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F/T Sensor Application For Robotic Deburring

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ABSTRACT

Machining is a bottleneck in robot application technologies because of uncertainty of position/form, poor reliability of robot function and low reaction speed of robot to changes of surroundings. But in grinding automation with relatively low machining speed it is feasible to integrate of sensor signal in machining. In this paper strategy for robotic grinding with F/T sensor will be presented and with that the experimental results will be discussed. F/T sensor signal in grinding of strategy weld seam are transferred to PC, which plays a role as cell computer and transform F/T data to robot position and/or orientation , speed correction data according to programmed algorithm. The possibility and boundary of robotic grinding with F/T sensor intergration is discussed.

1. Introduction

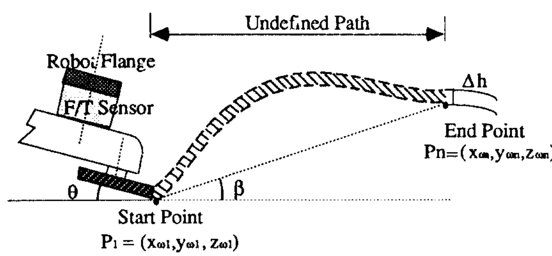
Recently robot applications in the field of surface machinning process like grinding of weld seam and deburring of castings are studied actively, and in spite of the being of proper robot, this processes are remaining as the fields which need much manual work because they need high technology. Also, these fields show low productivity, high cost, dangerous environment. To make success in robotic grinding automation, robot must move the predefined path maintaining constant pressure between the surface of workpiece and that of grinding wheel. In addition to this, when the surface of workpiece is 3 dimmensional, the orientation made by the tangential line of grinder wheel and the surface of workpiece is another important factor. Many reseaches utilized force sensor in measuring the force between workpiece and grinder, and controlling the force to approach the solution of this problem.

Haruhiko Asada[1] used optimal compliance in grinding and L. Liu[2] designed grinding modelling with PID scheme to control grinding process. 6 Degree of Freedom articulated robot, F/T sensor placed at robot wrist and the tool attached after the F/T sensor is used in this study. The algorithm and the developed grinding system which can trace the contour of workpiece surface with the control of robot orientation and path is analized. The object is a curved seam welding line only defined with the starting and ending point.

2. Robotic grinding system, Definition and Configuration

Robotic grinding in this research is defined as follows.

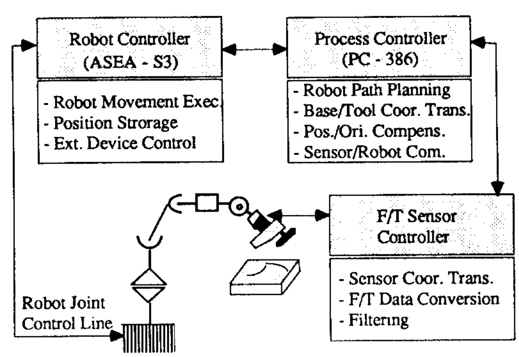
Process definition : The automatic robotic removal process of welding seam having height h_l with cutting depth Δh. Here, welding is placed on 2 dimensional free curve path and only the starting and ending point is defined.



θ ; The angle between tangential vector of workpiece and grinding wheel at grinding point

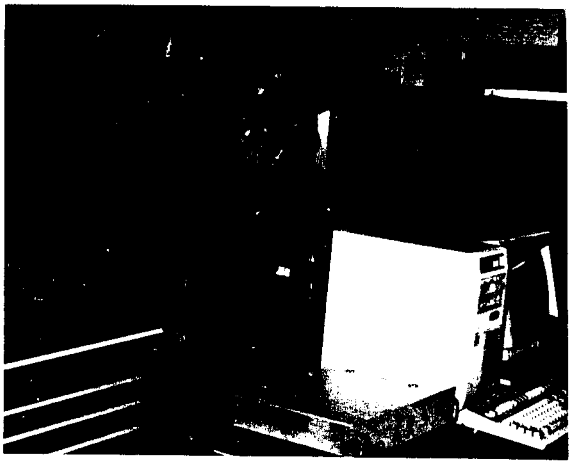
β ; Initial slope of robot path tracking

< Fig. 1 > Grinding Task



< Fig. 2 > Configuration of robotic grinding system

To make the operation like this, the system like <Fig.2> is constructed.



< Fig. 3 > Photo. of Grinding System.

Now, to execute operation like <Fig.1>, following three statements are assumed.

Assumption 1 : Grinding parameters(force, feedrate, rpm) that can produce standard cutting quantity is predefined.

Assumption 2 : The coordinate of F/T sensor is set equal to robot tool coordinate. The rotational and traslational components of F/T sensor coordinate defined when F/T sensor is attached to the end effector of robot and robot tool coordinate is pre-equalized.

