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Study on Synchronization for Laser Scanner and Industrial Robot

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Abstract

On this paper, a study of robot based remote laser welding technology for manufacturing light car body was conducted. Laser welding and industrial robotic systems were used with robot-based laser welding systems. The laser system used in this study was IPG's 1.6kW fiber laser (YLR-1600), while the robot system was Hyundai Heavy Industry's HX130-02 (payload : 130kg). The robot-based laser welding system was equipped with a laser scanner system for remote laser welding. Laser patterning on the fly needs to control some parameters to accomplish the desired shape and good quality of the welded pattern. The scan path and the mark speed as two control parameters of the laser scanner are numerically computed from pattern shape and robot motion. However, time-delay in operation of the laser scanner and the robot makes unexpected geometric error between the desired pattern and the welded pattern. To efficiently compensate the geometric error by time-delay, we divide the scan path for a pattern into the forward direction and the backward direction based on the direction of robot motion, where the time-delay is estimated through experimensts. The pattern sequence and the robot path is optimized to reduce total processing time. The proposed method is tested with various patterns and robot paths, and the welded patterns are validated by measuring their geometries and positions. Finally, the experimental results show that our method is suitable for laser patterning on the fly. The welding joints of steel plate and steel plate coated with zinc were butt and lapped joints. The quality testing of the laser welding was conducted by observing the shape of the beads on the plate and the cross-section of the welded parts, analyzing the results of mechanical tensile test. The remote laser welding system with laser scanner system is used to increase the processing speed and to improve the efficiency of processes. This paper proposes the robot-based remote laser welding system as a means of resolving the limited welding speed and accuracy of conventional laser welding systems.

Keywords: *synchronize, robot, path, galvano, meter, laser, system.*

1. Introduction

Recently laser welding has been proposed to improve productivity instead of spot welding in the car body manufacturing [1], [2]. Especially, laser patterning in cooperation with a conventional industrial robot has been spotlighted to reduce processing time from companies which produce industrial robots and automobiles [3], [4]. Laser patterning on the fly, that a laser scanner welds patterns while a robot is moving, needs specific techniques as scanner control, robot control, and weld inspection [5]. All parameters for welding are optimized to obtain good weld quality. However, on the fly, some parameters should be controlled in real time to keep up with robot motion [6]. We would consider to redraw the pattern under robot motion and to control the mark speed of the laser scanner in the redraw pattern. However, it is difficult to exactly weld a desired pattern on the fly, because unexpected factors such as time-delay, beam deflection, or low accuracy affect for welding.

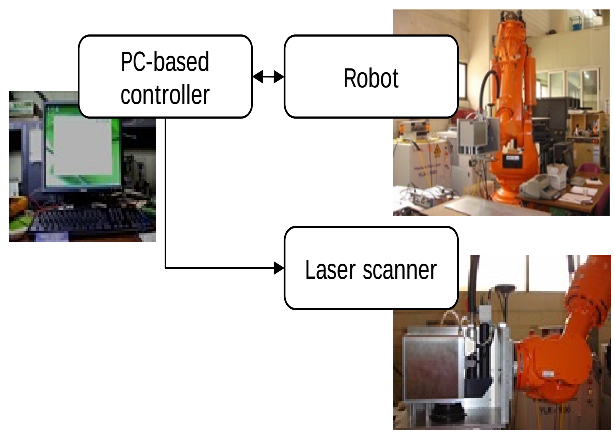


Fig. 1 Robot-laser welding system

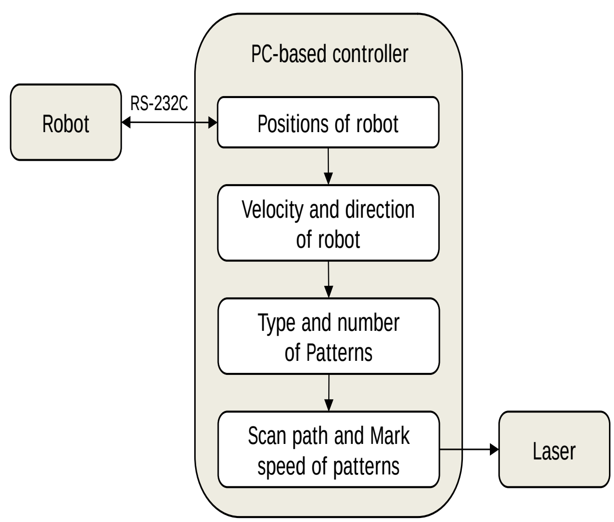


Fig. 2 Control scheme of robot-laser welding system

In general, since a manufacturing line using industrial robots repeats a same process, an operator teaches a robot the path which is empirically obtained [7]. However, in laser pattern welding, if the number of patterns increases or the robot path is complicated, it needs enormous amounts of time and many trial-and-errors. Hence, we propose a method which automatically determines a robot path for laser- patterning process.

