❏   196

Development and integration of laser sensor tracking system in robotic arm for path correction during welding operation

Tejaswini P.[1], M. V. Achutha[2], Ananda Doddagatte[3]

[1]Industrial Automation & Robotics, Department of Mechanical Engineering, The National Institute of Engineering, Mysore, India
[2]Department of Mechanical Engineering, The National Institute of Engineering, Mysore, India
[3]Department of R&D, Yaskawa India Pvt Ltd, Bangalore, India

Article Info

ABSTRACT

An industrial robot is mainly used for manufacturing. Industrial robots are 6 or more axes, which can be automatically controlled by programming. Typical applications of robots include welding, painting, picking, and placing printed circuit boards, packaging and labelling, palletizing, product inspection, and testing with high accuracy, precision, and fast speed. Robotic welding is a complex, nonlinear and time varying process which can be affected by various natural or any random disturbances. Due to the effect of various factors, the actual welding path may differ. So, welding robots should be able to detect the actual welding path, then adjust the difference in welding path and complete the welding process accurately. Laser welding is one of the most important technologies in the manufacturing field. It is the most frequently used technology which has made new demands. So, the manufacturer ensures to meet the quality of laser welding and improve the production efficiency. Due to the increase in demand of quality, accuracy, precise, productivity, flexibility and adaptive control of welding robot, an automatic laser seam tracking system is developed with welding robot to precisely follow the welding path and make the necessary corrections during welding operations.

Corresponding Author:

Tejaswini P.
Industrial Automation & Robotics, Department of Mechanical Engineering, The National Institute of Engineering
Mysore, India
Email: tejaswini097@gmail.com

1. INTRODUCTION

The process includes various technologies of welding, robotics, and sensor technology. Sensor technology plays a very important role in observing and measuring the parameters in the process. It has the ability to gather information from the sensor and analyze it. This sensor information is the input source to the robot controller [1]. The time taken by the light to emit back to the sensor after hitting the welding plates helps in measuring the difference in the welding path [2]. The change in the welding path affects the position of the light concentrated on the detector. This makes the sensor identify the welding joints [3]. The adjustments and setting of the sensor can be done using an application software. Thus, use of sensor technology in robotic welding leads to risk-free manual welding operation in dangerous work environments. This helps in maintaining the quality of welding.

The main benefits of laser seam tracking system with welding robot are that the process is faster and accurate than manual welding, the adjustments and setting of the sensor make the welding accurate, thus the process helps in maintaining the quality of welding.

The challenge faced in the automobile industries while welding continuously is searching the start point, end point, and real time tracking [4]–[6]. Another problem is that the taught line and welding (actual) line may differ. Robots should be automated to detect the path and complete welding continuously. The one more problem faced in the welding operation is selecting the joint type and setting the joint parameters. So, this project gives an accurate solution to these features. in the user interface application.

An automatic laser seam tracking system for welding operations plays a very important role in automobile industries [7]. There are lots of studies done in seam tracking for welding, but no research has been done in selecting the joint type for the welding and also for customizing the sensor parameters and joint welding parameters. These inspired us to develop this system.

The main objective of the project is i) to develop most accurate welding operating robot with laser sensor in all different environment (like in oily surface, uneven surface, in distractive surface etc.), ii) to find the starting and ending point of the welding line, iii) the laser sensor should be able to detect the path automatically if there is any difference in taught line and welding (actual) line, iv) to build a user interface application for selecting the type of joint and for the customized joint setting, and v) to make it fully automated system in real time monitoring of welding operation.

2. LITERATURE REVIEW

Michalos *et al.* [8] used a laser diode to remove the effects of lighting and any random disturbances in the surrounding welding area. The paper explains that the disturbance in the laser lines helps in identifying the part to be welded, flange, and the path correction. This makes the proper welding in the required area. This proposed system is deployed on an assembly cell that produces a part of a commercial vehicle door.

Graaf *et al.* [9] describes an algorithm for real time seam tracking. This makes the laser welding accurate. The algorithm is based on the trajectory-based control architecture. The position and orientation in cartesian coordinates are added to the robot trajectory while the robot is moving. This helps in getting the sensor information and generate the robot trajectory.

