Computer simulation for seam tracking algorithm using laser vision sensor in robotic welding

Taikmin Jung*, Kieun Sung**, Sehun Rhee†

*Graduate Student Research Assistant, Department of Mechanical Engineering, Hanyang University

**Manager, Advanced Automotive Battery Business, LG Chem

†Associate processor, Department of Mechanical Engineering, Hanyang University

Abstract

It is very important to track a complicate weld seam for the welding automation. Very recently, laser vision sensor becomes a useful sensing tool to find the seams. Until now, however studies of welding automation using a laser vision sensor, focusedon either image processing or feature recognition from CCD camera. Even though it is possible to use a simple algorithm for tracking a simple seam, it is extremely difficult to develop a seam-tracking algorithm when the seam is more complex. To overcome these difficulties, this study introduces a simulation system to develop the seam tracking algorithm. This method was verified experimentally to reduce the time and effort to develop the seam tracking algorithm, and to implement the sensing device.

Keywords: Laser vision sensor, robotic welding, simulation, seam tracking

1. Introduction

Welding automation with a robot, has been widely used in many industries. It is necessary to track the seam for full automation. Seam tracking is important in laser welding as well as in arc welding. In order to track the seam, many types of sensors have been used. Among these sensors, laser vision sensor is effectively used to track the complex seams that require high precision.

Smati[1] et al., Clocksin[2] et al. and Agapakis[3] et al. introduced a method that tracks the seam by recognizing the welding line from the information of the range data. Fujita and Ishide[4] used a vision sensor for the welding control and the automatic weld inspection. Finally, Beranek[5] et al. studied the technology and applications of the welding robot control, while using a laser vision sensor.

Because most studies are focused on image processing or covered the whole area, seam tracking algorithms, to a large extent, are not being considered. Furthermore, the development of the seam tracking simulation systems, in the view of the laser vision sensor, is extremely rare and most welding automation simulation systems are limited to the robots off-line program.[3,5,6] It consisted of image processing, recognition of seam extraction, and design of seam tracking controller to track the weld seam while using a laser vision sensor. The seam tracking process becomes more important as the system is fast and complicated. Developing an algorithm, in order to track the seam, is accomplished through many trial-and-error methods, and hence requires a great deal of time and effort for many experiments. In this study, in order to reduce the time and effort to make the seam tracking algorithm, a seam tracking simulation system is introduced and an application is demonstrated. With the computer simulation system, a designer can quickly and accurately obtain the information on how the tracking algorithm will operate without experiment. This method can reduce the costs when developing tracking algorithm.

2. Seam tracking simulation system

In order to simulate a seam tracking system, a model of an actual process is required. To develop this model, the seam tracking system is divided into two parts, hardware and software. The hardware part consists of the seam, the laser vision sensor, and the robot. The software part consists of two areas. The first area is the seam finding process, which models the seam tracking with a laser vision sensor. Next one is the seam tracking algorithm, which decides how the seam is tracked with the data acquired from the laser vision sensor. This includes the robot motion simulation, which operates the robot from these model. The configuration of the system is shown in Fig. 1.

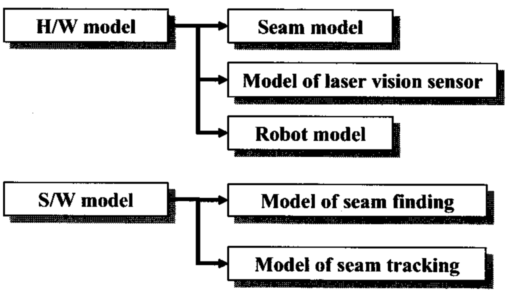

Fig. 1 System diagram.

2.1. Seam model

A seam is the joint line of the workpiece that is going to be welded. The welding torch follows this line. In the simulation system, this seam to be welded is imaginatively created.

Most seams can be shown in a simple 3D line. There are two methods to represent this three-dimensional line, one is using a mathematical equation acquired from the curve fitting, and the other is set of the points.

In the case of the first method, we may represent a line as a linear or curvilinear function. Thus, it is possible to obtain a continuous line and hence small amount of data are required. However, with this process it is difficult to represent a nonlinear or a discontinuous phenomenon. It is also difficult for the computer to analyze this data. In the case of the three-dimensions, it is hard for the human to intuitively understand the overall appearance.

