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A Study on Weld Bead Profile Measurement System for Use in Automatic Weld Bead Removal System

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Abstract

Automatic weld bead removal system is consisted of bead removal tool, bead profile measurement system and tool motion control system. In this paper, design of weld bead profile measurement system which is used for automatic weld bead removal system is described. The system measures the weld bead position, normal vector of the auto-body and weld bead profile. The optical sensor with structured laser beam is used as a sensor and comparison of the sensor that can be used for this purpose is discussed in detail. The measurement process and the related software developed for this purpose are also described. A median filter, average filter and long line filters are used and their effects in bead profile measurement are discussed. The measurement system is integrated into automatic bead removal system and is used to remove weld bead in rear pillar of automotive body. The whole system operates well in automotive body assembly line and thus the system is proved to be good for this purpose.

1. Introduction

Automotive body is manufactured by assembling sheet metal panels, and assembling is mainly done by resistance spot welding. The spot welding is widely accepted due to its cost effectiveness and high productivity. But, in some cases, line welding should be accepted inevitably. For example, in assembling the roof and pillar of auto-body, arc brazing, a kind of line welding, is used instead of spot welding, to keep the nice appearance of auto-body. In some cases, although another methods are used in assembling the roof and pillar, it is known that the arc brazing is, until now, the best process for good appearance of auto-body.

In assembling the roof and pillar with arc brazing, the weld bead, which is formed after arc brazing, should be removed to make the auto-body in smooth shape. The conventional way of removing weld bead is consisted of two stages. In the first stage, the weld bead roughly removed with rough grinder, and in the second stage, the remainder of the weld bead is removed thoroughly. The processes are done by human workers and it is regarded as one of the difficult and dirty process among workers for the following reasons.

1. The heavy metallic dust, which is produced by grinding process, is not good to health.
2. The noise induced by the grinder is very high level, and may cause hard of hearing (bradyacusia).
3. It is an hard to work process.

For the above reasons, it is decided to automate the process, and through 18 months of research and development, the process is automated and is now installed in auto-body assembling line of Kia motors. The weld bead removal system is mainly consisted of the following three sub systems.

1. Weld bead profile measuring systems, which measures various kind of 3-dimensional geometric parameters of the weld bead and auto-body.
2. Specially designed weld bead removal tool system.
3. Tool motion control system with six degree of freedom articulated robot.

This paper is concerned with this automated process and the main subject is focussed on the weld bead profile measuring system.

This paper is constructed as follows. In next section, the overall weld bead removal system is reviewed and the roles of the weld bead profile measuring system are discussed. In section 3, we discuss the design considerations of the weld bead profile measuring system, and all the details of the design is described. In section 4, we describe the software of the measurement system, which is mainly consisted of image processing. In section 5, the conclusions of this paper are summarized and some related topics are discussed.

2. Overview of Automatic Weld Bead Removal System.

The design requirements from field engineers and factory managers can be summarized as:

1. Save human workers as much as possible.
2. Keep uniform quality of auto-body. Avoid touching or grinding the auto-body.
3. Low investment and high reliability

To meet the first requirement, the weld bead should be removed as much as possible. And there are many bead removal systems that meet this kind of requirement. To meet the second requirement, the weld bead cannot be removed completely not to touch or grind the auto-body. In fact, the sheet metals used for auto-body is plated with Zn-Ni to meet the anti-corrosion requirements. If the grinding wheel is contacted to auto-body, the Zn-Ni plating may be injured and the whole auto-body is rejected by quality manager of assembling line. To meet the first and second requirements, the weld bead should be removed as much as possible, but the system should not touch the auto-body except weld bead. So we decided that 3-dimensional profile of the weld bead and auto-body should be measured as precise as possible in order to meet the 1-st and 2-nd requirements. For third requirement, we made a rigorous design review for reliability and cost at each step of design.

The overall system operates in the following sequence.

