

## 시간 동기화에 근거한 리모트 레이저 용접 시스템에서의 로봇과 스캐너 인터페이싱

김정중\*, 이준우\*, 이주장\*, 권경업\*\*, 강희신\*\*\*, 서정\*\*\*✉

\*한국과학기술원, \*\* (주)에스아이에스, \*\*\*한국기계연구원

### Interface between Robot and Scanner for Remote Laser Welding System Based on Time Synchronization

Jeong-Jung Kim\*, Joon-Woo Lee\*, Ju-Jang Lee\*, Kyung-Up Kwon\*\*,

Hee-Shin Kang\*\*\* and Jeong Suh\*\*\*

\*KAIST, \*\*SIS Co., \*\*\*KIMM

#### Abstract

Remote laser beam welding (RLW) has the benefits of high speed and high quality welding, especially as applied to automotive industry. RLW is designed in a way that end effector and head of scanner move simultaneously, and require the compensation for the motion of end effector in order to weld proper position. In this paper, we show the algorithms of RLW that enable the end effector to synchronize with scanner based on time. The proposed method consists of two algorithms. These algorithms make it possible for the moving end effector to weld on desired place. The effectiveness of the algorithms is shown by experiments.

#### 초 록

원격레이저 용접(RLW)은 고속으로 고품질의 용접을 가능하게 하고 특히 자동차산업에 적용할 때 그 장점이 발휘된다. RLW은 로봇의 말단과 스캐너가 동시에 움직이도록 설계되는데 적합한 위치에 용접을 하기 위해서는 말단의 움직임에 대한 보상이 이루어져야 한다. 본 논문에서는 스캐너와 말단을 시간에 기반하여 동기화 하는 RLW을 위한 알고리즘을 보인다. 제안된 알고리즘은 두 개의 알고리즘으로 구성 되어 있고 본 알고리즘으로 움직이는 말단이 원하는 위치에 용접을 가능하게 한다. 제안된 알고리즘의 효용성은 실험을 통해 보인다.

**Keywords:** Remote welding system(리모트 용접 시스템), Industrial robot(산업용 로봇), Galvanometer scanner(갈바노 스캐너), Time synchronization(시간 동기화)

### 1. 서 론

A typical welding is conducted on a fixed place and this configuration limits the welding range. Remote laser beam welding (RLW) has the benefits of high speed and high quality welding, especially as applied to automotive industry<sup>1,2</sup>. This study targets a system combined with robots that can increase welding range<sup>3-6</sup>. RLW is designed in a way that

end effector and head of scanner move simultaneously, and require the compensation for the motion of end effector in order to weld proper position.

In this paper, we show the algorithm of RLW that enable the end effector to synchronize with scanner based on time. The proposed method consists of two algorithms: (1) a scanner-speed modification algorithm aimed at the compensation for the move of the end effector. (2) a welding-time calculation algorithm for start time of trajectory. These algorithms make it possible for the moving end effector to weld on desired place. All input variables

투고일 : 2013년 3월 12일 심사완료일 : 2013년 3월 18일  
계재승인일 : 2013년 3월 21일  
교신저자 : 서정 ✉ jsuh@kimm.re.kr

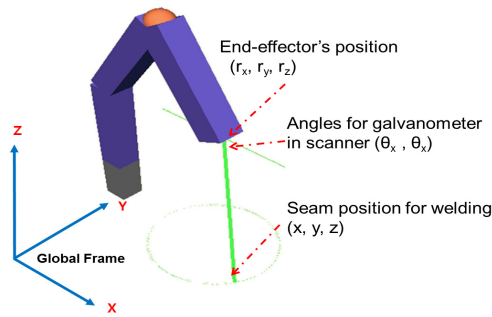
necessary for the each algorithm are five items including trajectory of the end effector, trajectories of welding points, robot speed, welding speed and welding starting time.

The proposed algorithms are described in Section 2, experimental result and discussion are followed in Section 3, and conclusion is shown in Section 4.

## 2. Algorithm Description

### 2.1 System description

Fig. 1 illustrates the system used in the paper.



**Fig. 1** Target system where both scanner and laser generator are attached to the end effector of industrial robot and the welding process can be conducted while the end effector is moving.

The scanner and the laser generator are attached to the end effector of the industrial robot. This scanner is also connected to a control board in PC, and serves as locating the laser to desired positions while the PC controls the welding position, welding speed, and delays values. Welding process can be relatively easy when the end effector is not moving, but in case the end effector is moving, relative speed should be taken into account for welding on accurate position.

