EXPERIMENT OF CONCRETE FLOOR FINISHING ROBOT

Woo Kwang-Sik, Lee Ho Gil, Kim Jin-Young, Song Jae-Bok
*Division for Applied Robot Technology (DART)
Korea Institute of Industrial Technology (KITECH), KOREA
{koreaman, leehg, kjy, wowmecha}@kitech.re.kr
**Intelligent Robotics Laboratory
Department of mechanical Engineering Korea university, KOREA
jbsong@korea.ac.kr

Abstract: In this paper, a self-propulsive and small concrete floor finishing trowel robot with twin trowels is proposed. Due to the small size and omni-directional moving capability, it is adequate for small space such as apartment. By adjusting the posture of trowels, it can move in any direction without wheels. We used cheap PIC processor for the cost saving design of the modules and adopted mode processors for easy operation of control stick. For the position control of the robot, we made a motion control algorithm appealing to the stepping motor driver module and the wireless communication module between the robot and PC (or control stick). In this paper, we discuss the control problem of the floor finishing robot in order to move to the right position. By comparing experimental result with simulation, we show the validity of the robot mechanism, sensors, and the control system.

Keywords: Concrete floor finishing robot, omni-directional driving, trowel

1. INTRODUCTION

Automation technology is having an effect on all sorts of industry beyond the limitation of factory, as industrial society have being developed highly. Particularly, the construction field, a typical 3D industry, must be automated without delay. According to this trend, domestic construction industry also began to introduce automation equipments for construction, and advanced countries began to put robots for construction on the market.
The existing concrete floor finishing robots, which are developed in the construction companies of Japan, are large machines that their weight reach more than 180kg. They are the applicable types to works of large floor surface such as an airplane shed and a large warehouse. But a small robot developed by us is largely used for the concrete floor finishing works in the small floor surface, but on the other hand in the work of many demand. Accordingly, we produced the miniaturized robot that meet the necessary requirements for automation of the concrete floor finishing works in place such as high buildings. Also, we developed a controller and interface so that anybody as well as experts can easily handle the robot, and replaced the existing expensive controller with an inexpensive controller to materialize the robot that have the movable characteristic into omni-direction at low price[1][2][3].

2. ANALYSIS ON DYNAMIC MOTION OF THE CONCRETE FLOOR FINISHING ROBOT

A thrust of the robot come from the reaction force against the friction force originates from the touch with floor surface by the rotation of Blade. Accordingly, to measure thrust of the robot, it must firstly calculate the friction force that act on each Blade of trowels. It defines coordinates axes as Figure.1 to analyze motion of the robot by the friction thrust come from the friction force of each Blade[4][5].

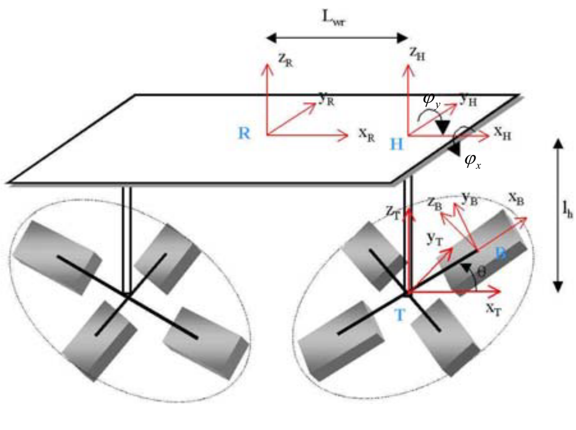

Figure 1. Coordinate System of Concrete Floor Finishing Robot

$$f_f = -f_N i \tag{1}$$

A friction force that act on each Blade of trowels can be calculated.

$$\begin{aligned} {}^{B}f_t &= Rot(x_B,\gamma) \bullet f_f \\ &= \begin{bmatrix} 0 \\ -\mu f_N \cos\gamma \\ -\mu f_N \sin\gamma \end{bmatrix} \end{aligned} \tag{2}$$

Here, μ is a friction coefficient and f_N is a vertical force that act on Blade.