1. The auto-body is transferred to the station and process start signal is received.
2. Weld bead measurement system measures the geometric profile of weld bead and auto-body. In this step weld bead quality is also checked. The measurement system is attached at the end of robot, and measurement is done with the approximate motion of robot.
3. The system calculate motion of tool system and determine the pressure of the tool.
4. If the welding quality is good, the weld bead is removed by grinding wheel, which is attached at the other side of robot end effector.
5. At the end of the process, the overall system returns to ready state, and end of process signal and process success signal are reported to line controller via interlock signal controller.

In Fig. 1.,the overall bead removal system is presented. In the figure, the measurement system is located at the end effector of robot.

3. Design of Weld Bead Profile Measurement System

The role of bead profile measuring system in automatic bead removal process can be summarized as follows:

1. Provision of information to select appropriate process variables such as pressure of grinding wheel. In this respect, width , height and volume of weld bead provide enough information. This information is used tool motion control subsystem.
2. Measurement of three dimensional position and orientation of the auto-body surface. Based on the

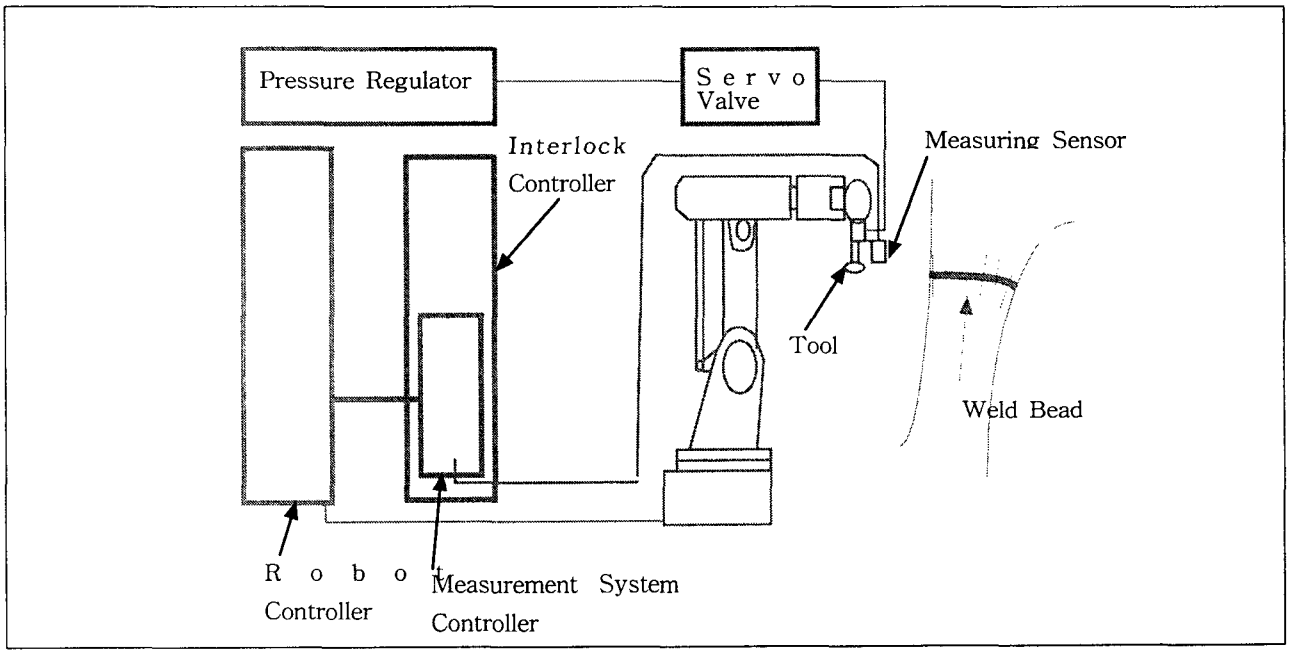

Fig. 1. Schematic Diagram of Automatic Weld Bead Removal System.

informations, tool motion control system decides the direction and position of the tool with respect to auto-body.
3. Measurement of three dimensional position of weld bead. Based on this information, tool motion control system tracks the path of contact between tool and weld bead.
5. Monitoring of welding process.