The second method uses the set of the points, which are placed to produce the three-dimensional line. This method is extremely easy to perform, and also easy to understand. With this method it is also possible to add new information to each point. However, when the seam becomes longer, or a higher resolution is required, the number of data becomes much more. As data points are discontinuous, regression is necessary to obtain a continuous information.

The second method, using the points, was used in this study for many reasons. First, it is easy to express and calculate, and a mathematical equation model can invert the point model easily. Next, as the line model can directly acquire the seam from the CAD data, it is easier to approach automation. Also, each point must have information about the position and the normal vector for the control position of the robot and this method allows such data to be easily entered. As there is no information between two points, the information should be deduced. A linear interpolation is used to reduce the amount of calculation.

2.2 Model of a laser vision sensor

A laser vision sensor acquires range data, with a structured laser and camera. In a simulation system, the laser vision sensor uses the current position information to calculate the relative position between the sensor and seam. This task is divided into the modeling of the sensor's hardware and the modeling of the measurement process, which acquires welding point data from the seam.

As shown in Fig. 2, a laser vision sensor obtains the distance information from the structured laser light source and the position of the CCD camera.

When the reflected laser is imaged on the CCD camera, the range data can be obtained from the camera's coordinate. Then, the relationship is decided by the perspective transformation and the structured light's plane equation. As the laser and camera have a geometric relation, as shown in Fig. 2, the range is decided with the structured light's coordinates system {L}, according to Eq. (1), (2) and (3).

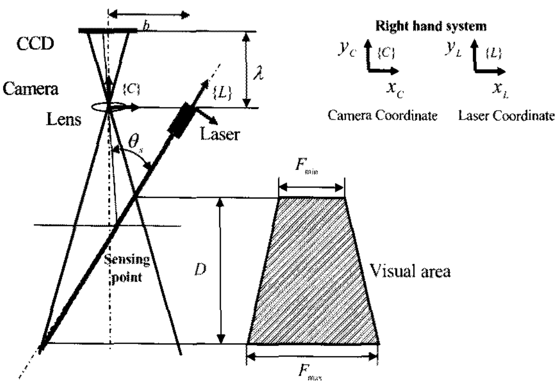

Fig. 2 Geometry of laser vision sensor.

$$x_L = 0 \tag{1}$$

$$y_L = \frac{bz_c}{x_c \cos\theta_s + \lambda \sin\theta_s} \tag{2}$$

$$z_L = \frac{b(\lambda\cos\theta_s - x_c \sin\theta_s)}{x_c \cos\theta_s + \lambda \sin\theta_s} \tag{3}$$

Here, x_c, z_c are the positions of the structured light in the CCD camera, and θ_s is the angle between the camera and the laser. b is the base line between the laser and camera, and λ is the focal length. The visual field of the sensor is shown in a trapezoidal shape, as shown in Fig. 2, and it relies on the size of the CCD camera. However, when the size along x_c-direction is H, and the size along z_c-direction is V, the sensor's depth of field and field of view can be equated as shown in Eq. (4), (5) and (6).

$$D = \frac{4b\lambda H}{4\lambda^2 \sin^2\theta_s - H^2\cos^2\theta_s} \tag{4}$$

$$F_{\max} = \frac{2bV}{2\lambda\sin\theta_s - H\cos\theta_s} \tag{5}$$

$$F_{\min} = \frac{2bV}{2\lambda\sin\theta_s + H\cos\theta_s} \tag{6}$$

Here, as shown in Fig. 2, D is the field that the laser vision sensor recognizes as depth. The lateral range when the sensor is at the furthest position, is F_{max}, and at the closest position it is F_{min}. Also, the resolution of the sensor is dependent on how many pixels there are in the CCD camera. If there are N_H pixels in the direction of x_c, and N_V pixels in the direction of z_c, and the resolution for depth is R_D, then the lateral resolution, R_L, can be shown as in Eq. (7) and (8).

$$R_D = \frac{D}{N_H} \tag{7}$$

$$\frac{F_{\min}}{N_V} \le R_L \le \frac{F_{\max}}{N_V} \tag{8}$$

As seen in the laser vision sensor above, the visual field and resolution depend on the geometry of the device, and the characteristics of the CCD.