Huang *et al.* [10] describes a system for identifying the information of welding seam deviation. The information can be taken by four parts: sensors, controller, servo system and actuator. The sensors detect the path deviations of the laser beam from the welding path. The control system controls the output signals. Then the servo system drives the actuator. At last, the laser beam welds the path in the real seam line.

3. RESEARCH METHOD
3.1. System architecture
3.1.1. Motoplus SDK

Motoplus SDK is an application software used for controlling and monitoring robot systems. The SDK has a set of programming instructions for the custom application task which simultaneously runs on the robot controller. These are the real time tasks to control and monitor the robot with high performance. The set of programming instructions is written in C programming.

As the features, the Motoplus key can be integrated with any device to develop an application and can run on offline mode using windows PC. It also does not require any hardware, and there is a list of application programming interfaces (APIs) for programming.

Motoplus APIs which are used for giving commands to robot are mpUsrRoot to start the entire application, mpCreateTask to create a task, mpConnect to send a connection request from client to server, mpSocket to create a Socket, mpTaskDelay to delay a task, mpClose to close a socket, mpReceiveSkillCommand to receive a sensor command, mpEndSkillCommandProcess to notify the system that the sensor command is received, mpClockAnnounce to wait for an interpolation control cycle to start, and mpMeiPutCorrPath to give the path correction for every interpolation control cycle.

The API mpMeiPutCorrPath() used for path correction synchronize with the system's interpolation control cycle by using an API mpClockAnnounce(), which waits to start the per interpolation control cycle. Therefore, mpMeiPutCorrPath() corrects the path for every interpolation control cycle. Thus, we can say interpolation control cycle plays a very important role in path correction.

Therefore, the interpolation control cycle per calibrated length is given by:

$$\frac{\text{Length of the welding line}}{\text{Interpolation Control Cycle Per Calibrated Length}}$$

Then, correction amount is given by:

$$\frac{\text{Calibration Length}}{\text{Motion Speed}} \times \frac{1}{\text{Interpolation Control Cycle}}$$

For every interpolation control cycle, the request for path correction is checked, and if there is any request for path correction, then the amount of path correction is calculated by an API mpMeiPutCorrPath().

3.1.2. Hardware Components

The first component is the YRC1000 Robot Controller and Motoman. The YRC1000 is a compact, fast, and flexible robot controller for small robots like MOTOMAN GP Series as shown in Figure 1. YRC1000 Robot Controller is a compact design with reduced space requirements. The I/O communication speed in it is 50% increased for work efficiency. It is independent of motion speed. This gives a high path accuracy with increased precision in trajectory performance. It also has a machine integrated for simplified setup. Thus, it improved reliability by single controller-to-robot cable [11].

Since it does not require 380VAC to 480VAC input voltages and it is globally standardized, it is compatible with both the Standard Teach Pendant and the Smart Pendant, and it communicates with the Laser sensor through Ethernet connection. This helps in updating fast and makes the tracking more accurate. Thus, YRC1000 Robot Controller is faster, more precise, and more compact. Yaskawa Motoman is a fast and efficient industrial robot. These robots are mainly used for adaptive welding operation. The series of Motoman robots used in welding operations are of GP series. The key benefits of Yaskawa Motoman robots are high payload, allows wrist moment, compact and space-efficient, can be easily installed, can easily operate, and can easily maintain.

The second component is a seam tracking laser sensor. It has a non-contact torch system for welding operations. A laser sensor is placed in front of a welding torch so that the sensor is able to find the welding joints. This helps in calculating and dynamically correcting the torch position in real time welding operation. The KML Seam Tracking laser sensor Figure 2 works on a 12VDC adapter supply and it has a maximum focus length of 160 mm The sensor can be interfaced by an ethernet cable [12].