Assumption 3 : The infinitestimal change of F/T data due to the infinitestimal F/T coordinate change that is occured with the wearing of grinding wheel is neglected.

The robotic grinding problems using F/T sensor under the assumptions of above are as follows.

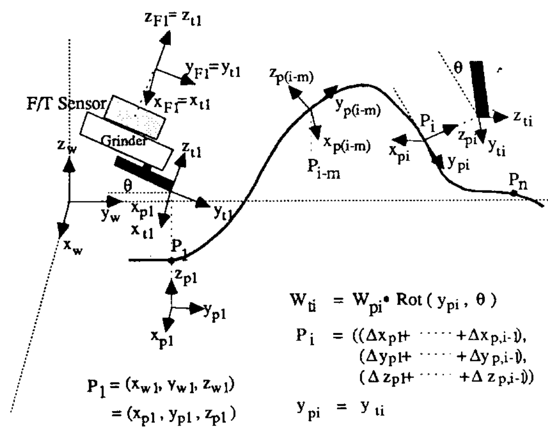
1. Position searching : Unknown position searching occured at unknown path tracking due to small step motion of robot.
2. Orientation compensation : The compensation of θ change due to curved path.
3. Force compensation : The compensation of pre-setting force of grinding due to workpiece contour change.

Each coordinate and the coordinate relationship is required to solve above problems using the F/T data. As a result, W_w is defined as world coordinate(robot base coordinate), assumed coordinate W_p as workpiece coordinate, W_t as tool coordinate. From the above definitions, the relationship between workpiece coordinate and tool coordinate is defined like <Eq.1>.

$$W_t = W_p \cdot Rot(y_p, \theta) \text{ ------------------ } (1)$$

θ : Initial setting

Global coordinate figures like <Fig.4>.



< Fig. 4 > Global coordinate system

As we can see at <Fig.4>, the point of each small step motion of workpiece can be indicated in robot base coordinate and the change of normal direction on each workpiece surface can be transformed to tool coordinate. So, on the base of predefined desired force data, the contact pressure, position, orientation can be controlled.

3. Position, orientation control

Grinding force of 2-dimensional workpiece is related with the grinding position and orientation of robot. The next position searching and orientation error compensation using F/T sensor data on the basis of desired contact force can give a solution to contact force problem. So, the contact pressure problem need not to be solved.

3-1. Orinetation compensation

As shown <Fig.5>, the force data from F/T sensor has the added force like <eq.2>

$$F = F_{yt}\, y + F_{zt}\, z \text{ ----------------------- } (2)$$

Also, the normal directional force to workpiece surface F_{zp} and the anti-directional force to robot path F_{yp} can be said like below

$$F = F_{yp}\, y + F_{zp}\, z \quad \text{------------------------(3)}$$

So,

$$F_n = F_{zp} = F_{yt} \cdot \sin\theta + F_{zt} \cdot \sin(90 - \theta) \quad \text{-----(4)}$$

$$F_t = F_{yp} = F_{yt} \cdot \cos\theta + F_{zt} \cdot \cos(90 - \theta) \quad \text{-----(5)}$$

From above equations, the rotating angle between arbitrary grinding force vector F and workpiece coordinate can be derived.

$$\tan\alpha = F_n / F_t = 1 / \mu$$

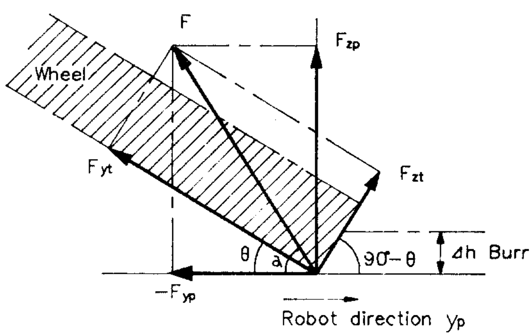
μ : friction coefficient

$$\alpha = \tan^{-1} (F_n / F_t) \quad \text{----------------------(6)}$$

So, the difference betweem α and α_d(desired angle) is the rotation component for orientation compensate.

$$[T_i] = [T_{i-1}] \cdot Rot (x , (\alpha - \alpha_d) \quad \text{----(7)}$$

The orientation of the grinding tool to workpiece can be compensated from <eq. 7>