2.3 Robot modeling

The robot model can be divided into the kinematic part and the robot controller part. The kinematic model of the robot can calculate the speed and the position of each part of the robot when the actuators move. The robot controller will send the data information to the actuators of each axis to obtain a desired speeds and positions. In the real process, the controller will calculate the necessary force to move each motor, and control the current. 3-axis-cartesian-robot used for simulation is controlled independently by each motor.

2.4 Model of seam finding

In the case of the real laser vision sensor, optical trigonometry method or beam phase difference method is used to obtain the range data. The positions of weld seam line will be determined by the relationship among the weld seam model and robot positions as well as laser vision sensor model in the simulation system. The basic sensing system is shown in Fig. 3.

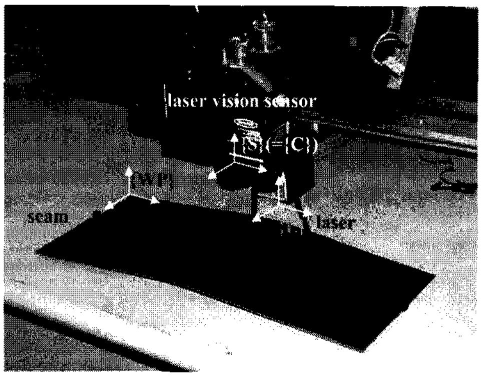

Fig. 3 Configuration of seam and laser vision sensor diagram.

As shown in the simulation system above, the seam consists of many digitized points. The laser vision sensor has a particular angle between the CCD camera and laser source. The camera captures the laser stripe formed by the object. Then the position and the shape of the stripe are obtained. In the case of the simulation, the point where the seam and the laser stripe cross, can be found. The algorithm to find a seam is shown in Fig. 4.

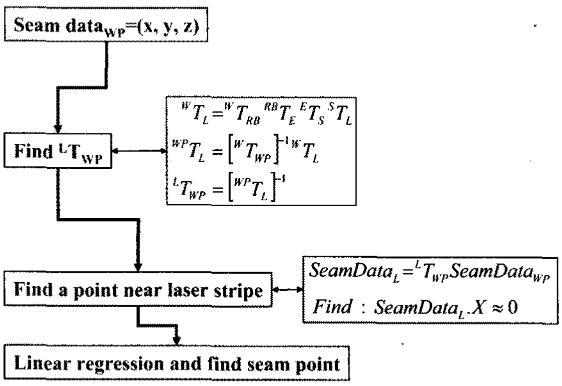

Fig. 4 Block diagram of algorithm for finding a seam.

2.5 Model of seam tracking

It is sometimes necessary for users to modify the seam tracking algorithm. Hence, the C-language was used to give the users to change the algorithm. Also, the DLL (Dynamic Link Library) was used to connect the programs with the outside part.

The program as shown in Table 1, consists of two in-processes and an extern-process. The main program has two in-processes, which are responsible for the initialization and simulation. The extern-process of the seam tracking algorithm must be developed by the user. Therefore the main program must be linked from the outside to allow updating.

Table 1 Program structures

Parts	Description
In-process I	Initialization and setup
In-Process II	User interface, Display and computation
Extern-Process (DLL)	Seam tracking algorithm

The simulation system helps in the preparation of the data file needed in the initialization. If the values are input according to the standard of the initialization program, an initializing file will automatically be produced. A user can make their own initialization file if they want a detailed one. The initialization file is saved as ASCII code.

Programming of the simulation process consists of the following parts: the calculation part, the user interface part, and the estimation part with the simulation results. The order is as follows; load the initialization file, then execute the simulation, and afterwards estimate the seam tracking performance. The simulation part is shown in Fig. 5.

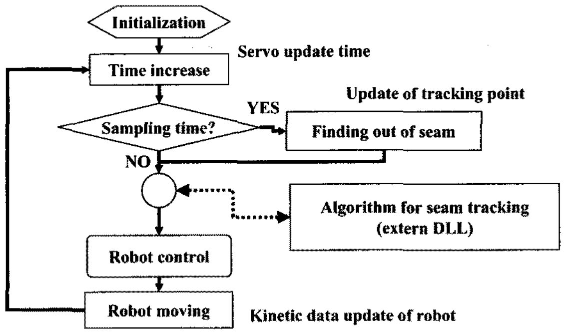

Fig. 5 Flow chart of simulation part.

