A STUDY ON WORKING PLAN OF INTELLIGENT EXCAVATOR

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ABSTRACT: Intelligent excavator has four sensors which can detect the length of each cylinder and electronic valves which are used to control flow rate of hydraulic oil electrically. Intelligent excavator is controlled by the information from these sensors and control signals. Using the position control, excavator can work on the programmed path. In this case, controller needs to know how deep the excavator digs the ground in the short working time efficiently. Considering the working time and fuel efficiency, the most efficient work is similar to the work that the experts drive the excavator usually. In this paper, we study the path used by the expert of excavator and then the controller generates the similar path for applying this generated path to the real excavator.

***Keywords**: Intelligent Excavator, Expert, Path, Program*

1. INTRODUCTION

In industrial field, the excavator is good to move the heavy things, dig the ground for its hydraulic characteristics. As the excavator works in the dangerous environment, the researches about automation of excavator have been studied a lot for the safety and convenience of excavator drivers. There are some difficulties because the hydraulic system is different from electric motors. It is difficult to control the hydraulic system exactly due to nonlinearity. So to overcome these difficulties, many researches have been conducted. The control strategy is restricted to PID control with gain scheduling [1]. The position control and force control of hydraulic cylinders for a smaller hydraulic excavator were studied in [2, 3] which concentrated on the earth-digging problem of hydraulic excavators and implemented position control and force control of hydraulic cylinders of the working arms for the earth digging process. The excavator's end tip has always disturbances from the ground. So to reduce the effect of the disturbance, the disturbance observer and PI control was applied to a small excavator [4]. This paper presents the method that the excavator digs the ground efficiently with the researches about intelligent excavator.

2. KINEMATICS OF EXCAVATOR

The kinematics of the robot was derived using D-H convention from Denavit and Hartenburg. Because the manipulator lacks swing motion of excavator it can be seen as planer manipulator. Planer manipulator has 2 DOFs for end-effector position, but excavator has 3 planer links, therefore redundancy occurs. To handle the redundancy issue, user must specify bucket angle, which is measured from reference frame. Therefore, once bucket angle is defined, with trigonometric relationships inverse kinematics solution can be derived without any problem. There are for homogenous transformation matrices and calculation does not cost much. Coordinate transformations for the manipulator will be derived as follows:

$$ {}^{0}T_4 = {}^{0}T_1\,{}^{1}T_2\,{}^{2}T_3\,{}^{3}T_4 \qquad (1)$$

In a same way, the hand position from reference from can be described as: θ_y is the angle of bucket and p_x, p_z is the end-effector position relative to reference frame which can be obtained as:

As can be seen in the Figure 1, end-effector position (p_x, p_z) and θ_y is given. From the configuration, values of p_x' and p_y' can be obtained from following relationship.

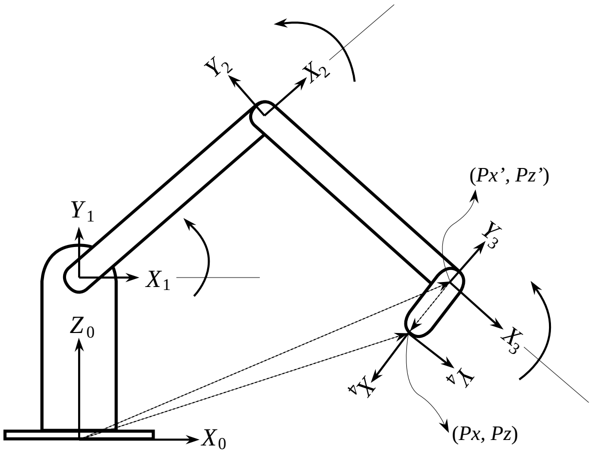

Fig. 1 Excavator joint variables.