We developed the laser-robot welding system of Fig. 1, where a laser scanner is fixed at the robot's end-effector. The laser generator has a fiber-laser of 1.6kW, and it transfers laser beam to the head which is attached at the end-effector. The 6-dof robot is a 'HX130-02' model of Hyundai Heavy Industry Co., Ltd. The robot moves along the planned path. The PC-based controller supervises all welding process along information flow of Fig. 2. The x, y, and z of the end-effector are obtained through the RS-232C from robot controller. Robot motion and laser scanning are synchronized to weld a pattern whenever the robot reaches weld points. The velocity and the motion direction of robot are induced from the change of robot positions. If types and number of patterns for welding are known, laser patterning is progressed according to the velocity and the direction of robot. The scan path and the mark speed for the laser scanner can be computed numerically, because we define shapes of patterns topologically. Nevertheless, the scan path cannot realize a desired pattern due to time-delay in operation of the robot and the laser scanner. The time-delay makes poor quality as well as geometrical error of welded patterns. Therefore, we consider time- delay compensation to obtain the desired pattern in this study.

In this paper, we propose an efficient method to weld the desired patterns on the fly. First all patterns are defined with their geometries and positions on workspace. On the fly, they are revised according to the velocity and the direction of the robot at each welding points. During welding each pattern, the laser scanner is controlled with the scan path and the mark speed to obtain desired shape of a pattern and good quality of the welded pattern. Some patterns are grouped with a synchronized point and make an order to be welded sequentially. Then the robot path is optimized between the welding points or the synchronized points to reduce processing time.

Table 1 : Definition of patterns for laser welding

Pattern	Definition
Line	$L_i=\{p_1=(x_1, y_1), p_2=(x_2, y_2)\}$
Circle	$Cr_i=\{c=(x, y), r=\text{constant}\}$
Arc	$Ar_i=\{c, \quad r, \quad \theta_1=\text{constant},$
Diamond	$D_i=\{p_1, p_2, p_3, p_4\}$

2. Laser Patterning on the fly

All patterns for laser welding are defined by geometric information. The four basic patterns are exampled to test our proposed methods. They are represented with two points for a line, an origin and a radius for a circle, a starting angle and an ending angle for an arc, and four points for a diamond. Then we can numerically compute the scan path and the mark speed for laser scanner without robot motion or under robot motion. First workspace for laser patterning is divided into scan space and robot space as Fig. 3. Then we assume that the orientation O_L of the scan space coincides with the orientation of the robot's end-effector. The O_L is acquired through the RS-232C interface from robot controller in real time. The robot motion $\vec{V}_R$ is described at O_L. Then the direction and the velocity of robot is represented as θ_R and $\|\vec{V}_R\|$, respectively. The robot path and the sequence of patterns are determined in robot space. In other words, the O_L moves along the robot path while the scan space passes by all patterns. Some patterns make a group with a synchronization signal s_i and sequence between them, where the s_i indicates the i-th group of the patterns which should be welded continuously in a scan space.

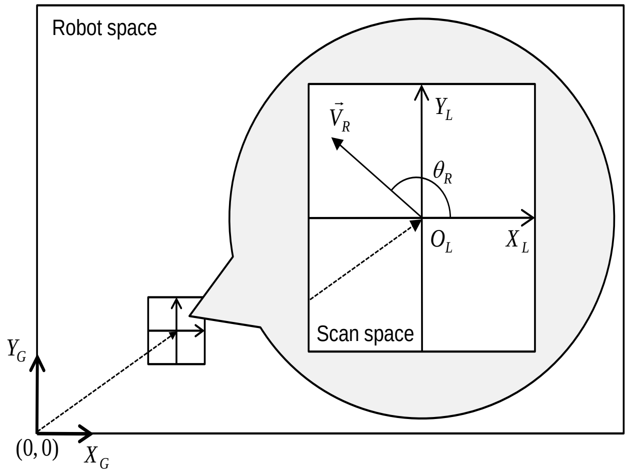
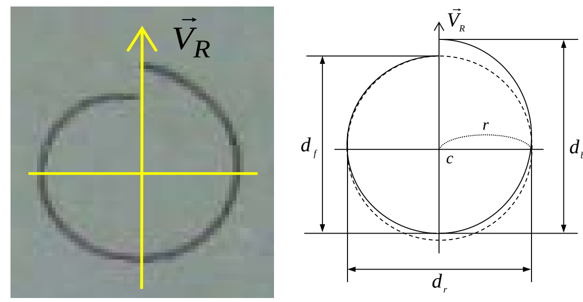


