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3-dimentional Formaiton System Using A Robot Hand

○Keita MORITA*), Fumio KASAGAMI**),
Takakazu ISHIMATSU*)

*) Mechanical Systems Engineering, Nagasaki University
Nagasaki, JAPAN 852
**) Mechatronics Division, Daihen Corp. Ltd.
5-1, Minamisenrioka, Settu-Shi, Osaka, Japan 566

Abstract: In this paper we propose a 3-dimensional formation system using an arc welding robot. The principle of our system is just only to accumulate welding beads, so that the target 3-dimensional surfaces can be built up. Considering the effects of the gravity on the arc welding, the welding torch is steadily clamped and the position and the posture of the target board on which target work is formed is controlled by a 6-axis robot hand. Movements of the target board are controlled considering the 3-dimensional shape of the target and the accumulating speed of the welding bead. In order to realize such systems, a distance sensor is mounted on the tip of the robot hand. And a coordinate transformation technique is employed

1. Introduction

Nowadays CAD systems are rapidly developing. They are now popular in the designing fields in the automobile industries, the electric equipment industries and many other industries. Due to these progressed CAD systems, we can obtain target images and drafts on the screen or papers easily. However, obtaining 3-dimensional concrete object is rather difficult. We have to design the procedure of the fabrication, select the NC machines, make the NC data and drive the NC machine. These procedures are inevitable, and they are much more complicated if the target work has 3-dimensional free surface. Recently one new system to form a 3-dimensional plastic model concentrated much interests at the designing level. This system enabled to form 3-dimensional free surfaces using phto-hardened resin. This system is very useful to evaluate the 3-dimensional shapes design since the concrete model can be obtained easily. However, the formed model is limited to plastic one, since the photo-hardened plastics essential to this method[1],[2].

In this paper we propose a 3-dimensional formation system using an arc welding robot. The principle of our system is just only to accumulate welding beads, so that the target 3-dimensional surfaces can be built up. While the principle is simple, the arc welding robot needs to be tactful enough so that smooth 3-dimensional surfaces can be obtained. Considering the effects of the gravity on the arc welding, the welding torch is steadily clamped and the position and the posture of the target board on which target work is formed is controlled by a 6-axis robot hand. Movements of the target board are controlled considering the 3-dimensional shape of the target and the accumulating speed of the welding bead. In order to realize such systems, a distance sensor is mounted on the tip of the robot hand. And a coordinate transformation technique is employed.

2. 3-dimensional creation methods

2.1 Optical stereolithography method[2]

The principle of the optical stereolithography is shown as follows. As in Fig.1(a), the fine beam of ultraviolet rays is applied at the surface of liquid phto-hardened resin, which is filled with the tank, and deposit it as the hardened sheet layer on the sheet that is floating on the liquid hardened resin. One deposit liquid phto-hardened resin as hardened sheet layers on the hardened layers which got by the way shown in Fig.1(a), and they are piled up (see fig.1(b) and (c)). By repeating above process again and again a hollow 3-dimensional object shown in fig.1(d) can be created. Since this method form the 3-dimensional shape by hardening the phto-hardened resin, quality of a product is restricted to resin. This method is not suitable for creating a solid product.

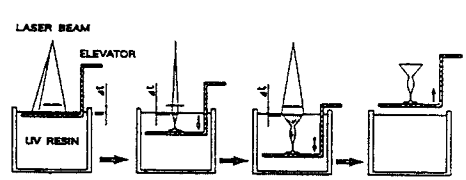


Fig.1 Stereolithography

Well-known stereo lithography system consists of three main components, namely a laser scanning device, a UV resin box and a system controller. The process to create the solid model is as follows:

1. Forming data use CAD data.
2. Cross-section slice data is computed from CAD data at equal intervals of 0.1mm to 0.3mm.
3. Actual product molding starts when the slice data are transferred to the system controller.
4. Solid creation is ensured by repetitive scanning and hardening of the UV resin surface using the X-Y laser scanner, layer upon layer.

2.2 Arc welding method

A method of forming 3-dimensional object based on padding of arc welding can be considered.As in Fig.2 welding rod is brought into contact with base metal, and then the 1st layer is padded by arcing. While stability of this arc is maintaining, each layer is piled up continuously.

