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A TUBE FLEXIBLE ASSEMBLY AND WELDING SYSTEM BASED ON PHOTOGRAMMETRY AND ROBOTS

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ABSTRACT

To improve the efficiency and accuracy, as well as decrease the cost of the tube assembly and welding, this paper presents a tube flexible assembly and welding system based on the combination of photogrammetry and cooperating robots. This system consists of the measurement subsystem, the cooperating robot subsystem and the software subsystem. Based on these, the methods of calculating the allowance position for cutting and computing the posture of robots are proposed. A simulation process based on CATIA was built to verify the validity of the presented method. A control document, containing the information of robots' kinematic parameter, can be created by the system and guide the cooperating robots to gripe, assemble and weld the tubes flexibly and rapidly.

KEYWORDS

Tube, assembly and welding, cooperating robots, allowance cutting, posture.

1. INTRODUCTION

Pipeline system has been used in almost all the electromechanical products, which holds the function to deliver kinds of medium (EG. water, oil, gas) to each part. Especially in the field of aerospace, pipeline is an important part of the aircraft and spacecraft. Based on a study, it is a guarantee of the quality of products whether the pipeline system can run normally or not [1]. A pipeline system is consisting of a group of various tubes and adapters (i.e. connectors or couplings). According to a research, a large number of the tubes need to be jointed and welded [2].

Traditionally, many kinds of dedicated or modular fixtures must be designed, aiming at locating and clamping different types of tubes during assembly and welding. Based on a study, the traditional approach of assembling and welding the tubes has some disadvantages, such as low efficiency, low universality, and long period, high cost [3]. In terms of flexibility and automation, it is necessary to develop a novel tube flexible assembly and welding system.

Some researches about the tube flexible manufacturing, using modified particle swarm optimization and flexible combine-clamp, have been proposed in literature [4,5]. Study showed the measurement of pipeline based on photogrammetry and laser-scan has also gotten some achievements in [6-8]. But all of these approaches are just focused on the tubes layout or fixture design flexibility and tubes rapid measurement rather than the automation level in tubes production system.

To solve the problems mentioned above, this paper discusses and design the method to calculate the position of allowance for cutting and posture of robots in the tube flexible and automatic assembly and welding system, through analysing the characteristics of the data from the visual measurement equipment and the data used to control the motion of robots.

2. OVERVIEW OF THE SYSTEM

According to the requirements of the assembly of tubes, the system includes software and hardware. The hardware mainly consists of vision measurement equipment, industrial robots, tube cutting machine and auxiliary fixtures. While the software contains three modules of allowance calculation, posture computing and kinematics simulation.

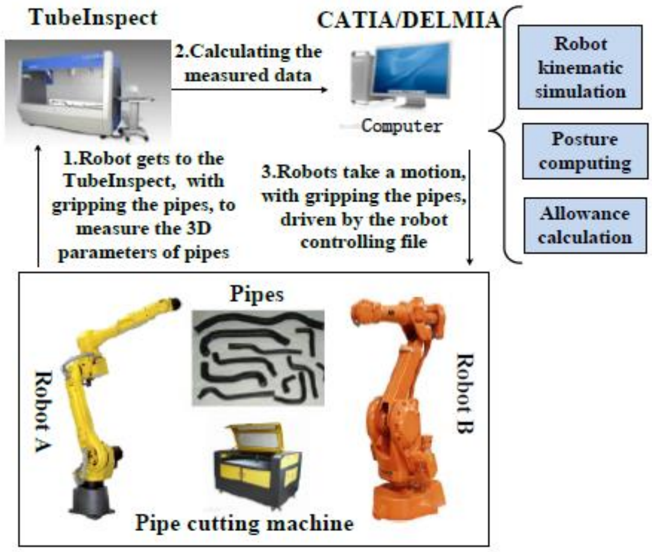

Figure 1: Overview of the proposed system.

In short, three major steps are involved: (i) Measuring the 3D parameters of tubes; (ii) Processing the measured parameters to obtain the relevant data; (iii) Creating the robot controlling file. A more detailed steps is outlined below and see Figure 1.

(1) Robot enter into the vision measurement equipment with gripping the tubes, to measure the 3D parameters of the tube. The measured data need to be transmitted to software module (CATIA/DELMIA). All the data needed for the later calculation can be extracted from this measured data file.