3. Verification of simulation system

The results of the simulation system were compared to the actual system. The configuration of system used in this experiment is shown in Fig. 6. The modeling of the seam, as shown in Eq. (15), created 200 points, at an interval of 2mm, in the direction of X, and has a total length of 400mm. This can be substituted into Eq. (16) and (17) to find the coordinates of each point.

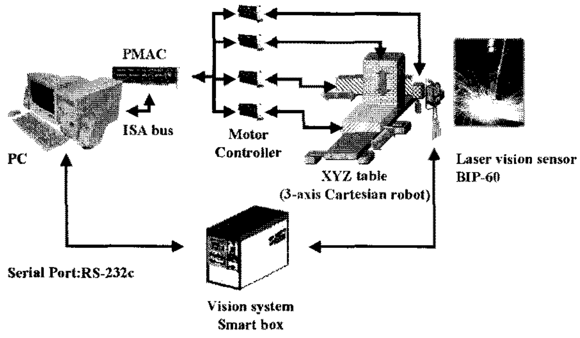

Fig. 6 System configuration.

$$X = 0 \cdots 400 \text{ interval } 2 \ (\text{welding direction, mm}) \quad (15)$$

$$Y = 10\cos\left(X \times \pi / 200\right)(\text{mm}) \quad (16)$$

$$Z = 10\sin\left(X \times \pi / 200\right)(\text{mm}) \quad (17)$$

X, *Y*, and *Z* are based on the coordinates of workpiece ({WP}). A 3-axis-cartesian-robot was used in this experiment. In order to model this robot, transformation matrix $^{W}T_{RB}$, $^{RB}T_{E}$, $^{E}T_{S}$ which were given in commercial robot company, were used. These are shown in Table 2.

Table 2 Robot modeling data[8]

Specification of robot (X, Y, Z direction for {RB})	
Position limit size	800, 150, 150 (mm)
Velocity limit size	20, 10, 10 (mm/sec)
Acceleration limit size	30, 15, 15 (mm/sec^2)

Table 3 Laser vision sensor model parameters[8]

Parameters	Values	Unit
Stand-off (A)	46	mm
Depth of field (D)	60	mm
Field of view (close, F_{min})	18	mm
Field of view (far, F_{max})	32	mm
Average depth resolution (R_D)	0.01	mm
Average lateral resolution (R_L)	0.01	mm
Laser angle ($_{ss}$)	16.17	°
Transfer matrices	$^{S}T_{L}$, $^{W}T_{L}$, $^{L}T_{WP}$	mm, °

The specification of the laser vision sensor is shown in Table 3. By applying the following seam tracking algorithm, the results of both the simulation and the actual experiment, are as follows.

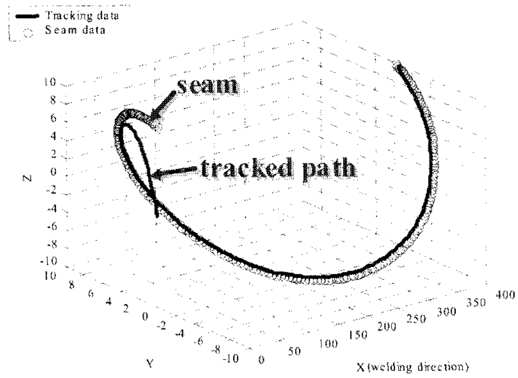

Fig. 7 Simulation result.

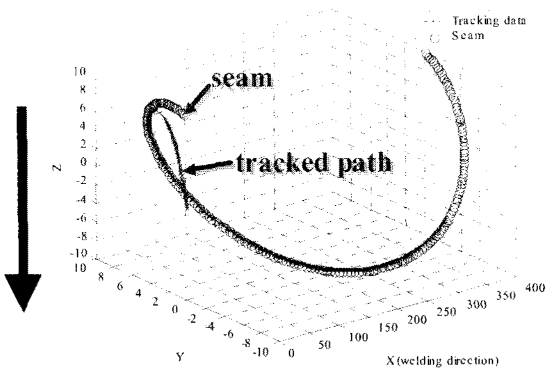

Fig. 8 Experimental result.

Fig. 7, 8 show the seam tracking results by the simulation program and by experiment, respectively. In both cases, even though the starting points were different, they show the robot follows the seam well. Though the results, it can be found that the simulation can be used to model the system by trial-error or any other methodology without real experiments for seam tracking with a laser vision sensor.