### 2.2 Algorithm for welding speed modification

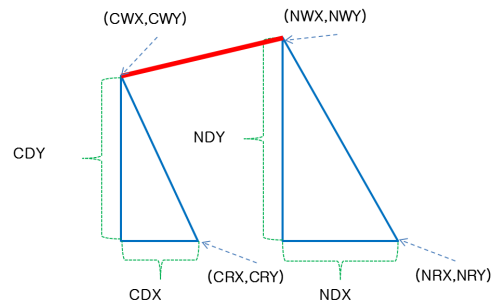
With the welding speed modification algorithm based on the system with scanner and robot, values such as trajectories of end effector and of welding are given in advance. The welding points and the relative speed of end effector are calculated by substituting the given values above. The resulting

values can make it successful to weld on preferred positions even when the end effector is moving. When the end effector is moving, this algorithm modifies the welding speed and weld on appropriate trajectories. The inputs required for this algorithm are length  $S_w$  of welding trajectory, welding speed  $V_w$ , and end effector speed  $V_r$ .

Assuming that the welding speed is constant in welding trajectory, the welding time  $T_w$  is calculated to be  $S_w/V_w$ . And since the duration for welding has the same value as that for movement of the end effector,  $T_r$  equates to  $T_w$ . When the welding time is determined, the total step of trajectories, named TS, can be obtained after being divided by  $dt$ , a sampling time. The welding performed within the trajectory proceeds at a speed of  $V_w$  during  $T_w$  and TS steps. Welding is conducted based on the relation between variables including  $T_w$ , duration and  $V_w$ , speed and TS, stage. At a time  $t$ , the positions of the welding and the end effector,  $WX(t)$ ,  $WY(t)$ ,  $RX(t)$ , and  $RY(t)$  are calculated by the above relation. In a case when the end effector moves, the relative welding position needs to be considered for accurate welding along the trajectory.

The current relative position between the weld and the end effector, on X and Y axis are expressed by  $CDX = CWX - CRX$  and  $CDY = CWY - CRY$ , where  $CWX$ ,  $CWY$ ,  $CRX$ ,  $CRY$  are  $WX(t)$ ,  $WY(t)$ ,  $RX(t)$ , and  $RY(t)$  respectively.

The next relative position between the weld and the end effector, on X and Y axis are expressed by  $NDX = NWX - NRX$  and  $NDY = NWY - NRY$ , where  $NWX$ ,  $NWY$ , and  $NRX$ , and  $NRY$  are  $WX(t+dt)$ ,  $WY(t+dt)$ ,  $RX(t+dt)$ , and  $RY(t+dt)$  respectively.

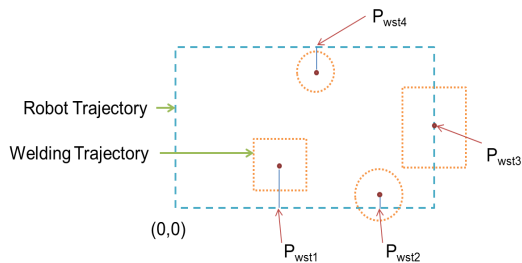


**Fig. 2** The geometrical relations between variables while a robot is moving.

The geometrical relations between variables with end effector moving. The solid line from the point (CWX, CWY) to (NWX, NWY) is welded during sampling time  $dt$ . The distance of the straight line  $DIST_g$  is calculated using the formula,  $DIST_g = \sqrt{(NDX - CDX)^2 + (NDY - CDY)^2}$ . During the sampling time  $dt$ , the welding is conducted at a constant speed. The welding speed  $V_g$  is calculated by the formula  $V_g = DIST_g / dt$ . The welding is conducted from the point (CDX, CDY) to (NDX, NDY) with the calculated welding speed  $V_g$  during sampling time  $dt$ . The speed compensates the speed of the moving end effector and a welding can be conducted on a proper position.

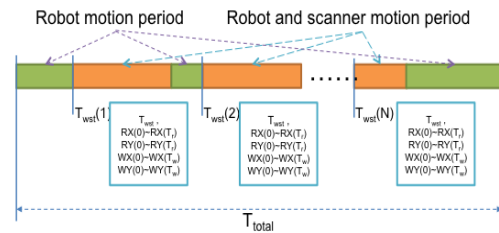
**2.3 Algorithm for welding starting time computation**

The start times for each welding trajectory are computed when the values including the trajectory of the end effector, welding trajectories, robot speed and welding speed are given. This algorithm assumes that welding process initiates at a point that is closest to the center of the welding trajectory. The welding start point is defined as  $P_{wst}$ , which of the relation is shown in the Fig. 3.