If Blade's dressing angle γ -angle between Blade and floor-exist, a thrust ${}^{B}f_t$ on Blade coordinate system that come from the friction force is as following.

$$
\begin{aligned}
{}^{\mathrm{T}}f_{\mathrm{t}} &= Rot(z_T,\theta) \bullet {}^{\mathrm{B}}f_t \\
&= \begin{bmatrix} \mu f_N \cos\gamma \sin\theta \\ -\mu f_N \cos\gamma \cos\theta \\ -\mu f_N \sin\gamma \end{bmatrix}
\end{aligned} \tag{3}
$$

Given the transformation matrix of coordinates system, a thrust ${}^{T}f_t$ that act on the trowel coordinate system T by the friction thrust of Blade can be calculated as following.

$$
\begin{aligned}
{}^{\mathrm{T}}\tau_{\mathrm{t}} &= l_{bc} \times {}^{\mathrm{T}}f_t \\
&= \begin{bmatrix} -l_{bc}\mu f_N \sin\theta \sin\gamma \\ l_{bc}\mu f_N \cos\theta \sin\gamma \\ -l_{bc}\mu f_N \cos\gamma \end{bmatrix}
\end{aligned} \tag{4}
$$

For calculation from the geometrical relation in consideration of the distance l_{bc} from trowel's center to Blade's center, a torque ${}^{T}\tau_t$ by the friction thrust of Blade that act on the trowel coordinate system is as following.

$$
\begin{aligned}
{}^{\mathrm{T}}\tau &= {}^{\mathrm{T}}\tau_a - {}^{\mathrm{T}}\tau_t \\
&= \begin{bmatrix} -l_{bc}\mu f_N \sin\theta \sin\gamma \\ l_{bc}\mu f_N \cos\theta \sin\gamma \\ \tau_a - l_{bc}\mu f_N \cos\gamma \end{bmatrix}
\end{aligned} \tag{5}
$$

Also, as the driving motor of the robot provide trowels with the driving torque ${}^{T}\tau_a$, a acting torque ${}^{T}\tau$ of trowels can be calculated as a equation (5), given the driving torque and the friction thrust torque.

$$
\begin{aligned}
{}^{\mathrm{H}}f_{\mathrm{t}} &= Rot(y,\varphi_y) \bullet Rot(x,\varphi_x) \bullet {}^{\mathrm{B}}f_f \\
&= \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}
\end{aligned} \tag{6}
$$

Here,

$$
\begin{aligned}
a_1 &= \mu f_N \cos\gamma \sin\theta \cos\varphi_x - \mu f_N \cos\gamma \cos\theta \sin\varphi_y \sin\varphi_x \\
&\quad - \mu f_N \sin\gamma \sin\varphi_y \cos\varphi_x \\
a_2 &= -\mu f_N \cos\gamma \cos\theta \cos\varphi_x + \mu f_N \sin\gamma \sin\varphi_x \\
a_3 &= -\mu f_N \sin\gamma
\end{aligned}
$$

Given the transformation matrix between coordinate axes of trowel by the angle of trowel that incline toward x-axis and y-axis, or the posture control angle of trowel φ_x, φ_y to calculate the thrust, a friction thrust of Blade ${}^{H}f_t$ on the coordinates system of hip H located in the top of trowel can be calculated as a equation (6).

$$
{}^{H}M = l_h \times {}^{\mathrm{H}}f_t = \begin{bmatrix} l_h a_2 \\ -l_h a_2 \\ 0 \end{bmatrix} \tag{7}
$$

Meanwhile, a moment ${}^{H}M$ that act on the hip by the friction thrust, is as following.

$$
{}^{\mathrm{R}}f_t = {}^{\mathrm{H}}f_f \tag{8}
$$

A thrust ${}^{R}f_t$ come from the friction forces of Blade is the same in the center of robot R, as rotation is not transformed in the coordinates system of hip and robot center. Accordingly, a thrust in the center of robot is as following.

$$
{}^{R}M_r = l_w \times {}^{\mathrm{R}}f_t = \begin{bmatrix} 0 \\ -l_w a_3 \\ l_w a_2 \end{bmatrix} \tag{9}
$$

A moment in the center of robot can be also calculated.

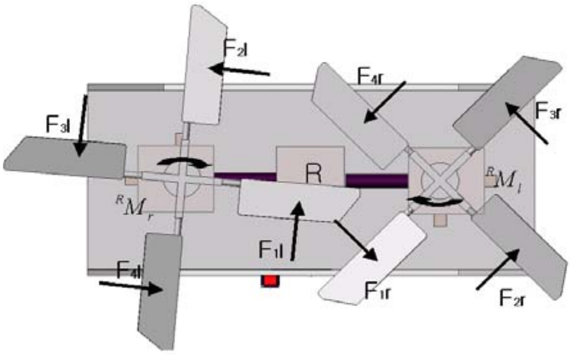

Figure 2. Dynamic Moment Coordinate System of Concrete Floor Finishing Robot

$$
\begin{aligned}
{}^{R}M &= {}^{R}M_r + {}^{R}M_l = l_w \times {}^{\mathrm{R}}f_{t_r} + l_w \times {}^{\mathrm{R}}f_{t_l} \\
&= \begin{bmatrix} 0 \\ 0 \\ 2 l_w a_2 \end{bmatrix}
\end{aligned} \tag{14}
$$

$$
{}^{R}M - \mu f_f \sin\gamma \times Lw = I\ddot{\alpha} \tag{15}
$$

A thrust ${}^{R}f_{t_r}$, ${}^{R}f_{t_l}$ by two trowels on the right side and left side, and a moment ${}^{R}M_r$, ${}^{R}M_l$ in the center of robot is as following [6]. Figure2 show the friction and moment about trowel.

