheral devices exist. The base coordinate system is the coordinate system for the robot. The hand coordinate system is at the face of the robot end-effector where tools are attached. The tool coordinate system is at the tip of the torch and defines the Tool Center Point (TCP) and the Tool Center Line (TCL). When several tools are used, it is convenient to define a TCP for each tool.

There are many advantages associated with defining the different types of coordinate systems, for example:

- Easy manual operation of a robot.
- Easy management of the tool data.
- Easy position data manipulation for work pieces of similar geometry.
- Easy application of offline programming.

(B) Interpolation Control Function. Robot path programming is based on interpolation technique. Basically, the interpolation is carried out either in joint space or Cartesian space. For more details, readers may refer to robotics text book. We introduce four techniques directly related to industrial application.

Point to point interpolation. This is the simplest and fastest interpolation technique. Point to point interpolation commands the TCP to move from one point to another regardless of the intermediate path. This technique is good when there are no obstacles in between. When there is an obstacle it may be avoided by defining intermediate via points.
Linear segments with parabolic blends. When a constant speed trajectory in the world coordinate system is needed, this interpolation technique is used. At the beginning, the speed linearly increases and near the end, the speed linearly decreases.
Minimum time trajectory This technique seeks the minimal time trajectory between two positions. The trajectory is obtained for maximal acceleration and deceleration and is called bang-bang trajectory.
Interpolation for weaving. When weaving is used for thick work piece welding, paths for weaving are calculated based on basic welding path.

3.3 Cooperation with a Peripheral Device

(A) External Axis Control. External axis control is used for peripheral devices such as manipulators, columns, tracks, and gantries which need analog signals for a servo motor or actuator control.
(B) Functions for Off-Line Programming. The final goal of an automated system is unmanned operation. Therefore, a higher level computer, or a controller, should be able to control the system. The higher level computer shown in Fig. 17 not only controls a system at the lower level but also stores data with larger memory storage playing the role of backup memory.

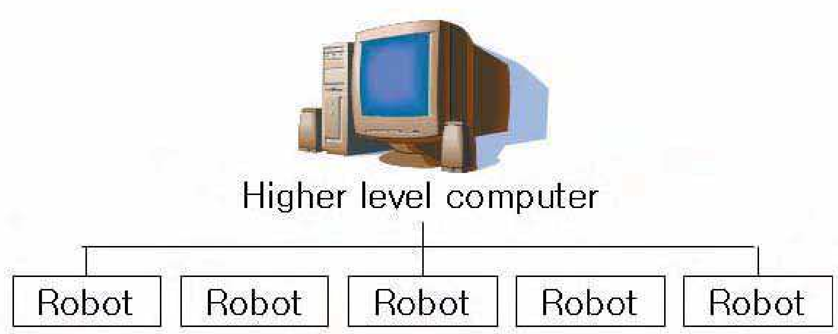


Fig. 17. A Higher Level Computer and the Robots.

4. Special Welding Automation

(A) TIG Welding Automation. TIG welding (GTAW) uses a tungsten electrode to generate arc with a base metal and a filler metal is supplied separately. TIG welding is used for various metals such as aluminum, magnesium, and stainless steel providing high weld quality. Also, TIG welding does not need post-treatment and does not have spatter. When a robot is used, the filler metal should be supplied ahead of the torch. Also, the process is sensitive to noise and, therefore, care has to be taken for various noises in the area. Figure 18 shows a TIG welding system welding thin stainless steel plates with nickel alloy for a jet engine part. There is a dual manipulator, a power source for 150A, and a robot with an arc welding software.

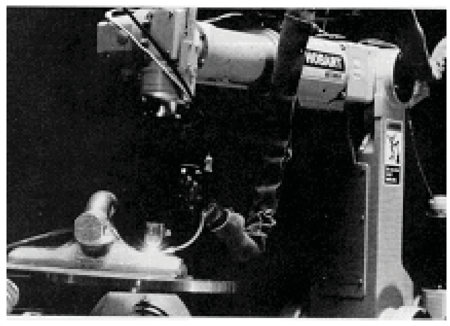


Fig. 18. A TIG Welding System of Stainless Steel Plates with Nickel Alloy.

(B) Aluminum Welding Automation. Aluminum is a metal that is very difficult to weld. DC reverse polarity needs to be used in MIG welding and AC needs to be used in TIG welding. Aluminum has the following unique properties:

- Aluminum oxide surface coating.
- High thermal conductivity.
- High thermal expansion coefficient.
- Low melting temperature.
- No color changes approaching melting point.

In order to weld aluminum, the following is a list of some critical considerations:

- Base metal and filler metal should be kept clean and dry and oxide surface should be removed.
- Appropriate filler metal should be chosen.
- Welding parameter should be accurate.
- High welding speed should be maintained.

For an arc welding robot system, a good coordination of peripheral devices with simultaneous control of external axes are very important issues.

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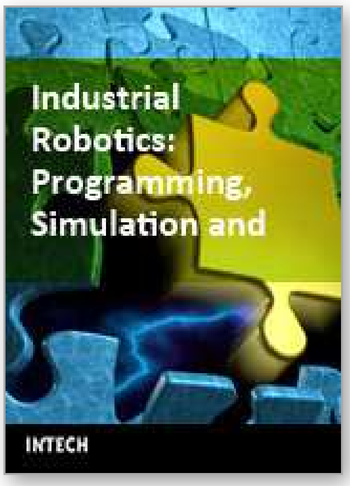

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This book covers a wide range of topics relating to advanced industrial robotics, sensors and automation technologies. Although being highly technical and complex in nature, the papers presented in this book represent some of the latest cutting edge technologies and advancements in industrial robotics technology. This book covers topics such as networking, properties of manipulators, forward and inverse robot arm kinematics, motion path-planning, machine vision and many other practical topics too numerous to list here. The authors and editor of this book wish to inspire people, especially young ones, to get involved with robotic and mechatronic engineering technology and to develop new and exciting practical applications, perhaps using the ideas and concepts presented herein.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821