**Fig. 3** Computation of welding start time. Both welding start position and welding time at welding trajectory are calculated using the given values of trajectories of end effector and welding.

The values of each welding start time,  $T_{wst}$ , can be gathered to make time schedule, which includes total processing time, called  $T_{total}$ .  $T_{total}$  is calculated by dividing  $S_{ir}$  by  $V_r$ ,  $S_{ir}$  is the total length of robot trajectory and  $V_r$  is the robot speed.  $T_{wst}$  is calculated by dividing  $L_{wst}$ , by  $V_r$ .  $L_{wst}$ , is the length ranging from the initial position of the end effector to  $P_{wst}$ . The example of the time schedule is shown in Fig. 4.



**Fig. 4** Time schedule for welding on each welding trajectories.

**Table 1** Summary of experimental conditions

Figure Num.	WSM	WSC	Vw(mm/s)	Vr(mm/s)	W(mm)/R(mm)
5 (a)	No	No	200	15	10 / 5
5 (b)	Yes	No	200	15	10 / 5
6	Yes	No	100	15	20 / 10
7 (a)	Yes	No	200	30	20 / 10
7 (b)	Yes	No	200	60	20 / 10
7 (c)	Yes	No	200	120	20 / 10
8 (a)	Yes	Yes	200	15	20 / 10
8 (b)	Yes	Yes	100	15	20 / 10
9 (a)	Yes	Yes	200	30	20 / 10
9 (b)	Yes	Yes	200	60	20 / 10

The timer starts when the end effector begins to move. When the time is reached to each  $T_{wst}$ , then relative welding points are calculated based on the robot speed and welding speed and the welding process is conducted during  $T_w$ .

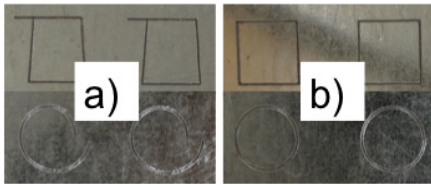
**3. Experiment**

Two major experiments were chosen to verify the proposed algorithm. Table 1 summarizes experimental conditions. Conditions from the first row to sixth row are for first experiment and from the seventh row to last row are for second experiment. The notations WSM, WSC, W and R represent welding speed modification algorithm, welding starting time computation algorithm, width of a rectangle, radius of circle, respectively.

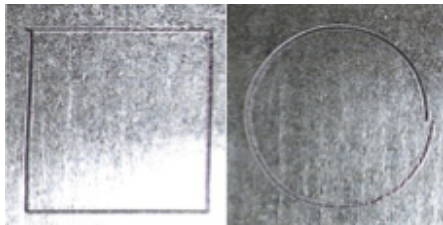
The first experiment is to test a welding speed modification algorithm. This experiment consists of welding the shapes of rectangle and circle, and welding at a speed of end effector and at various welding speeds. As shown in the Fig. 5, the proposed algorithm successfully welded on desired trajectory, but the result without this algorithm failed to weld on desired trajectory.

The reason is that proposed algorithm compensated the speed of the moving end-effector and welded on proper positions.

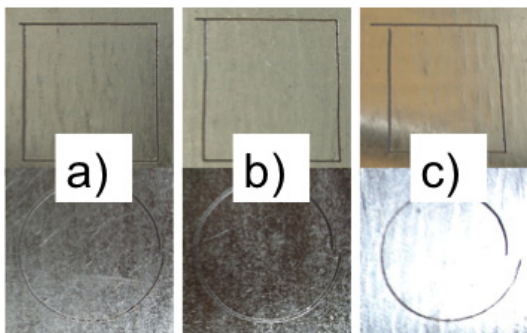
The results when the welding speed is decreased is shown in Fig. 6 and speed of the end effector is varied is shown in Fig. 7.



**Fig. 5** Experiment results of welding-speed modification algorithm. (a) the welding before applying the speed modification algorithm (b) the welding after applying the speed modification algorithm.



**Fig. 6** Experiment results of speed modification algorithm when applying various welding speeds, at a welding speed of 100 mm/s.