Using Figure2, we made dynamic modeling(15) about moment from R.

$\mu f_f \sin\gamma$ is friction when Robot is rotating. Rotation of the thrust by control angle the right and left trowel ($\varphi_{x_r}, \varphi_{y_r}$), ($\varphi_{x_l}, \varphi_{y_l}$) is controlled respectively.

Therefore. We can control motion of the robot into omni-direction by handling intensity and direction of power that act on the trowels with above equations.

3. CONCRETE FLOOR FINISHING ROBOT SYSTEM

The mechanism part of the robot movement and work of it, where consist of trowel that perform flattening of the concrete floor finishing surface and trowel posture controller. The robot can move trowel toward voluntary direction to control posture to help it move toward omni-direction. Manufacture is shown in Figure3. Table 1 is the specification for the floor finishing robot [7].

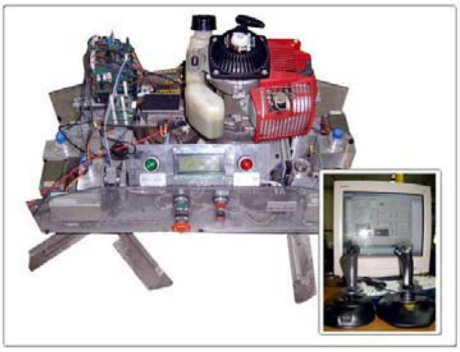

Figure 3. Photograph of Concrete Floor Finishing Robot

Table 1. Specification of Concrete Floor Finishing Robot

Item	Specification
Weight(kg)	45
Size(mm)	900×500×600
Control Method	Microprocessor & Joystick
Power Source	Gasoline Engine
Number of Trowel	2

We could develop the electronic equipment part, which control work and motion of it, with the produced mechanism part, and materialize a basic movement of it. User must input command value to controller installed it to materialize a basic movement of it with joystick stuck to PC. If so, the controller calculate the input value as inclination angle and rotation speed of each trowel through driving algorithm measured by telecommunication module. The figure4 shows overall structure chart of the controller and block diagram of control signal.

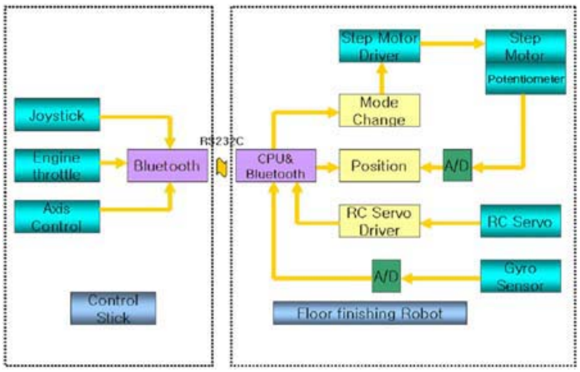

Figure 4. Block diagram of Concrete Floor Finishing Robot

We made up two-control parts-controller and engine throttle, which command driving of the robot, with PC. User can control movement of it with controller, which connects two joystick for game, to calculate rotation angle displacement of trowel. Here, user is necessary to understand connection relation between output values of joystick, user's control command, and rotation angle displacement of trowel that calculate motion type of it. We define this connection relation as control rule. User can control the direct motion of it alone with one out of two joystick, and control the rotation motion of it alone with another joystick. Accordingly, each joystick can control each trowel in detail, reducing a error come from it, when it is in a direct motion or a rotation motion.

The engine throttle can change throttle angle of posture controller by step motor's rotation to move it into omni-direction. But this paper shows that movement and work level of it depend on the rotation speed of throttle. Accordingly, we controlled engine throttle, which can adjust trowel's rotation speed properly, to materialize it that is driven at a proper rotation speed. We used to make up above two-control parts as Figure 5 as user interface.

