Vision Based Self Adaptive Algorithm for 6 Axis ABB Industrial Welding Robot

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Abstract. The ultimate aim of this work “Vision Based Self Adaptive Algorithm for 6 Axis ABB Industrial Welding Robot” is to develop a self-adaptive RAPID algorithm based on the captured image of the work piece. The image of the work piece is captured using NI Guppy pro F031C camera which has 300 DPI with 120 FPS resolution. The captured image is transferred to the LabVIEW software for developing the self-adaptive algorithm through RS232 serial communication protocol. The LabVIEW vision assistant module is used to develop an algorithm based on the geometry of the captured image. The various image processing operations like Thresholding, Morphological operation (Thinning), and edge detection are carried out. The caliper tool is used to measure the distance between the coordinate points (welding distance). With the aid of Visual Basic, the measured values are converted into coordinates. The coordinates are used to develop a RAPID program with the aid of ABB Robot Studio library functions. The virtual server is established between the ABB Robot Studio and IRC5 Controller with the use of MOD-BUS protocol with VISA. After receiving the data from the MOD-BUS, the IRC5 controller moves the ABB Industrial Robot End effectors along with the welding gun for the welding purpose. The work piece is located on the designed jigs and fixtures. The different types of welding with different design can be incorporated with the Vision Assistant module for further development. To illustrate the developed algorithm, robot assisted MIG welding process is carried out. The welded work-pieces are tested for its strength quality and the results are verified. Optimal welding parameters for the good quality of weldment identified by using Taguchi method of optimization.

Keywords: NI Guppy pro; Thresholding; Edge Detection; Thinning; MOD-BUS; IRC5 Controller; Taguchi Optimization

1. Introduction
The Robotic system considered in this study consists of the robotic arm namely the ABB IRB 1410 with 6 axes. Robot studio software is used for effective control of the robot. The IRC5 controller is the ABB’s fifth generation controller. Its motion control technology, True-Move and Quick-Move, are key to the robot’s performance in terms of accuracy, speed, cycle-time, programmability and synchronization with external devices. All ABB robot systems are programmed with RAPID (ABB’s flexible high-level programming language). It also incorporates powerful support for the most
common robot process applications such as welding and assembly. The ABB IRB 1410 is a 6 axis industrial welding robot with a payload of 5kg. It is being used in the industries for the continuous welding operations. It has a high accurate control and easy movement, the speed and response of the robot manipulator is also pretty impressive while compared to other models in that category.

![IRB 1410 with Welding gun](image1)

**Figure 1.** (a) IRB 1410 Work Volume; (b) Welding Robot.

ABB IRB 1410 work range is shown in the figure 1 (a). It gives the idea about the maximum reach of the end effectors and the work volume that the robot manipulator can reach in order to make the work done. IRB 1410 is the 6 axis robot used for the purpose of welding. The robot is proven in MIG welding applications and provides outstanding performance. The IRB 1410 has integrated wire feed cabling and mounting holes for optimized assembly of process equipment on the arm. MIG welding functions are included as standard in the IRC5 robot controller. They are made available via the operation interface unit nothing but the flex pendent. The real time integration of the welding gun with the robot end-effectors is shown in the figure1 (b). Enhanced welding automation, safety from dangerous fumes, higher quality welds and more efficient processes are just some of the advantages of it.