For these purposes, many kind of measuring sensors are considered. The sensors can be classified into contact and non-contact type. Although contact sensors have many advantages over non contact type sensors, it is excluded because it may leave some dirt on the auto-body. At the end of auto-body assembling, auto-body enters the painting shop, and the dirt left may influence painting process. For this reason, non-contact type sensors are considered. Non-contact type sensors may be roughly classified into optical type and non optical type. Non-optical type sensors, such as sensors using eddy current or hall effect, have the disadvantages that the sensors should be placed close to the weld bead. On the other hand, optical sensors can measure the profile of weld bead placed relatively far from the weld bead. There are many types in optical sensors. The typical one is the one using 2-dimensional CCD camera. Even though the information from 2-dimensional CCD camera has enough information to measure the 3-dimensional position and orientation, its relatively low resolution yields not so precise measurement. And because it uses the visible light, the measurement may be influenced by floor illumination and lights. So, for the robust measurement of weld bead profile, we decided to use the sensors that accepts certain range of wavelength. And to easily measure the 3-dimensional position and orientation, structured beam is used. This active vision system with plane beam of red laser is relatively robust to illumination and lights. And the amount of information from sensors is not so much, and image processing is thought to be relatively easy compared with the 2-dimensional CCD camera sensor. But since the sensor uses cylindrical lens and optical filters, it has the disadvantage of keeping the optical system clear. Because we devised the mechanism of clearing the optical system, we decided to use this kind of sensor. The main reasons of choosing the optical sensor with monochrome plane laser beam can be summarized as follows:

1. Immunity to humidity and temperature.
2. Noncontact type sensor.
3. Measurement speed is relatively high.
4. 3-dimensional geometric information can be easily analysed with this sensor.
5. Relative immunity to illumination and lights.

But, because it has the optical system, blooming effect, which occurs in measuring reflective surface, may yields measurement error. In our experiments, Zn-Ni coated steel surface do not results in blooming effect with visible red semiconductor laser. The measurement software calculates3-dimensional coordinate with triangular relations which are well known in image processing engineers. The method is summarized in Fig. 2., and we skip the principle of calculation.

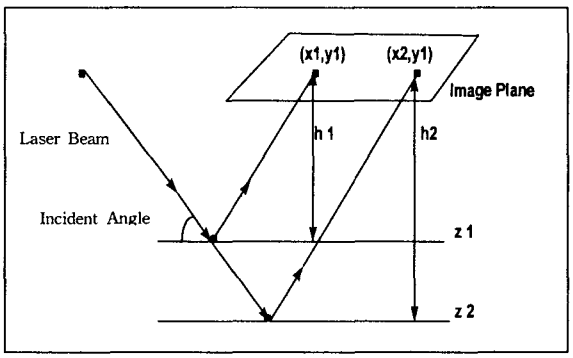

Fig. 2. Principle of Measurement by Triangular Relations.

In the process of measurement, there are many factors that interfere the identification of weld bead profile, and can be summarized as:

1. Spatters caused by welding process.
2. Warping of base material, i.e., auto-body.
3. Oil contamination and dirts on auto-body
4. External optical noise.
5. Irregular shape of weld bead

All these factors must be excluded to get accurate geometric data of weld bead and auto-body. But, all these factors cannot be excluded by improving the hardware system only. In fact, most of these factors are effectively handled by software. In next section, our discussion is focussed on measurement software.