$$ {}^{R}T_{H} = \begin{bmatrix} \cos\theta_y & 0 & -\sin\theta_y & p_x \\ 0 & 1 & 0 & 0 \\ \sin\theta_y & 0 & \cos\theta_y & p_z \\ 0 & 0 & 0 & \end{bmatrix} \quad (2) $$

$$ \begin{aligned} p_x &= a_2\cos\theta_2 + a_3\cos\theta_{23} + a_4\cos\theta_{234} \\ p_z &= a_2\sin\theta_2 + a_3\sin\theta_{23} + a_4\sin\theta_{234} + d_1 \end{aligned} \quad (3) $$

$$ \begin{aligned} p_x' &= p_x - a_4\cos\theta_y \\ p_z' &= p_z - d_1 - a_4\sin\theta_y \end{aligned} \quad (4) $$

Other angular values can be derived from trigonometric rules such that:

$$ \theta_3 = a\tan 2\left(\frac{a_2^{\,2} + a_3^{\,2} - (p_x'^2 + p_y'^2)}{2a_2a_3} \sqrt{1-\left\{\frac{a_2^{\,2} + a_3^{\,2} - (p_x'^2 + p_y'^2)}{2a_2a_3}\right\}^2} \right) - \pi \quad (5) $$

$$ \theta_2 = \begin{vmatrix} a_2 + a_3\cos\theta_3 & -a_3\sin\theta_3 \\ a_3\sin\theta_3 & a_2 + a_3\cos\theta_3 \end{vmatrix}^{-1} \begin{vmatrix} p_x' \\ p_y' \end{vmatrix} \quad (6) $$

$$ \theta_4 = \theta_y - \theta_3 - \theta_2 \quad (7) $$

3. PATH GENERATION

The points which are showed by Fig. 2 make the whole path. Each points are expressed in $(x_i, y_i), (x_{i+1}, y_{i+1})$.

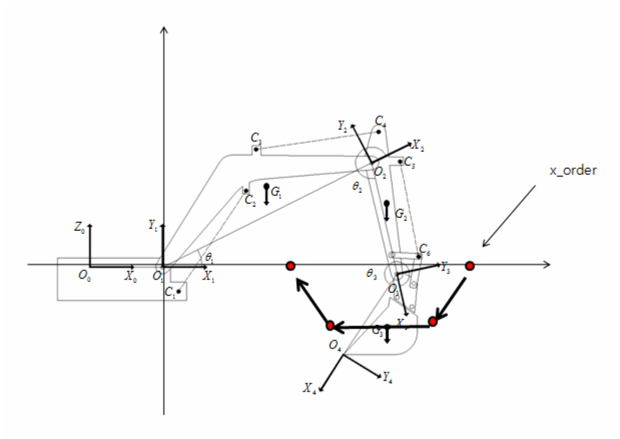

Fig. 2 Path generation

The path abides by the following equations. The whole distance of this path is like this.

$$ s = \sqrt{(x\_order - init\_pos\_x)^2 + (y\_order - init\_pos\_y)^2} $$

The moving time is $T = \frac{s}{v}$. Eq. (8) and (9) represents the order of movement about X and Y Axis.

$$ \begin{aligned} & x = v \cdot t + init\_pos\_x \\ & (init\_pos\_x < x < x\_order) \end{aligned} \quad (8) $$

$$ y = ax + b \quad (9) $$

In the Eq. (9), a and b are calculated by Eq. (10) and (11).

$$ a = \frac{y\_order - init\_pos\_y}{x\_order - init\_pos\_x} \quad (10) $$

$$ b = y\_order - a \cdot x\_order \quad (11) $$

Eq. (12) and (13) shows the order of movement and the velocity of the bucket.

$$ th4 = v\_th \cdot t + init\_pos\_th \quad (12) $$

$$ v\_th = \frac{bucket\_move}{T} \quad (13) $$

$init\_pos\_x$: Initial position of x
$init\_pos\_y$: Initial position of x
x_order : Desired x position
y_order : Desired x position
$th4$: Angle of bucket
$init\_pos\_th$: Initial position of bucket

4. CONCLUSION

This paper presents the method that the excavator digs the ground efficiently with the researches about intelligent excavator. The study approaches to analyze the inverse kinematics of excavator and generates the path which can make the intelligent excavator dig the ground efficiently.

5. ACKNOWLEDGEMENT

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