Lee et al (2010) proposed an intelligent welding robot in shipbuilding, the RRXC which consist of the industrial robot and auxiliary transport device in this process the six axis ABB industrial robot is being used. Paes et al (2014) on his work with trajectory control of the ABB industrial robot, describes about the path planning and development of dynamic robot module. Trajectory optimization technique is done by using the dynamic parameter of the robot module developed. Muzan et al (2012) on his work on using robots for painting application, discuss about precise movement of the end effectors for specific target letter which are pre-programmed into the controller system. Later the end effector and manipulator is imported into the robot studio for RAPID programming. Antonelli et al (2013) the algorithm developed which filters inaccurate and noisy data, re-orders points and computes a trajectory suitable for a welding robot, which is done by using the Bluetooth for transfer and manipulation of the data. Antonelli et al (2016) proposed a system on the qualification of a collaborative human-robot welding cell and the welding process is more reliable. Luo et al (2014) on their work presents a weld pool edge detection technique based on an off axial green illumination laser and a coaxial image capturing system that consists of a CMOS camera and optic filters. By studying the reflection of the green laser illumination the appropriate width of the keyhole generated by the welding process is identified. Tsai et al (2011) on his work presents the path planning of golf club head welding robot by using machine vision system, the robotic welding path is obtained by rotations and translation along the axes of the task frame according to the requirement of the welding attitude. The respective mathematical frame is designed for the transformation of the vision data into the path.
planning coordinate value. Luo et al (2015) proposed a system on the Vision–based weld pool boundary extraction and width measurement during keyhole fiber laser welding in which the green laser illumination the appropriate width of the keyhole generated by the welding process is identified. Dinham et al (2013) presented a paper work on the autonomous weld seam identification and localisation using eye-in-hand stereo vision for robotic arc welding that enables the robust identification of narrow weld seams for ferrous materials combined with reliable image matching and triangulation through the use of 2D homograph. Zhang et al (2013) presented on the real-time seam tracking control technology during welding robot GTAW process based on passive vision sensor that enables the analyzing the features of welding images, a new improved Canny algorithm has been proposed to detect the edges of seam and pool, and extract the characteristic parameters of welding images. Special PID controller is used. Bragun et al (2015) proposed asystem on the Stereo vision based measuring system for welding path inspection which measures the arc position in 3D space based on the stereo vision principle. The simulated irregularities are visible as anomalies in the welding path. Xu et al (2012) presents a technology about real-time seam tracking, a set of vision sensor system has been designed for the welding robot. By analyzing the features of welding images, a new improved Canny algorithm has been proposed to detect the edges of seam and pool, and extract the characteristic parameters of welding images. A specifically designed PID controller is being used for the proper functioning of the algorithm. Zhang et al (2014) on there work uses the common CCD camera for through image processing and calibration, the shapes and sizes of both the keyhole and the weld pool were measured under different welding conditions. The observation results lay solid foundation for optimizing the welding process parameters and implementing process control of plasma arc welding. Bracun et al (2015) on their work on weld path inspection uses the stereo vision based system, which measures the arc position in 3D space based on the stereo vision principle. The simulated irregularities are visible as anomalies in the welding path.

2. PROPOSED SOLUTION
In this system, the robot and the vision camera are incorporated together into a single system for the effective control of the robot. Figure 2 shows the block diagram of the incorporated system with the data flow in it. Initially, the with the help of the NI camera the image is captured automatically by the triggering Lab VIEW’s virtual tool kit. The captured image is then passed through series of process under the vision assistant in which thresholding, morphology, edge detection and caliper process are carried out. Then the system would refer the captured image with the predetermined sample images for the final change in the coordinate system. These coordinates are then transferred to the IRC5 controller through the Robot Studio software.

![Figure 2. System Architecture and work flow.](image-url)
3. **SYSTEM DEVELOPMENT**

3.1 *Vision Development Module*

The initial step of the entire process is to capture the image in the allotted perimeter for the further processing. LabVIEW is the tool used for the image capturing and processing. In LabVIEW, the vision assistant is responsible for accessing the hardware unit i.e. the camera by the software for capturing the image. The Vision development module uses the vision assistant for the development of the various sub level process in the image processing section. The captured image is regulated by the threshold value so that the proper monochromatic image with singularity image detection is done. Then in the next process of morphology the noise in the image is reduced by the thinning process of the edges and is represented in the figure 3.

![Figure 3. Image Development Process](image1)

Then the two edges as described in the sampling process are detected automatically by the edge detector unit of the vision assistant. The final image after all the process flow is shown in the figure 4.