Fig. 3 The scan space and the robot space for laser-robot welding

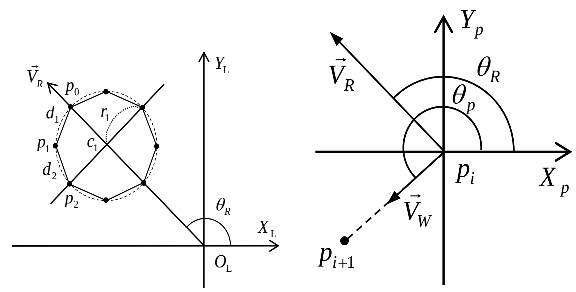
For good quality of welding, it is important to determine properly welding parameters. Especially, in welding using laser scanner, it needs to decide many parameters such as the weld speed, the scan path, the laser power, the jump speed, the jump delay, the mark speed, the mark delay, laser on/off delay, etc. Since the scan path and the mark speed among these laser parameters dramatically change on the fly, we choose them as control parameters and appropriately fix the others. Although all welding parameters is set appropriately, unexpected factor such as time delay causes bad quality as well as the geometric error of a welded pattern. As mentioned before, we deem that the time-delay happens in operations of the scanner and the robot. Since a laser scanner makes a scan path by manipulating two galvanized mirrors in X_L and Y_L axes, even small motion error by time-delay cause large geometric error of a pattern on the fly.

In this paper, we divide a scan path of a pattern into the forward direction and the backward direction as examples of Fig. 4, because shapes of welded patterns on the fly are significantly distinguished by the two directions as Fig. 4(a). The forward direction indicates sections of the pattern in which a scan path follows the robot's direction, and reversely the backward direction is sections of the pattern in which it follows against the robot's direction. To measure effect of time-delay with respect to the two directions, we define the geometries of a pattern as Fig. 4(b). The hidden line and the solid line indicate the desired pattern and the welded pattern, respectively. The d_r, which is measured from welded pattern, has nearly the diameter equal to the desired pattern. However, d_f for forward direction and d_b for backward direction have some difference on the fly, where d_f and d_b should be identical numerically.



(a) (b)

Fig. 4 The effect of time-delay: (a) a welded pattern and (b) geometry of pattern



(a) (b)

Fig. 5 Segmentation of a welding pattern

The control objective is to decide a scan path and a mark speed to get the desired pattern. First the weld speed $\vec{V}_W$, the robot speed $\vec{V}_R$, and the mark speed $\vec{V}_M$ have the relation of (1) based on Fig. 5(b), where $\vec{V}_W$ is given by an operator and $\vec{V}_R$ is monitored from the robot controller.

$$\vec{V}_W = \vec{V}_M + \vec{V}_R \cos(\theta_p - \theta_R) \qquad (1)$$

where θ_R is motion direction of the robot in scan space. The $(\theta_P - \theta_R)$ is the angle between $\vec{V}_R$ and $\vec{V}_W$, and is computed by change of O_L in robot space.

3. Experiment

The better your paper looks, the better the Journal looks. Thanks for your cooperation and contribution. The experimental results of Fig. 6 show that the effect of time-delay makes a scan path under robot's direction. Then the time-delay t_d can be estimated by $[1-2d_r/(d_b+d_f)]t_m$, where t_m is the marking time of each pattern. Fig. 7 shows the relation between the time-delay and the weld speed which is obtained from results of Fig. 6 and is a graph of the time delay versus the robot speed. From these experiments, we found that robot speed rather than weld speed causes geometrical error of welded patterns by time-delay. Therefore, we compensate the time delay according to only robot speed in this paper. A linear equation is induced through linear regression. The time-delay at each pattern is estimated with this equation.

In our method, laser welding of a pattern is begun at the start point p_s of the forward direction or of the backward direction. Namely, the p_s is entirely amended in motion direction of the robot. Then we can obtain the same properties of welded patterns regardless of robot motion. Since the laser scanner basically moves in line between two points, curved patterns such as a circle or an arc is regenerated with segmented lines as an example of Fig. 5(a). The laser scanner welds from p_i to p_{i+1} sequentially. The number of segmented points should be decided carefully, because too many segmentation increases welding time and time-delay. Also, too small segmentation makes it difficult to maintain the pattern shape.