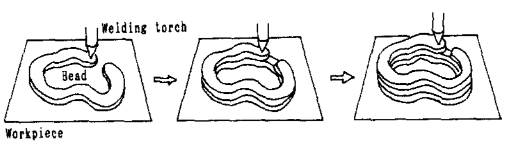


Fig.2 Arc welding method

Features of 3-dimensional formation method based on arc welding are as follows :

Merit

1 .A product made from metal such as iron, aluminum, stainless or steel can be created.
2. The product has high solidness.
3. It is possible to form even a complicated 3-dimensional free surface by completely automatic process.
4. The realized system is downsize.

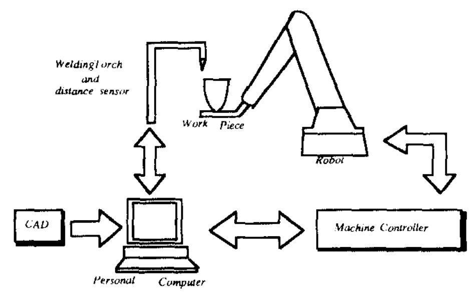
Demerit

1. It is difficult to create a thick-thin object.
2. After forming, modification of shape is quite difficult.

Considering about feature, the 3-dimensional forming method based on arc welding is effective to solve ever problems concerning to casting method.

2.3 3-dimensional formation using arc welding robot

The system configuration is shown in Fig.2. We use a industrial robot with six degrees of freedom. A workpiece is fixed on the robot. The robot is controlled by a personal computer (PC-9801RA21,NEC) which calculate the angle of each joint. It is important that the stability of arc is maintained in the forming system based on arc welding. In order to maintain the stability of arc the welding speed must be kept constant. Unless the welding speed is kept constant, the surface of the object become rough because of variety of bead. Since the quantity of bead depends on the distance between the welding torch and the workpiece, a distance sensor is mounted on the tip of the robot hand. Furthermore, we consider effects of the gravity on the arc welding in order to obtain smooth 3-dimensional surface.



Fig,2 System Configuration

In general there are two methods of arc welding using the robot.

1. The target board on which target work is formed is fixed. The robot forms the object by arc welding.
2. The welding torch is steadily clamped. The position and the posture of the target board on which target work is formed is controlled by the robot.

In this paper we employ the method 2. The effects of the gravity can be reduced by controlling the position and the posture of the target board in the method 2. However, the allowable mass of the payload is limited. It is impossible to create the heavy object by the method 2.

3. Control method

3．1 Definition of Coordinate Systems

The position and posture of the workpiece robot should be controlled by considering the relative position to the welding torch in order to move the welding torch as desired. We introduce the coordinate system shown in Fig.3 so that the robot can be controlled by considering the above relative position.

In this paper we use following notations.

Σ World: The world coordinate system of robots and welding torch.

Σ Work: The work coordinate system settled at one reference point on the workpiece.

Σ Tool: The tool coordinate system settled at the tip of the welding torch.

Tt: Homogeneous transformation matrix of the torch manipulator.

Tw: Homogeneous transformation matrix of the workpiece manipulator.

Ew: Homogeneous transformation matrix of the gripper.

Zw: Homogeneous transformation matrix of the between world

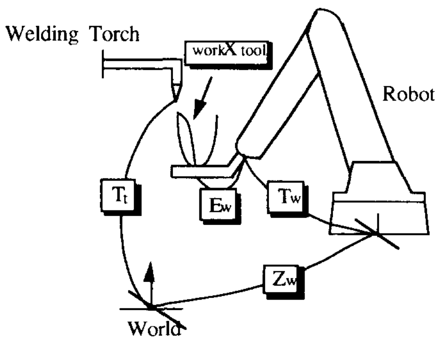


Fig..3 coordinate systems

We have following equations by using the above transformation matrices.

The position and posture of the welding torch based on the world coordinate system is represented by

$({}^{world}X_{tool}) = T_t$ (1).

The position and posture of the workpiece robot based on the world coordinate system is given by

$({}^{world}X_{work}) = (Z_w)(T_w)(E_w)$ (2).

Considering the relation between the tool and workpiece manipulators, we have

$({}^{world}X_{tool}) = ({}^{world}X_{work}) \cdot \times ({}^{work}X_{tool})$ (3)

Therefore, the coordinate system of the welding torch based on the work coordinate system is obtained as follow.

$({}^{work}X_{tool}) = ({}^{world}X_{work})^{-1} \times ({}^{world}X_{tool})$ (4)

For the given relative position and posture of the welding torch to the workpiece $({}^{work}X_{tool})$ the position and posture of the robot $({}^{world}X_{work})$ is calculated by eq.(4). 3.2

3.2 Procedures of forming the 3-dimensional model

In general the 3-dimensional data should be given by a CAD system running on a workstation. In order to simplify the complicated data processing a cylindrical object is considered in this paper. The object shown in Fig. 4 is formed by following procedures.