![Figure 4. Processed Images](image2)

The image mentioned above is the final processed image in which the points marked with green boxes as number 1 and 2 represents the joints of the welding process. The point 1 indicates the starting point and the point 2 indicates the destination point. Then the Caliper tool is being used for the identification of distance between these points for the purpose of coordinate development.

3.2 *Pixel Conversion*

The output value from the vision assistant is the distance between the two points but the system provides the value in the form of pixels. But the robotic module does not understand the values in pixels. So these pixels are to be converted into mm (millimeter) unit for the transformation of the
values to the robotic unit. For the conversion of pixels to mm, some of the parameters of the camera are required such as the DPI (Dots per Inch). Dpi is nothing but the representation of quantity or number of dots or pixels present in the square of side one inch. The Dpi of the NI Guppy pro is 300 from that the formula is derived to converting the pixel to mm. For this conversion, separate mathematical functions are performed under coordinate transfer algorithm.

\[
1 \text{ mm} = (\text{Pixels} \times 25.4),
\]  

(1)

3.3 Algorithm Development

The algorithm is developed to get the data from processed image and to transfer it into programming coordinates. Value of X, Y and Z form and replace the values in the RAPID program. The main part of the system is the coordinate development algorithm which is shown in the figure 5. The image is captured and evaluated in the vision development module and the final image is converted into necessary data values as per the coordinate system of the robot controller for the easy communication of the system. Initially the vision acquisition block is used for the capturing of the image by accessing the camera; the captured image is displayed in the display unit with the help of the display block. Once the image is captured it is sent into the Vision assistant where the image processing technique is done and as an output from the block it gives the measurement value in pixel unit. Later on the pixel unit is converted into millimeter by means of the formula derived with the help of dpi of the camera. Then the value is sent into the bundle to binary unit block. In that block, the measurement values are changed to coordinates with respect to the two dimensional image captured.

![Figure 5. Co-ordinate Development Algorithms](image)

3.4 Communication Module Development

The communication between these two software is done with help of the virtual server named as MODBUS. In this case, LabVIEW acts as server and the robot controller acts as the slave. With the help of the developed virtual environment, the robot controller is controlled by the LabVIEW. Figure 6 shows the designed Communication Protocol.
3.5 Development of end effector

The welding gun must be attached to the robot manipulator; a separate end effector must be designed. The end effector is one of the important parts of the robot manipulator. In robotics, an end effector is the device at the end of a robotic arm, designed to interact with the environment. The end effector is manufactured with the CNC machining process. Since the robot manipulator is highly precisely manufactured and operated in all condition, good quality of manufacturing is necessary for the perfect match of the end effector with the manipulator. Figure 7 shows the view of the manipulator where the welding gun is placed horizontally.

3.6 Program Execution Module

The coordinates calculated from the LabVIEW are uploaded into the Robot Studio by means of three coordinate transform variables. For three separate x, y and z coordinate values separate variables are assigned. The Sub-program variables for the data transfer are:

- Visionpick.trans.x
- Visionpick.trans.y
- Visionpick.trans.z

These three variables carry the data from the LabVIEW script to the robot studio to generate the RAPID program for the robot controller to operate. Then the robot manipulator will move along the X, Y and Z axis to reach the starting point and move to the ending point. This movement will make the welding process to complete. The real time integration of the welding gun with the robot end-effector is done. Due to this integration, the welding automation, safety from dangerous fumes and weld quality are enhanced.

4. EXPERIMENTATION
Once the welding process is ready to operate, the optimal welding parameter for the effective and better welding is to be identified. The parameter which affects the welding process is identified initially. In case of the MIG welding process using robot, three parameters are considered:

- Gas flow rate
- Current rating
- Feed rate

In the automated MIG welding process, the speed of the welding gun is constant since it is controlled by the robot. Based on these values, the design of experiments is used to identify the number of experiments using Minitab optimization software. Table 1 shows the values for the design of experiments.