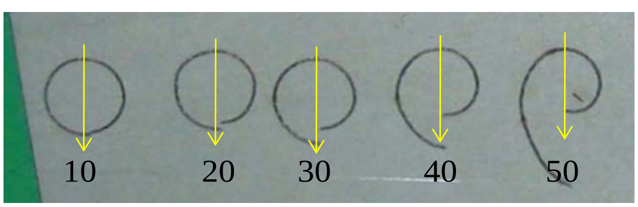


Fig. 6 Patterns welded by the robot speed of from 10 mm/s to 50 mm/s at the weld speed of 60 mm/s

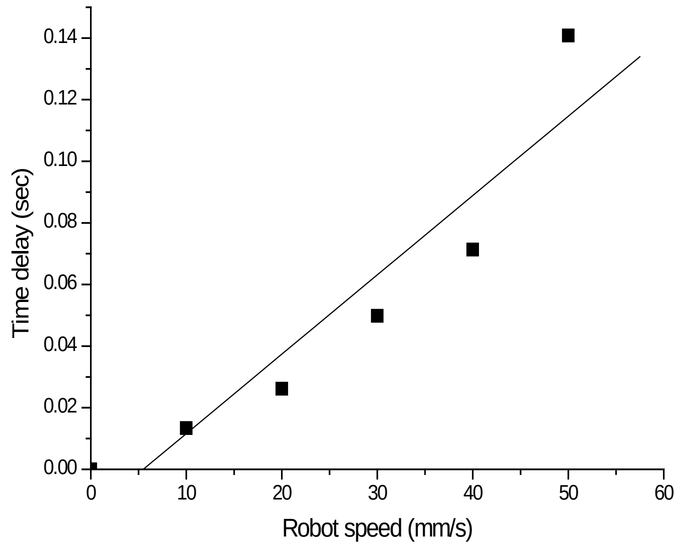


Fig. 7 Time-delay estimation through pre-experiments

Fig. 8 shows the results of strength test of laser welding lap joint specimens by using robot based remote laser welding system. Fig. 9 shows the cross section of laser welding specimen. Fig. 10 shows the side member welded by laser. The laser welding parts have the good welding quality. The laser welding specimens is compared to the spot welding specimens. The laser welding conditions are Maximum power 1.6kW and speed 2.0m/min. The laser welding strength is 60kgf/mm^2 as the spot welding strength. After fundamental experiments, the welding process for non-linear tailored blank and front side member is studied.

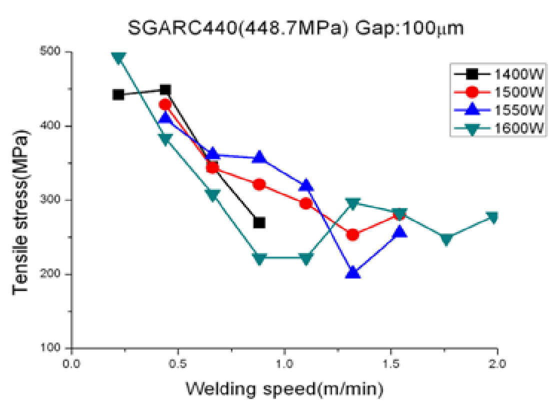


Fig. 8 Welding specimens for strength test

Fig. 9 Cross section of welding specimen

Fig. 10 Side member welded by laser

4. Conclusion

The remote laser welding robot system was built on the basis of the interfacing between the laser, the laser scanner, and the industrial robot system. We propose a method to weld patterns on the fly using the developed robot-laser welding system. Although the scan path is numerically computed using the geometry of the desired pattern, the time delay in operation of the robot and scanner make geometric error in welding. Through estimating the time-delay experimentally, the geometric error between the welded pattern and the desired pattern was more reduced than no compensation of time-delay. We ascertained that the proposed method can achieve the laser-patterning on the fly from experimental results, where all welded patterns satisfied the geometry and position as well as the weld quality.

Weld jigs for sample testing were designed and fabricated in order to conduct basic studies on the remote laser weldability of common and galvanized steel sheets. Using the remote laser welding system, butt and lap welding of common and galvanized steel sheets were conducted and the tensile strength of the samples was tested to determine the optimal welding parameters. Remote laser pattern welding tests were conducted with car body parts, and the weld joints and defects were analyzed. Further studies will be conducted to determine the optimal lap welding conditions and a desirable gap- maintaining technique for galvanized steel sheets. On the basis of the remote laser welding tests, the lap welding of galvanized steel sheets and the technique for evaluating the quality of laser welding will be tested in further studies.

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