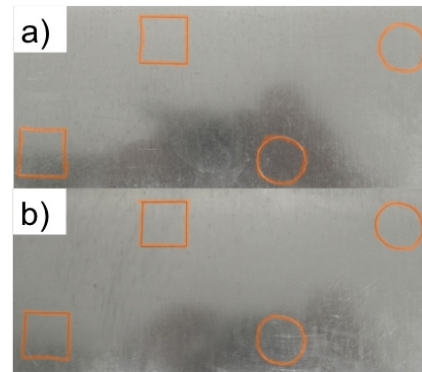


**Fig. 7** Experiment results of speed modification algorithm when applying various speeds of end effector, (a) 30mm/s (b) 60mm/s (c) 120mm/s.

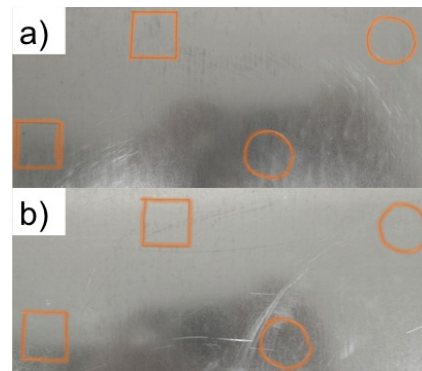
Even though the proposed algorithm is applied to the system, mismatch was found when the welding speed was decreased and end effector speed was increased as shown in the Fig. 6 and Fig. 7. In our experimental setting, the visible mismatch was found when the speed of the end effector was reached the 15% of the welding speed. It was result from the existence of time delay between PC and scanner controller and

control accuracy of the end-effector and scanner. The importance of degree of mismatch depends on applications. The mismatch should be reduced for a high accuracy application. The mismatch can be solved to a certain degree by adjusting the parameter of the scanner which includes: jump delay, welding delay, laser on-and-off time delay and improving the accuracy of the controllers.

The second experiment is to test welding-start time computation algorithm. The objective of this experiment is to start to weld the shapes of rectangle and circle at a proper time, using the given values such as end effector speed and various welding speeds.



**Fig. 8** Experiment results of start time computation algorithm at various welding speeds. (a)200mm/s (b)100mm/s.



**Fig. 9** Experiment results of start time computation algorithm at various speeds of end effector. (a)30mm/s (b)60mm/s.

The results in Fig. 8 show the comparison between welded shapes depending on various welding speeds and Fig. 9 show the comparison between welded shapes depending on various speeds of end effector. As shown in the Fig.8 and Fig. 9, the proposed

algorithm welded the shapes of rectangle and circle at a proper time and mismatches were detected when welding speed was decreased and speed of the end effector was increased. The reason for the mismatch is same as in the first experiment. The mismatch can also be solved to a certain degree by adjusting the parameter of the scanner and improving the accuracy of the controllers.

#### 4. Conclusions

In this paper, we have shown RWL that is operated by two algorithms where the end effector of a robot and the scanner move simultaneously. The proposed algorithms were verified through several experiments and turned out to be capable of welding on the desirable trajectories even when the end effector was moving. We expect the method to be applied to more complex and high dimensional system.

#### References

- 1) M. Grupp, T. Seefeld and F. Vollertsen, "Laser Beam Welding with Scanner," Proc. of the Sec. Int. WLT-Conf. on Lasers in Manuf., Munich, Germany, 2003.
- 2) G. Tsoukantas, G. Chryssolouris, "Theoretical and Experimental Analysis of the Remote Welding Process on thin, Lap-joined AISI 304 Sheets," Int. J. Adv. Manuf. Technol. Vol. 35, No. 9-10, pp. 880-894, 2008.
- 3) J. Stemmann and R. Zunke, Oper. "Robot Task Planning for Laser Remote Welding", Oper. Res. Proc., Vol. 2005, pp. 729-734, 2008.
- 4) J. Hatwig, G. Reinhart, and M. F. Zaeh, "Automated Task Planning for Industrial Robots and Laser Scanners for Remote Laser Beam Welding and Cutting", Prod. Eng. Res. Devel. , Vol. No. 4, pp. 327-332, 2010.
- 5) M. F. Zaeh, J. Hatwig, J. Musiol, O. Roesch and G. Reinhart, "Analysis of the Accuracy of Industrial Robots and Laser Scanners for Remote Laser Beam Welding and Cutting", Proc. of the 41st Int. Symp. on and 2010 6th German Conf. on Rob. (ROBOTIK), pp. 751-758, 2010.
- 6) H.-S. Kang, J. Suh, S. J. Kwak, "Welding on the Fly by using Laser scanner and Robot", Proc. of the 11th Int. Conf. on Con., Aut. and Sys., pp. 1688-1691, 2011.