4. Development of Bead Profile Measuring Software and Image Processing

In Fig. 3., the photograph of the measurement system hardware is presented which is taken on the experimental setup. The reader can easily see the laser beam on thin metal sheet and can locate the sensor system. The photograph shows the scene of taking one image. This kind of images are obtained at several or tens of positions while plane laser beam is illuminated on the auto-body. For each images weld bead profile and position/orientation of auto-body are calculated in the following sequence. The basic functions developed to measure the profile of weld

bead and to identify 3-dimensional relative position and orientation begins with the thresholding of the image transferred from hardware. This is the first step of image processing. The images after thresholding still contains much noise and it lost some of the useful information. The connected curves if the image is not contaminated with noise and it is properly

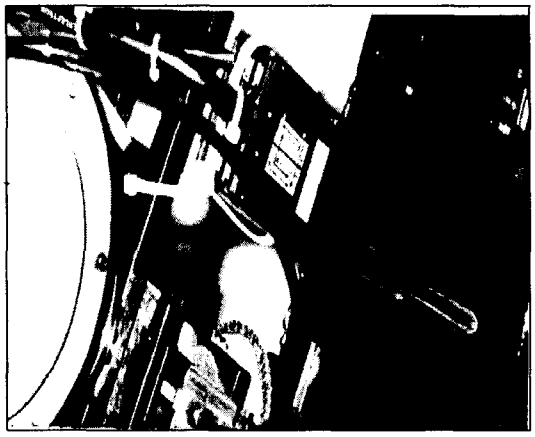

Fig. 3. Bead profile measurement using structured laser beam in experimental setup.

thresholded, may be disconnected, and the image contains various size of unwanted dots. The curve, which is believed to be formed by plane laser beam is connected and smoothed based on the belief that the curve is connected and it is very smooth on the auto-body surface except on weld bead. The identification and reconstruction of laser curve is done on the limited regions of image, and thus the speed is relatively fast. And then, the center, width, height and sectional area of weld bead is calculated. For each image, same analysis described above is done.

After the analysing all images, the actual profile of the weld bead is determined and the auto-body surface is modeled using the Hermite polynomials. In this process, the profile of weld bead and auto-body surface are smoothed again based on the CAD model of the auto-body design. In this process many theoretical and heuristic filters are developed and used.

At final step, the entire information is transformed to world coordinate system and transferred to robot controller. Then the robot approaches to the auto-body with new geometric information, which is calibrated based on the information from measurement system.

5. Conclusions and Discussions

In this paper, we presented the hardwares and softwares of the weld bead profile measurement system developed to automate the manual weld bead grinding process. The result of weld bead removal is turned out to be within 0.2mm while tool is not touching the auto-body. The ov obtained from optical

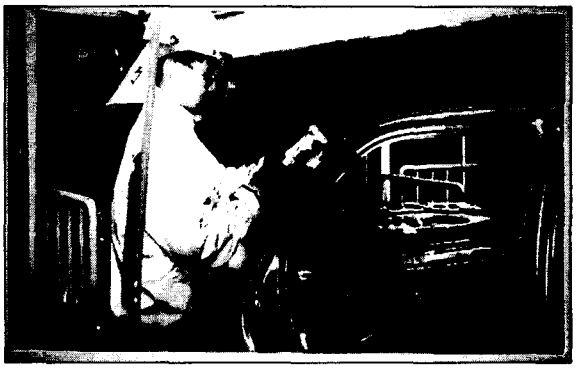

Fig. 4. Photograph of worker with hand grinder and auto-body(before automation).

sensorerall system is now on continuous operation in Asan Plant of Kia Motors Corp. The system marks over one year of continuous operation without irregular stops. The weld bead profile measurement system described in this paper is, thus, proved to be successful with enough reliability.

But the weld bead removal system can not remove the weld bead on sharp valley due to the geometric constraints of grinding tool. And the measurement system is not proven in measuring the sharp and deep valley. These weak points are considered to be improved in near future.

그림 5. Photograph of automated process. The robot equipped with the weld bead measurement system wears skirt in order to protect him from metallic dust(after automation).

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