Figure 1. Motoman and YRC1000 Robot Controller   Figure 2. Seam tracking laser sensor

Laser sensor operates on the principle of triangulation. Figure 3 explains the working principle of triangulation [13]–[15]. The laser triangulation sensor consists of a laser, detector and a lens, a lens focuses the beam on the detector. Firstly, the laser emits light on the surface. The laser beam on the surface is reflected on the detector through the lens. Depending on the position of the beam on the detectors, the angle (α) is calculated. The angle is inversely proportional to the height of the surface. Therefore, when the height increases the angle decreases and vice versa [16]. Thus, the height from the sensor to the target surface can be calculated.

3.1.3. Communication protocols

Socket communication is a two-way communication link between two nodes or programs running on the network. One socket or node called Server is the listener socket which waits and response to the clients on a particular port number at an IP, while other socket called client is the one that reaches out and establishes the communication with the server. To establish communication of a client with server, client has to know the Internet address and port number of the server [17]. Stages of client server communication are as shown in Figure 4. The stages of communication are socket creation, bind, listen, accept, and connect.
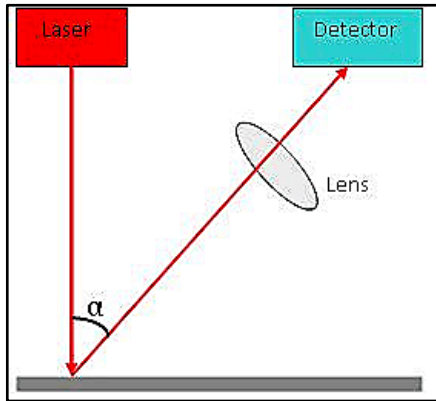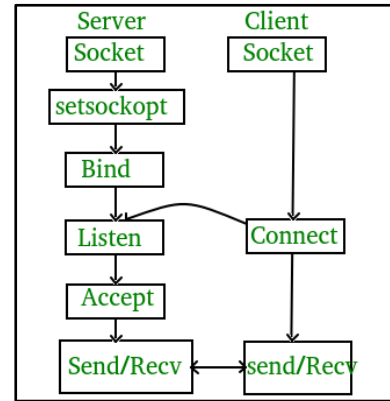
Figure 3. Laser triangulation principle

Figure 4. Client Server Communication

a. Socket creation: Socket creation is a process of creating a new socket to communicate.
    Syntax: int socket(int domain, int type, int protocol)
b. Bind: Once the socket is created, Bind function binds the socket to the specified IP address and port number.
    Syntax: int bind(int socket, struct sockaddr*localAddress, unsigned int addressLength)
c. Listen: makes the server to wait for the client connection. It also defines the number of pending connections. An error indication of ECONNREFUSED may occur when the queue is full.
    Syntax: int listen(int socket, int backlog)
d. Accept: when the server is in listener mode, server socket accepts the new connection request in the queue of pending connections. Then it creates a file of the new socket with function called new_socket(). This makes a new connection between server and client, and ready to exchange the data.
    Syntax: int new_socket = accept(int socket, struct sockaddr *localAddress, unsigned int addressLength)
e. Connect: The connect() function connects the socket referred to by the file descriptor socket of the specified addressed. The IP address and port number is specified in (struct sockaddr*localAddress).
    Syntax: int connect(int socket, struct sockaddr*localAddress, unsigned int addressLength)