| Ex.No | Gas Flow (kg/cm²) | Current Rating (A) | Feed Rate (mm/min) |
|-------|-------------------|---------------------|--------------------|
| 1     | 1                 | 1                   | 1                  |
| 2     | 1                 | 2                   | 2                  |
| 3     | 2                 | 1                   | 1                  |
| 4     | 2                 | 2                   | 2                  |
| 5     | 1                 | 2                   | 1                  |
| 6     | 1                 | 2                   | 2                  |

### 4.1 Material Processing and Testing

For the purpose of welding, the mild steel material is chosen and the dimensions of the work piece are same for all the eight experiments designed. For the effective penetration of the welding, the chamfering process is done at the welding joints for all the work pieces. The values for the welding parameters are identified and tabulated in the table 2. These values are changed in the real time system and welding process is carried out.

| Ex.No | Gas Flow (kg/cm²) | Current Rating (A) | Feed Rate (mm/min) |
|-------|-------------------|---------------------|--------------------|
| 4     | 40                | 1.8                 |                    |
| 4     | 40                | 3.7                 |                    |
| 6     | 60                | 3.7                 |                    |
| 4     | 60                | 3.7                 |                    |
| 6     | 40                | 1.8                 |                    |
| 6     | 40                | 3.7                 |                    |

Based on these parameters, the eight experiments are done one by one with respective change in the welding parameters. The eight welded work-piece are shown in the figure 8.
After the completion of the welding process, the eight work-pieces are made to undergo hardness test and tensile strength test. This is done in order to identify the work-piece with highest strength and hardness, so that the particular parameter of welding could be used for the effective welding purpose and to obtain a good quality of welding.

5. Selected Results
After the completion of the test over the work-piece, the tensile strength and hardness values are enumerated in the table 3.

Table 3. Test Values

| Experiment | Tensile Strength (N/mm²) | Hardness   |
|------------|-------------------------|------------|
| 1          | 2.012                   | 83.334     |
| 2          | 0.321                   | 80.667     |
| 3          | 0.724                   | 77.334     |
| 4          | 6.197                   | 85.000     |
| 5          | 10.060                  | 77.000     |
| 6          | 2.012                   | 82.000     |
| 7          | 1.529                   | 64.000     |

The test values enumerated from the table are uploaded into the Minitab optimization software in order to apply the Taguchi method of optimization to the system. So the three parameter and two level processes is selected and the respective values are uploaded into the processing area. Then the Taguchi method of optimization is applied over the values for the identification of the optimistic parameter.

Table 4. S/N ratio for tensile strength

| Experiment | Tensile Strength (N/mm²) | S/N Ratio |
|------------|-------------------------|-----------|
| 1          | 2.012                   | 2.434     |
| 2          | 0.321                   | 2.112     |
| 3          | 0.724                   | 4.728     |
| 4          | 6.197                   | 4.406     |
| 5          | 10.060                  | 5.090     |
The signal to noise ratio for the parameter tensile strength is calculated and are tabulated in the table 4.

| Experiment | Hardness | S/N Ratio |
|------------|----------|-----------|
| 1          | 83.334   | 75.834    |
| 2          | 80.667   | 82.416    |
| 3          | 77.334   | 75.000    |
| 4          | 85.000   | 81.583    |
| 5          | 77.000   | 79.083    |

Similarly, for the hardness the S/N ratio is calculated and is represented in the table 5.

6. Discussion
The Signal to noise ratio is considered for the optimization process because if the signal to noise is higher than the output parameter will also be higher. The noise in the system must be lower than the signal in the system in that approach the signal to noise ratio is considered. So from the Signal to Noise ratio obtained from the hardness and tensile strength as an influencing factor the graphical representations are made. They are shown in the figure 9 and 10. In both the cases the better result is considered as higher. Because higher the tensile strength higher the quality of welding. Similarly higher the hardness value delivers the good quality of welding.

**Figure 9. S/N ratios for Tensile Strength**
Discussion
From both the graphical and numerical representation, the optimal parameters can be obtained. In case of the tensile strength, the experiment number five with tensile strength of 10.06 N/mm$^2$ provides better result. In case of the hardness value, the experiment number six with hardness value of 82 provides better result.

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