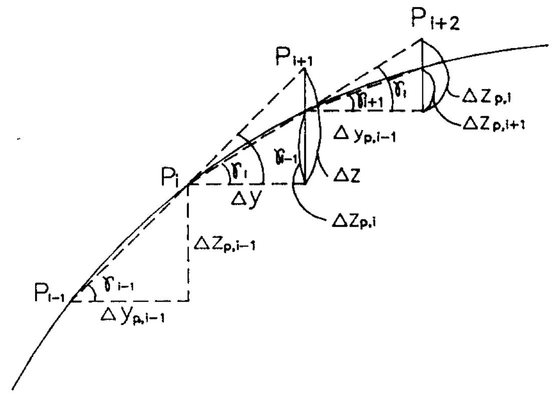


< Fig. 5 > Orientation recognition using F/T data

3-2. Small step movement and position error

a) small step motion of robot

In workpiece contour tracking of robot, the motion of rest steps except first step is shown in <Fig.6>



< Fig. 6 > Small step motion

As shown at <Fig.6> the (i+1)th robot movement proceed to the angular direction of γ which is determined $\Delta y_{p,i-1}$, $\Delta z_{p,i-1}$ at P_i ,and so

$$p_{i+1} = (x_{p,i} + \Delta x_{p,i-1} \,,\; y_{p,i} + \Delta y_{p,i-1} \,,\; z_{p,i} + \Delta z_{p,i-1})$$

Robot can execute small step movement with the tranformated value.

b) position searching

The small step movement at (a) is adaptable only in the case that the tangential direction of of the workpiece is equal to that of Pi. In other words, Only when the workpiece contour is line, that is suitable. The object of this research is not line but curve, and so the tangential angle varies is not defined. So, the the change of the inclined angle should be informed from force data and new point must be generated. Because F value at <eq.2> is the value at that point, it can be compared with pre-settinged desired force F_d.

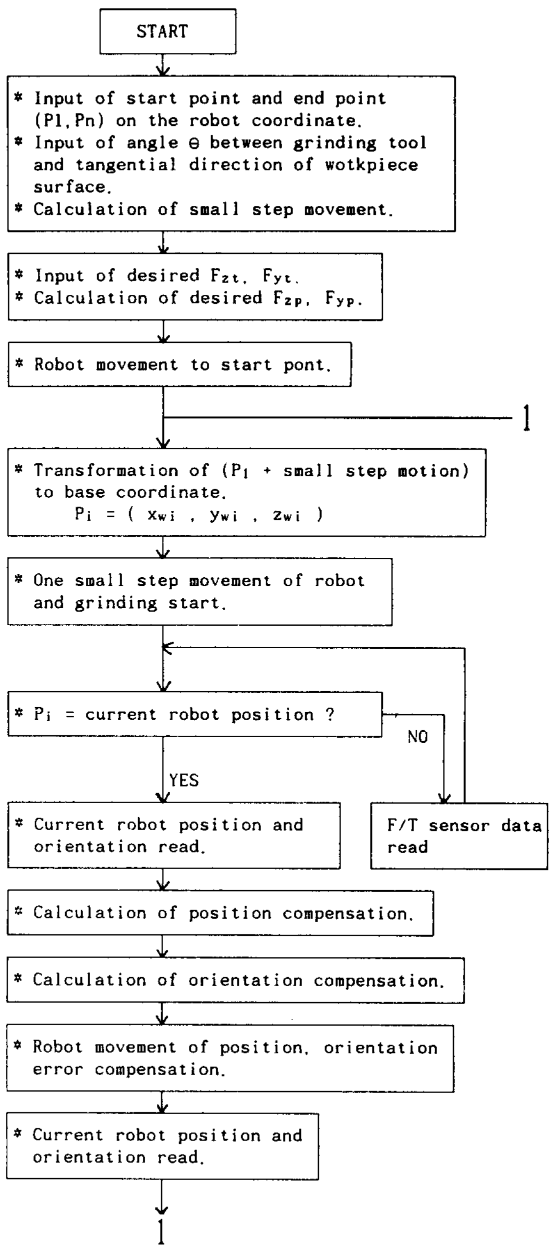
From the fact, position error ΔP_e(Δx_e, Δy_e, Δz_e) can be compensated with equation below.

$$\Delta p_e = K1 (F_d - F) \quad \text{------------------------(8)}$$

k1 : constant

From the above equations , position and oriention compensation during the small step movement of robot enabled the grinding process with constant contact force on the surface of workpiece and the solution is obtained.

4. System control flow chart.



5. Conclusion

The grinding force control algorithm with robot position and orientation control using F/T sensor data is suggested in this research and robotic grinding system is developed. The grinding object of this research is the welding seam with 2-dimensionally curved contour. Especially, the developed algorithm which finds the position and orientation at a grinding point on free form surface enables the robotic grinding with curved path only from starting point and ending point without position and orientation data . Also, this system can trace arbitrary contour with constant force and contact angle to keep the area of grinding surface and depth constant.

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