3.2. Implementation

The setup of the proposed system is explained in Figure 5 with a block diagram. The proposed system of the laser seam tracking system with Yaskawa robot for continuous welding operation is developed. The robot controller should be set up properly with the robot and laser sensor for tracking [18]. So, connect the ethernet cable from the ethernet switch to the ethernet port 1 inside the robot controller.
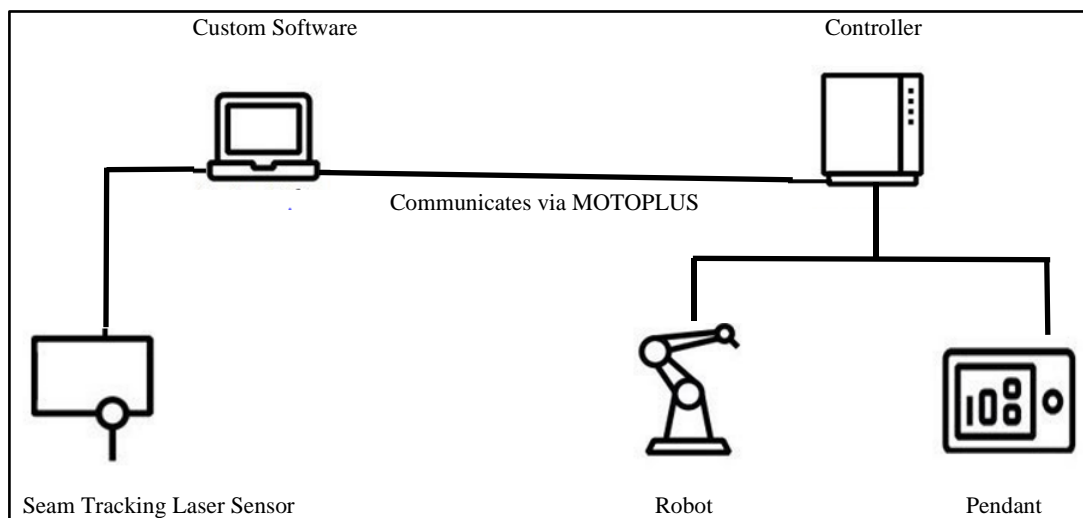

Figure 5. Block diagram of this project

The robot communicates with the sensor through TCP/IP protocol. The IP address of the robot should be compatible with sensor's subnet mask to communicate [1]. Then run the sample program (JOB file) for testing the turning ON of the sensor. If the communication between sensor and robot is established, then run the path correction program (JOB file) from the robot pendant. The JOB file for path correction is explained further. JOB file is a file which is created in the pendant to communicate and give instruction to the robot.

```
NOP
*TOP
MOVJ P000 VJ=5.00
MOVL P003 V=11.0
SKILLSND "SET_SEAM" TIMER T=1.00
SKILLSND " START_TR "
SKILLSND "GET_M"
MOVL P004 V=11.0
SKILLSND "END_TRAC"
TIMER T=1.00
ADVINIT
JUMP *TOP
END
```

1) Run the JOB file. The command "NOP" is the no operation function. The command "*TOP" is used for the continuous looping of the operation. "MOVJ P000 VJ=5.00" is the command for robot to return to its home position. "MOVL P003 V=11.0" command moves the robot linearly to the point where the welding has to be started.
2) Next, the JOB file sends a command to check the seam number by a command SKILLSND "SET_SEAM" and waits for 1 second.
3) Then the Motoplus application receives the command and sets the seam number as it is customized in the application software.
4) Then the JOB file sends a command to start the laser sensor by giving an instruction SKILLSND "START_TR".
5) The Motoplus application receives the command and requests the laser sensor to turn ON and start to track.
6) After turning ON the laser sensor, the instruction SKILLSND "GET_M" command is sent to starts the path correction. The API mpMeiPutCorrPath() is used to give the amount of path correction. This process runs in an infinite loop.
7) The amount of path correction is received by the Motoplus application and applied to the process while executing MOVL command in the JOB file. MOVL is the command which is between start track SKILLSND "START_TR" and end track SKILLSND "END_TRAC" commands.
8) After the path correction, the JOB file sends a command to turn off the laser sensor by the instruction SKILLSND "END_TRAC".
9) The Motoplus application receives the command and requests the laser sensor to turn OFF.
10) After executing once, the path correction values are stored in the robot controller.
11) So, to initialize to the home position, an instruction ADVINIT is executed in the JOB file. ADVINIT is an instruction that clears all the path correction value for every interpolation cycle.

Application software is a user interface application used to customize the system process. The executable file of this application software is made to run on the PC. This application software works inside the laser sensor system and starts the sensor functioning.

An application software has the following screens: i) home screen, which consists of live profile image of welding, measurements, system status and laser sensor status, ii) info, to display the message logging, robot communication log and the live correction values during the process, iii) setup screen which displays the system parameters that need to be customized for the best performance during system operation, and iv) system parameters, which are joint type, joint width, joint mismatch, analysis sensitivity and tracking position.