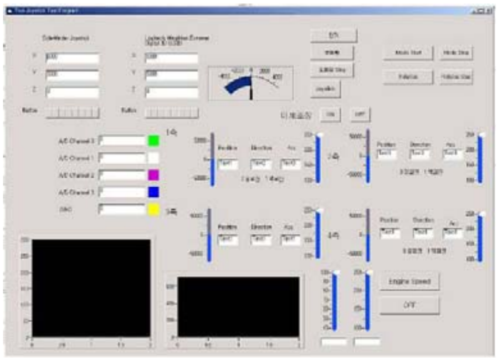

Figure 5. User Interface

We used microcontroller(PIC 16F876) for controller installed to the robot. This controller was produced by method that drive each step motor by changing command value, which control posture of trowel with joystick stuck to PC, with numerical equation through mathematical modeling. This controller, which can substitute for the existing controller and pulse generator, have the advantages that can not only cut down costs but also handle signal more stably and rapidly. Figure6 show the control board. The control board consist of micro-controller, pulse generation, control step motors , A/D converter and control of motor for RC server.

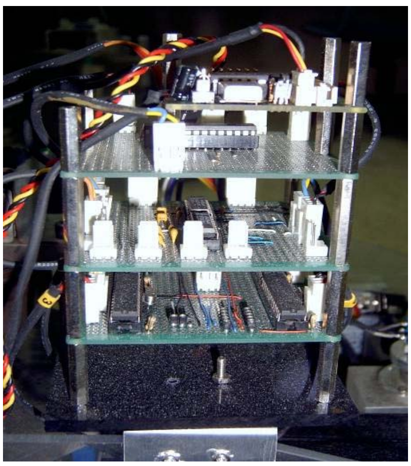

Figure 6. . Photograph of Controller

The robot of opened circuit is controlled by control command value that users input to each motor based on the previously decided pattern. This method has the advantage that additional sensor is not needed and that control algorithm is also simple, but has the shortcoming that users are required many experience and time to set the previously decided pattern for correct driving of it as users' intention and that it not adapt itself to change of the environment. Also, this has the troubles that are difficult to materialize automatic driving such as self-control driving and pattern driving. To supplement this problems, we equipped it with gyro-sensor and measured rotation of it, and then controlled the closed circuit to compensate rotation of it that can occur when it move. In result, we can run it regardless of the environment. The design structure is as following Figure 7[6].

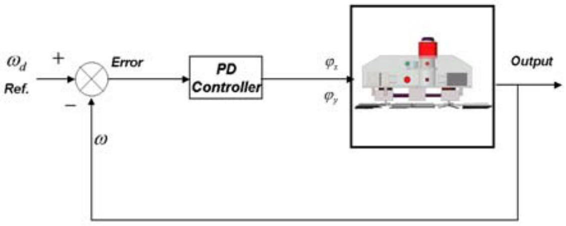

Figure.7 Design Structure For PD Controller

$$\begin{aligned}\varphi_{x_r} &= K_{p_r}(\alpha_d - \alpha) + K_{d_r}\alpha \\ \varphi_{x_l} &= K_{p_l}(\alpha_d - \alpha) + K_{d_l}\alpha\end{aligned} \qquad (16)$$

ω_d is input reference and ω is output. We can control the robot to move through PD controller using ω_d, ω. A angle of trowels can be calculated.

4. EXPERIMENT AND RESULTS

This clause examined into a moving capability of the robot to search if it perform the concrete floor finishing work according to user's demand. In other words, we controlled the inclination angle of trowel so that it can achieve moving such as forward, backward, left and right movement, and clockwise and counterclockwise rotation with controller of it. In the result, direction of friction force depend on the inclination angle of trowel, and the robot is moved by resultant of this friction forces. This study designed the robot so that trowel's angle incline by maximum $\pm 5^\circ$. But we set up the inclination angle by maximum $\pm 4^\circ$ to test the robot.

The following are adjustment rules of posture control by controller. First, left joystick was made up to help the robot move to direct direction alone such as forward, backward, left, right and diagonal movement. And if the robot not move as user wanted, right joystick was designed to help compensate this in detail. In other words, it was made up to help the robot move to clockwise and counterclockwise direction alone at definite speed. Figure 7 shows the adjustment joystick operations [8].

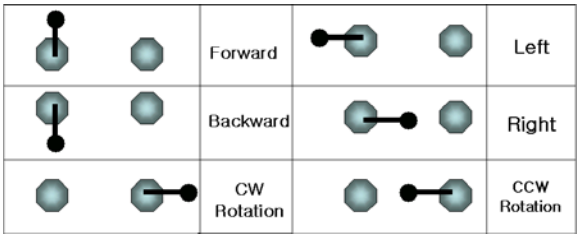

Figure 7. Joystick Operations

This test shows that the robot change moving direction clearly based on the inclination angle of trowel. The robot could move to left and right direction as user wished. But for forward and backward movement, it didn't move as user wished, as it give rise to yaw phenomenon. The reason shows that for left and right movement, a moment isn't occurred, as direction of friction force that act on trowel in the robot's center, is formed toward Y axis. And for forward and backward movement, a moment is occurred, as friction force between trowel and floor surface is formed toward X direction in the robot's center. In other words, if friction forces that act on two trowels differ from each other, the robot give rise to a moment. Because of this, it bring about rotation phenomenon, but on the other hand it is moved.