(2) The measured data need to be calculated and three kinds of results should be given: (i) The position of the allowance for cutting; (ii) The posture of the end- effector (i.e. TCP Posture); (iii) The robot controlling file.

(3) Robots take a motion, with gripping the tubes, driven by the robot controlling file. Then the tube allowance cutting and assembly complete.

Concluding from above overview, there are two core computing functions of this tube assembly and welding system: (i) Calculating the position of allowance for cutting; (ii) Computing the robot's TCP Posture when welding or assembling tubes. And the related concepts and definitions are summarized below (Figure 2)

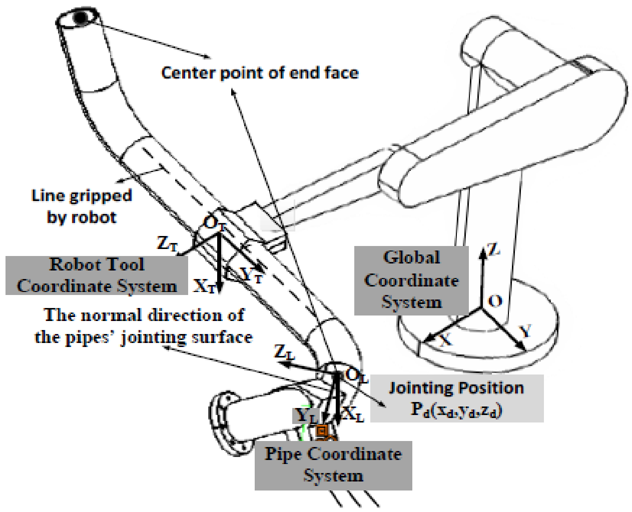

Figure 2: Concepts and definitions.

(1) O-XYZ: Global Coordinate System (i.e. one of the Base Coordinates of robots); OT-XTYTZT: Robot Tool Coordinate System; OL-XLYLZL: Tube Coordinate System, defined on the tube.

(2) The parameters of 3D model of tubes.

Step 2 – Calculate the position of allowance for cutting.

Firstly, the θ angle between the orientation of the line which robot gripe and the normal direction of the tube's docking surface could be gotten according to the parameters of 3D model of tubes.

The position of allowance can be expressed using a plane and the crossing point (i.e. Pc(xc, yc, zc)) of this plane and the axis of tube can be calculated using Equation (2).

Pc(xc, yc, zc): Center Point of the docking surface of tubes; PFc(xfc, yfc, zfc): The other endpoint of tubes; Vl(vxl, vyl, vzl): Orientation of the line which robot gripe; Vp(vxp, vyp, vzp): The normal direction of the tubes' docking surface.

(3) The measured data.

Pm(xm, ym, zm): The measured coordinate of the center point of the docking surface; PFm(xfm, fm, zfm): The measured coordinate of the other endpoint; Tm : The measuring posture of robot when tube is griped to the TubeInspect; Ts : The initial posture of robot; A: The allowance of the tube.

3. CALCULATE THE CUTTING POSITION OF ALLOWANCE

The machining allowance must be cut before tube welding and assembling. Aided by the gripping fixtures, tubes can keep the specific posture and see Figure 3. The calculative process and algorithm is depicted below.

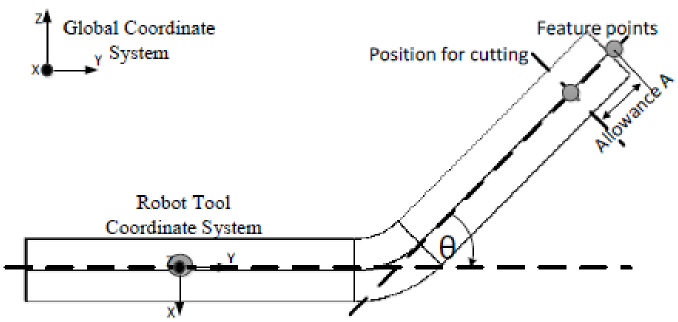

Figure 3: Expression of tube allowance.

Step 1 – Calculate the coordinate of centre point of the docking surface of tubes when robot back to the initial position.