The application software is launched by clicking the executable file. Once the communication between the application software and laser sensor is established, the display shows a correct initialization with no errors occurring. Therefore, the system is ready to begin tracking. Now the robot communicates with the sensor through TCP/IP. The IP address of the sensor has to be correctly set up in the robot controller. The IP Address of the robot should match the sensor's subnet so the robot can communicate with the sensor. Once the communication is established, in the info screen we can see "Connected to Robot" as shown in Figure 6.
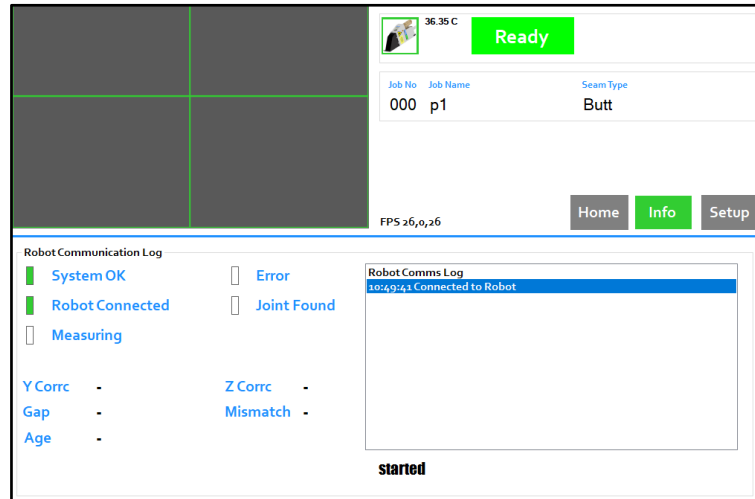
Figure 6. Display of robot connection in the application software

4. RESULTS AND DISCUSSION

The Prototype of developing and integrating the laser sensor with the robot for automatic path correction during welding operation repetitively was successful. The function of this system is to correct the targeted welding line based on the data received from the laser sensor. The seam tracking laser system uses a laser sensor and an industrial robot. The laser sensor is interfaced with robot by an ethernet connection [19].

The successful setup of the laser seam tracking system with YASKAWA robot is as shown in Figure 7. The figure gives a clear mounting position of the camera. This helps in detecting the joints and can be focused on the center of the sensor's field of vision. The problem faced in the welding operation was in finding the joint type and in setting the parameters [20]. The seam tracking laser sensor has a function which is capable of identifying the joint type [21]–[24].
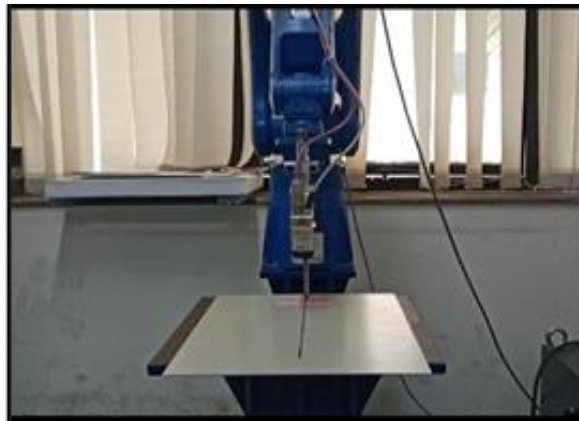
Figure 7. Setup of laser seam tracking systemwith YASKAWA Robot

The setting of sensors and its parameters can be adjusted by an application software, which is shown in Figure 8. The figure shows the successful live vision of tracking in the form of graphical form, the status of the proposed system and the successful connection of robot with the sensor.

In searching the start point, end point and real time tracking. The start point of the welding line is registered while teaching the robot. This position is registered in the command "START_TR" in the JOB file. By calling this command, the seam tracking laser sensor detects the start point of the welding line. Similarly, by calling the command "END_TRAC" the end point of the welding line can be detected.