This Figure 8 show the gyro-signal for hovering in graph under open control.

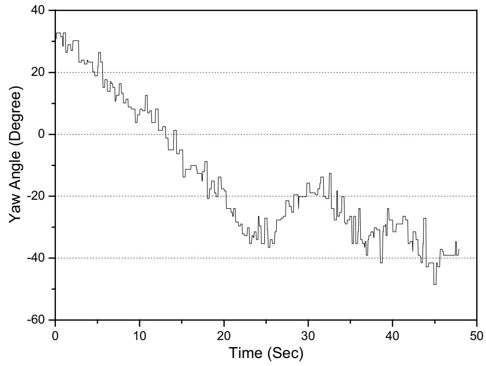

Figure 8. Gyro-signal of open control

To compensate an error based on the rotation of the robot, we used gyro-sensor to measure rotation of it, and then controlled an error based on the rotation by the controller. Figure9 is divided into two part-flat floor surface and rough floor surface-to conduct a test that compensate rotation based on the stop condition, as motion direction of it change according to the roughness of floor surface.

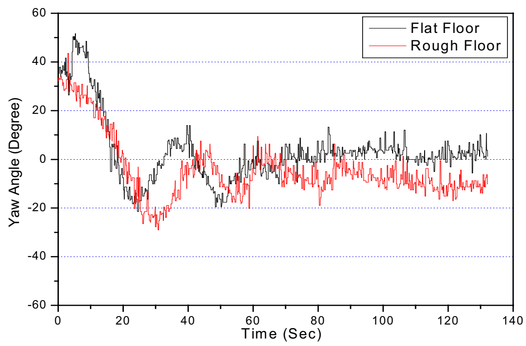

Figure 9. Gyro-signal of closed control

Above result shows that a response of the robot is in error. This is due to friction's change occurred by trowel's rotation based on the floor surface condition. The result shows that the robot come back stop condition by compensation of controller. In other words, the robot maintain it's location according to the compensation by rotation, although floor surface is in any condition.

5. CONCLUSION AND HEREAFTER PLAN

This thesis conducted design and sample products production of the small concrete floor finishing robots that big market size is estimated in the real demand aspect of the construction automation and robotics field. It used movement mechanism to the omni-direction by the contracting forces between trowels, which can simultaneously perform an efficient concrete floor finishing work and movement, to materialize movement based on the targeted location of the robot. From now on, the robot will be complemented by the continuous monitoring and the collected spot data such as environmental adaptation, durability, handling and evaluation of the concrete floor finishing side by throw it in the concrete floor finishing work of the construction spot. In the result, we expect that these studies can develop high performance robot-not only meet an effective algorithm and convenient handling but also is easy to work together with workers.

REFERENCES

[1] Automation Construction, *KICT*, 1992.
[2] Construction Robot, *Japan Robot Institute Paper*, Number 8-2, 1990.
[3] Ho Gil Lee etc, "Construction Robot Developing", 1997.
[4] Hiroshi Furiya, Noriaki Kiyohiro, "Floor Polishing Robot Driven by Self Propulsive Force," *JRSJ*, Vol.13, No.6, pp.854 ~ 859, 1995.
[5] Dong Hun Shin, Ho Joong Kim, "Self-propulsive Floor Polishing Robot," *Proceedings of IASTED Int*. Conf. on Applied Modeling and Simulation, pp.284 ~ 290, July, 1997.
[6] Hiroshi Furiya, Noriaki Kiyohiro, "Floor Polishing Robot Driven by Self Propulsive Force," *JRSJ,* Vol.13, No.6, pp.854 ~ 859, 1995.
[7] Dong Hun Shin, Ho Joong Kim, "Self-propulsive Floor Polishing Robot," *Proceedings of IASTED Int. Conf.* on Applied Modeling and Simulation, pp.284 ~ 290, July, 1997.
[8] D.H. Shin, H.J. Kim, H.G. Lee, and H.S. Kim, "Omni-directional Self-Propulsive Trowelling Robot," *Proceedings of 1998 IEEE International Conference on Robotics and Automation*, May 16-20, 1998