The coordinate Ps (xs, ys, zs) can be worked out using Equation (1), based on coordinate conversion rules.

$$\begin{cases} P_m = T^m{}_{TCP} \times P_{tcp} \\ P_s = T^s{}_{TCP} \times P_{tcp} \end{cases} \quad (1)$$

Step 2 – Calculate the position of allowance for cutting. Firstly, the θ angle between the orientation of the line which robot gripe and the normal direction of the tube's docking surface could be gotten according to the parameters of 3D model of tubes. The position of allowance can be expressed using a plane and the crossing point (i.e. Pc(xc, yc, zc)) of this plane and the axis of tube can be calculated using Equation (2).

$$\begin{cases} x_c = x_s \\ y_c = y_s - A \cdot \cos\theta \\ z_c = z_s - A \cdot \sin\theta \end{cases} \quad (2)$$

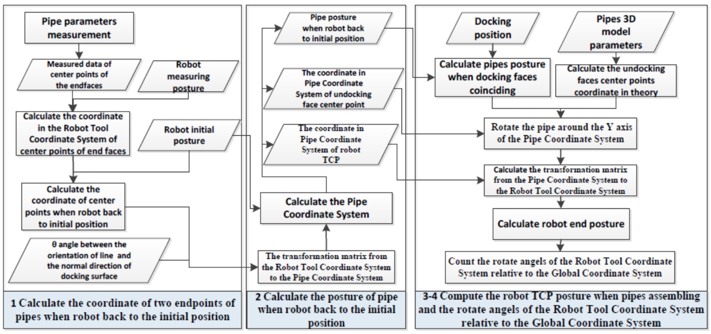

Figure 4: Calculating flow of robot's posture.

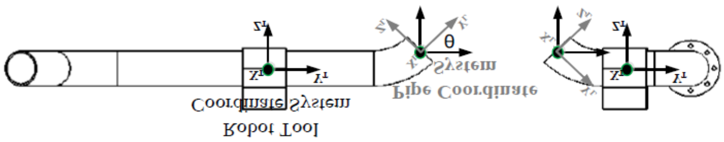

Figure 5: Rule of setting the Tube Coordinate System.

$$T^s{}_L = T^s{}_{TCP} \times T_1 = T^s{}_{TCP} \times \begin{pmatrix} 1 & 0 & 0 & x_t \\ 0 & \cos\theta & -\sin\theta & y_t \\ 0 & \sin\theta & \cos\theta & z_t \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} nx_{l_s} & ox_{l_s} & ax_{l_s} & x_s \\ ny_{l_s} & oy_{l_s} & ay_{l_s} & y_s \\ nz_{l_s} & oz_{l_s} & az_{l_s} & z_s \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (3)$$

In the actual manufacturing, four points (P1, P2, P3, P4) located in the circle mentioned above, are enough to present the position of allowance. Assuming that x = xc , xc , R, xc, - R respectively, the coordinates of the four points can be computed according to the contour equation.

4. COMPUTE THE POSTURE OF ROBOTS

To achieve space motion control of industrial robots and complete the scheduled tasks, the position and the posture of the end-effector must be known. So how to calculate the space posture of the robot tool is a key problem. The specific calculation process is outlined below (Figure 4). Step 1 – Calculate the coordinate of two endpoints of tubes when robot back to the initial position.

According to Equation (1), all the coordinates, Ps(xs, ys, zs), PFs(xfs, yfs, zfs), Ptcp(xt, yt, zt) and PFtcp(xft, yft, zft), can be figured out.

Step 2 – Set the Tube Coordinate System, calculate the posture of tube when robot back to the initial position.

After robot gripping the tube, the relative position between the end effector and the tube is constant. The tube's posture is Ts when the robot back to the initial position. The Tube Coordinate System is defined like that, move and rotate the Robot Tool Coordinate System relative to itself, and see Figure 5 for the rule to set the Tube Coordinate System.

Then we can get the transformation matrix T1 from the Robot Tool Coordinate System to the Tube Coordinate System. Thus, the posture Ts of tube when robot back to the initial position can be obtained through (3).

Besides, the coordinate Pp (x , y , z), the robot TCP coordinate in the Tube Coordinate System and coordinate PFp(xfp, yfp, zfp), the coordinate in the Tube Coordinate System of the other endpoint of tubes can also be computed.

Step 3 – Compute the robot TCP posture when tubes assembling.

The first step to assemble two tubes is moving tubes to make their docking surfaces coinciding. Giving the position Pd(xd, yd, zd) as the docking point of tubes. Tube A move to this point and keep its posture invariant, while Tube B move to this point too and keep its posture same with that of Tube A. The tube posture TeL can be gained when their docking surfaces coinciding.