4. The application of the simulation system

In welding a complex three-dimensional shape, the ability of seam tracking is not based solely on how well the sensor can find the seam. There are many limitations. This process inevitably needs trial-and-error experiments, since the variables are nonlinearly combined. A lot of time and effort are required to establish the seam tracking algorithm. Therefore, it is necessary to use a simulation approach for seam tracking to enhance the effectiveness.

4.1 The development of the seam tracking algorithm

A seam tracking algorithm, which can track the seam with a maximum error of 0.5mm, should be developed to verify the simulation system, as shown in Fig. 9. Thus, a seam tracking algorithm, like Fig. 10, can be developed. This is a laser vision sensor that follows the collected seam information one by one. Therefore, it repeats the process of convergence at one point then another. A more concrete model used is shown in previous section. The sampling time of the sensor was 1 frame per second, and the welding speed was decided as 5mm/sec. This was named "Seam tracking algorithm I". The simulation results are shown in Fig. 11.

4.2 The reviews of simulation results

The robot dose not track the seam by this algorithm, as can be seen in Fig. 11. The reason of tracking failure can be found in the path of the welding torch. The algorithm makes the robot track the line with the sensed data. Before the robot tracks the next point, it finishes performing by the previous command. Unfortunately, the robot was unable to converge to the desired point precisely. Therefore, the computer has to wait without next command, until the robot has completely finished converging. As the robot must keep the welding speed at 5mm/sec, for a good welding quality, it could not converge near the desired position. To overcome this problem, either the performance of the robot controller is improved or the seam tracking algorithm is improved. Though control accuracy is sacrificed, seam tracking performance may be improved by changing the algorithm since the robot controller was already fixed.

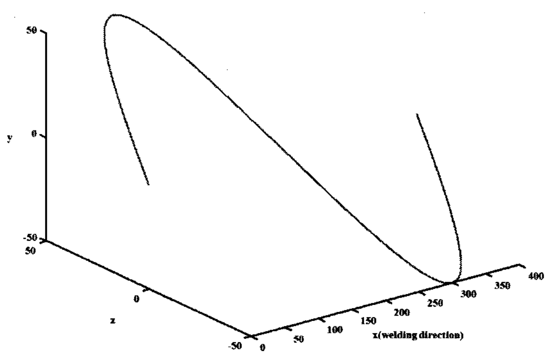

Fig. 9 Seam model.

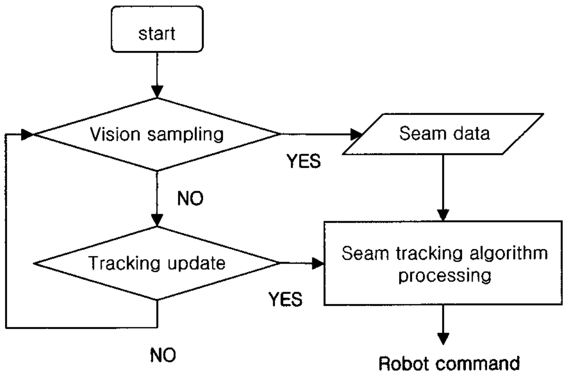

Fig. 10 Seam tracking algorithm I.

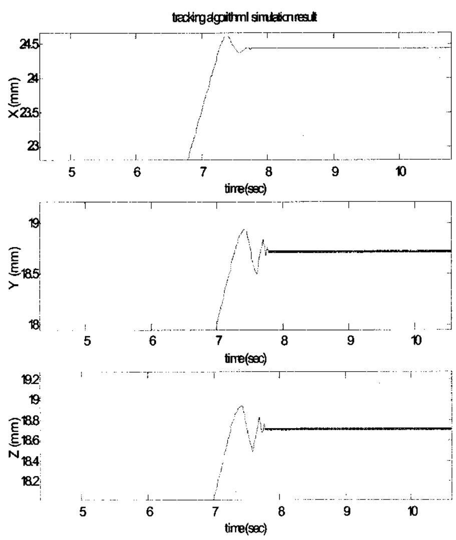

Fig. 11 Simulation results by seam tracking algorithm I.