1. The first layer is creating by the welding bead as the circle with radius r1.
2. After padding the first layer, let the workpiece down to the pre-specified height.
3. In padding after the second layer the tangent of the sectional curve of the object is inclined against the vertical direction so that the bead doesn't drop. Then the direction of the tangent is in parallel with the welding rod.
4. The workpiece is rotated under the above welding condition.
5. Repeat from step 2 to step 4 until the object become the pre-specified height.

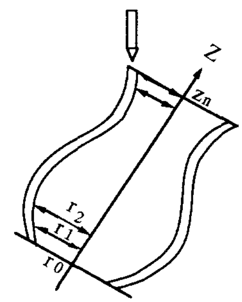


Fig.4 Forming Procedures

3．3 Algorithm

For a given sectional curve f(z) shown in Fig.4 the control algorithm is obtained as follows.

The radius of the object at height z is

$r=f(z)$ (5)

At the point P, which is in the n-th layer and height is z, the angle of the tangent of the sectional curve at this point is given by

$f'(z)=\tan(\Phi)$ (6)

During padding the n-th layer the workpiece is moved so that eq.(6) is satisfied.

The homogeneous transformation matrix at point P is given by

$({}^{work}X_{tool}) = \mathrm{Trans}(f(z)\cos\theta, f(z)\sin\theta, z) \times \mathrm{Rot}(y, \Phi) \times \mathrm{Rot}(z, \theta)$ (7)

In eq.(7) the notation comes form [3].

In the movement to the welding point of n+1-th it is necessary to consider the height padding. From the velocity of welding torch v [mm/sec] and the volume of padding per one second、 q [mm^3/sec] the variation of the height of the welding torch Δz is obtained as follow.

$\Delta z = q * \cos\Phi / hv$ (8)

where h denotes thickness of the object.
Thus, we have the welding height z_{n+1} of the n+1-th as follow.

$$z_{n+1} = z_n + q/hv \cos \Phi \tag{9}$$

The rotation angle of the workpiece is determined by following equation so that the welding velocity v is constant.

$$\theta = (v/f(z))*t \tag{10}$$

where t is welding time.

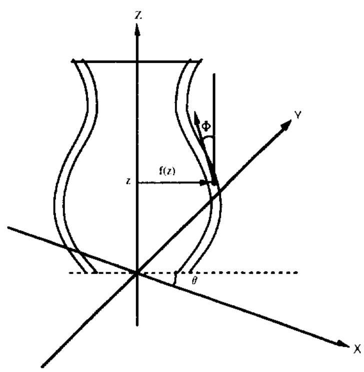


Fig.5 Control Algorithm

4. Experimental results

To illustrate the performance and forming accuracy of our system, several objects are formed by the method discussed in the previous section.

Experimental results are shown in Photo.1. Photo.1-(a) shows the bowl with 75[mm] diameter, 34[mm] height and 5[mm] thickness and Photo.1-(b) shows the flower vase with 150[mm] diameter, 250[mm] height and 5[mm] thickness. It takes 30 minutes to form the bowl and 80 minutes to form flower vase . The limitation of thickness is 3 [mm].

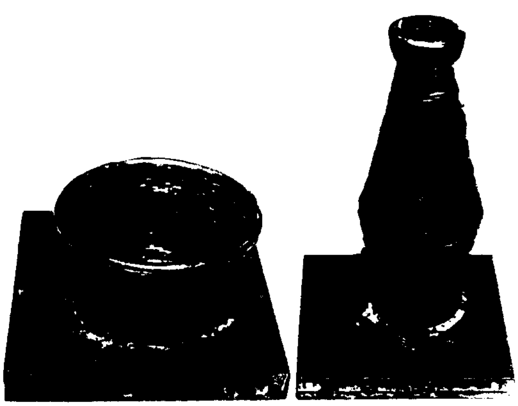


Photo. 1 (a) Photo. 1 (b)

Photo. 1 Experimental Result

5. Conclusion

3-dimensional formation system using a robot hand has been presented. The principle of our system is just only to accumulate welding beads, so that the target 3-dimensional surfaces can be built up.

Using the system, we formed several objects such as the bowl and flower vases. Experimental results showed possibility of creation using arc welding.

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