The transformation matrix T2 from the Tube Coordinate System to the Robot Tool Coordinate System also can be calculated. At the moment, the robot posture Te can be calculated using

$$T^{e}{}_{TCP} = T^{e}{}_{L} \times T_2$$

Then the second step is to rotate the tube around the Y axis of the Tube Coordinate System, and the purpose is to ensure the relative position of the two surfaces that are not butted.

The coordinate PFe(xfe, yfe, zfe) of the centre point of the not-butted surface in theory can be obtained according to the parameters of 3D model of tubes. Then assuming the rotate angle is Φ, the rotate matrix T3 can be computed. Thus, the posture Tj of the tube after rotating can gained according to $T^{j}{}_{L} = T^{e}{}_{L} \times T_3$

Meanwhile, the coordinate PFj(xfj, yfj, zfj) of the centre point of the not-butted surface in fact can be gotten. Finally, according to Equation (4), Φ and the end posture Tj of robot when tubes assembling together can be calculated.

$$\begin{cases} P_{Fj} = P_{Fe} \\ T^{j}{}_{TCP} = T^{j}{}_{L} \times T_2 \end{cases} \tag{4}$$

Step 4 – Count rotate angels of Robot Tool Coordinate System relative to Global Coordinate System.

The rotating sequence that the Robot Tool Coordinate System rotate around the axes of the Global Coordinate System is confirmed as Z→Y→X. Assuming the angles are α, β, γ, the robot posture can be computed according to (5), and then the three angles can be obtained.

5. SIMULATION EXPERIMENTS

The software module is implemented using the Secondary Development of CAD technology based on CATIA, where the tube assembly and welding is simulated in DELMIA using MOTOMAN robots.

Figure 6 is a snapshot about the calculation of the allowance cutting position and computing of robot's postures. Based on the measured data and the parameters of 3D model of tubes, four points presented the position of allowance for cutting can be computed, rotating can gain according which is same with the result calculated manually. As well as, after determining the assembly position, tubes assemble together successfully, and the actual robot posture is same with that in theory. Visibly, the method to calculate the position of allowance for cutting and posture of robots discussed in this paper is feasible and effective.

$$T^{j}{}_{TCP} = \begin{pmatrix} \cos\alpha\cos\beta & -\sin\alpha\cos\gamma+\cos\alpha\sin\beta\sin\gamma & \sin\alpha\sin\gamma+\cos\alpha\sin\beta\cos\gamma & 0 \\ \sin\alpha\cos\beta & \cos\alpha\cos\gamma+\sin\alpha\sin\beta\sin\gamma & -\cos\alpha\sin\gamma+\sin\alpha\sin\beta\cos\gamma & 0 \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} nx & ox & ax & 0 \\ ny & oy & ay & 0 \\ nz & oz & az & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{5}$$

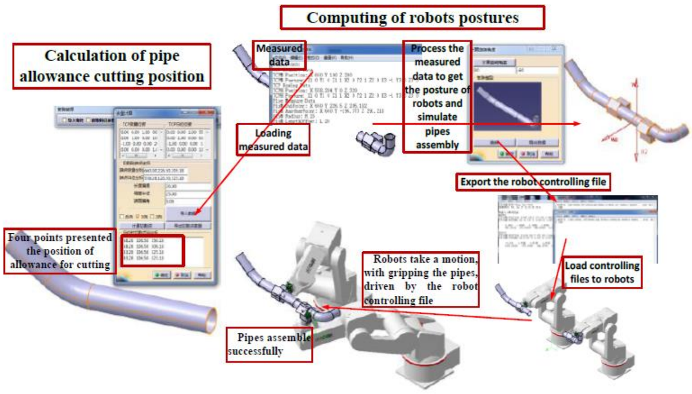

Figure 6: Calculation of allowance cutting position.

6. CONCLUSIONS

In this paper, a new approach of tube assembly and welding based on photogrammetry and cooperating robots is proposed. To begin with, the overall project is described, and then the algorithm to calculate the position of allowance for cutting and posture of robots is discussed. At last, the viability is verified through simulation. But the system described above has been just verified in simulation environment, the deviation has not been considered so far. For this reason, it will be a major subject in further work.

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