4.3 Improvement of the seam tracking algorithm

We have to improve the algorithm for overcoming the problem that robot could not follow the seam. One method to improve the algorithm is what if robot position is within suitable distance near the desired position, then robot goes to next point. This suitable distance is called as 'radius of convergence'. The example of this idea is shown in Fig. 12 and 13. If radius of convergence is getting bigger, then robot is safely converged but has large position error. However, if radius of convergence is getting smaller, then robot has small position error. This is unstable when the radius below a certain size, like in Fig. 11. Therefore, through many experiments the appropriate range is determined. Table 4 shows the tacking error according to the radius of the sphere. It can be seen that the radius of convergence must be less than 5mm when the maximum error limitation is 0.5mm. However, when the maximum error is below 0.02mm, strong vibration will occur and produce an unstable result. In this study, the resolution of the laser vision sensor is 0.01mm, and thus, it is meaningless to improve the performance which is lower then 0.01mm. Therefore, the radius of convergence is decided between 0.1mm and 5mm.

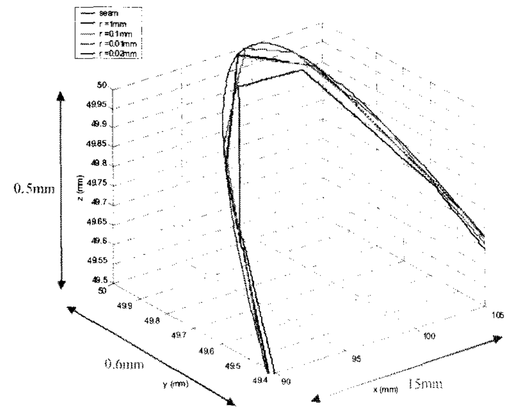

Fig. 12 Detailed view of corner.

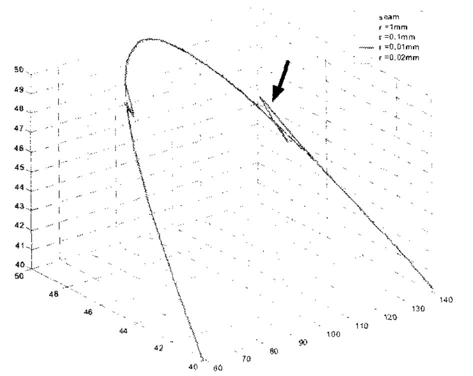

Fig. 13 Far view of corner.

Table 4 Seam tracking algorithm II simulation result

Radius (mm)	6	5	1	0.1	0.05	0.04	0.02	0.01
MaxError (mm)	0.63	0.497	0.288	0.288	0.288	0.288	0.288	0.288
MinError (mm)	0.158	0.123	0.027	0.0168	0.0154	0.0151	0.0149	0.0418

5. Conclusions

In this study, seam tracking algorithm using a laser vision sensor without experiments was proposed. Simulation system was modeled and established item by item. Proposed simulation system was verified to compare with the experimental results by using a real robot. It can be found that the results were almost same. To improve the tracking performance, the radius of convergence should be considered. Therefore suitable value of distance is determined considering the time and accuracy. It was found that proposed simulation approach was very useful to reduce the time and cost without experiment to develop the seam tracking system.

Acknowledgments

This work was supported by the Brain Korea 21 Project and Critical Technology 21 Project of the Ministry of Science and Technology, Korea.

References

1) Ronald Aarts, Ben Jonker, Johan Meijer. Real-time seam tracking for robotic laser welding using trajectory-based control, Elsevier, 2010
2) Jeong, J, W. and Kang, H. J., "Autonomous Robot Kinematic Calibration using a Laser-Vision Sensor," J. of KSPE, Vol. 16, No. 2, pp. 176-182, 1999
3) Hussein A. Abdullah, Rafiq A. Siddiqui, Concurrent laser welding and annealing exploiting robotically manipulated optical fibers, Elsevier, 2002
4) K.Y. Benyounis, A.G. Olabi, M.S.J. Hashmi, Effect of laser welding parameters on the heat input and weld-bead profile, Elsevier, 2005
5) Hee-Shin Kang, Jeong Suh, Jong-Su Kim, Jeng-O Kim, Taik dong Cho, A Study on High Speed Laser Welding by using Scanner and Industrial Robot, KWJS 2009-Autumn, 2009
6) Salman Iqbal, Muddassir M.S. Gualini, Ateequr Rehman, Dual beam method for laser welding of galvanized steel: Experiment at ion and prospects, Elsevier, 2009
7) NipponSteel, Weldability of galvanized steel sheets in laser welding. Nippon Steel Technical Report 95, 2007.