The real time tracking can be achieved by using the position data received from the laser sensor. This helps in preparing the corrected data of the welding line either in base coordinate system or user

coordinate system. Based on the data the welding torch is corrected. The data received from the laser sensor is sent to the YRC1000 robot controller. The data are in a three-dimensional position. The YRC1000 converts the input sensor data to robot position data. By converting, the sensor data and the robot position data relatable. Now the laser sensor will be able to detect the joint of the work piece at the sensor, which can be seen in the application software Figure 8.
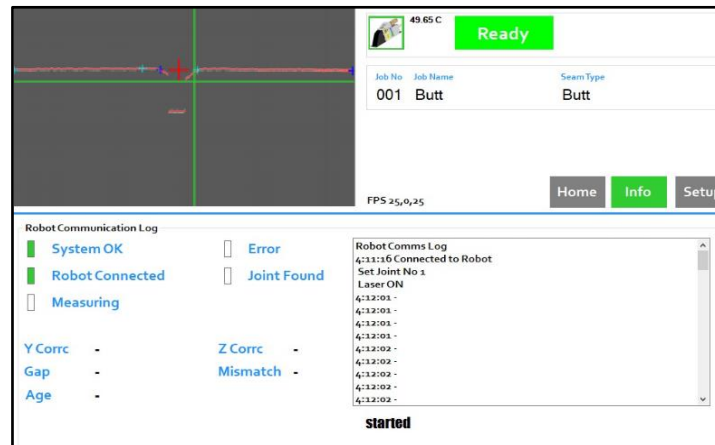

Figure 8. Data logging screen

The values of path correction can be viewed in the telnet software: Telnet is based on client-server protocol. In this system, Telnet client is our computer. Our computer establishes a connection to a remote host. Remote host is our robot controller which gives the path correction values to be displayed on the screen. To access this remote host, we have to login. The logging can be done by giving the host name. In this system, our host's name is "MOTOMAN".

Once logging is enabled, the data can be logged and saved. The successful data logging of the proposed system is as shown in Figure 9. In Figure 9, yCorr and zCorr are the path correction values in y and z direction respectively. These values are calculated by the path correction API mpMeiPutCorrPath(). The calculations of this API are explained in section 4.5.2. The path correction can be seen in this video: https://drive.google.com/file/d/1GlqTZnmFV4kT5RN_W7slwioIn40Bbdii/view?usp=drivesdk

Figure 9. Telnet data logging screen

In this video, first the robot follows the taught line of the welding path. In the second part (i.e., at 38 secs), let us consider there is deviation in the welding line. The laser sensor continuously scans and follows the welding line by getting the path correction values simultaneously from the robot controller. Thus, the real time tracking is made automatic and continuous.

5. CONCLUSION AND FUTURE SCOPE

Laser seam tracking system for welding operation is the most researched topic in the automation world. The development in the sensor technology has helped in detecting the path correction automatically and complete welding continuously. Thus, use of sensor technology in robotic welding leads to replacement of manual welding operation in dangerous work environments. This helps in maintaining the quality of welding.

Since there is an option of selecting the joint type and setting the joint parameters, the system gives an accurate solution for the welding operation in the automobile industries. The proposed system can be improvised in the application software by adding the calibration parameter settings and adding the features of data logging and live values of path corrections.

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BIOGRAPHIES OF AUTHORS

Tejaswini P. was a student of Automation and Robotics Engineer. She holds a Bachelor of Engineering in Electronics and Communication from VTU, Belgaum, KA, India, Master of Technology in Industrial Automation and Robotics from The National Institute of Engineering, Mysore, KA, India. Her interest is to convert semi-automated machines in the industries to fully automated. She has knowledge on how to operate and communicate with robots with the application software. She also has prior knowledge of programming language to build a user interface application for robot communication. She knows to interface different types of sensors with industrial robots. She can be contacted at tejaswini097@gmail.com.

Dr. M. V. Achutha is a professor at the Department of Mechanical Engineering, NIE, Mysore, KA, India. His primary research interests are in fatigue studies of metal matrix and polymer matrix composites. However, he is also quite interested in studies on wear and fracture of composite materials due to relationship between fatigue, wear, and fracture. He can be contacted at mvachutha@nie.ac.in.

Ananda Doddagatte is a software developer who was working in R&D, Yaskawa India Pvt Ltd, Bangalore, India. He has more than 7 years of experience in C# language in developing a user interface application for many industrial applications. He can be contacted at ananda_d@yaskawa.in.