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The Study of the Electromagnetic Robot with a Four-wheel Drive and Applied I-PID System

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Abstract – The purpose of this study is based on the electromagnet robot with a four-wheel drive which can climb up and down on structures of iron wall instead of human workers. Many of studies strive to develop wall riding-robots in terms of absorption system. However, the system needs additional devices too much to work out as well as electromagnetic wheel system also has much expense to make it. In this regard, this study makes efforts to find the way how to keep steady distance between wheel and wall while using general electromagnet to reduce motor load and to move robot so easily.

Keywords: Robot climber, Electromagnet, Robot with a four-wheel drive, Robot for a work, Robot

1. Introduction

Fuel consumption of engine has direct influence on high ship operation costs. In this background, the study put emphasis on minimizing the consumption and improving ship operation efficiency and discovered to bring on the efficiency by removing marine life living on ship walls. Hull body of a ship is always under the sea. So, there are naturally a lot of marine lives on the body such as barnacle and so on. In usual, workers immediately remove the marine life with their tools when a ship comes to an anchor in a dock. However, this way is dangerous for workers and workers should be exposed to harmful substances it makes safety concerns [1-3, 17-19].

So, scholars have been developing how to remove marine organism living on the surface of ships by using industrial robot cleaners, instead of human workers. Nowadays, most of the robots have Vacuum absorption system. But, the system has many of problems in terms of costs and technologies owing to additional devices to the system. This being so, this study focuses on developing electromagnet robot which is cheaper rather than robot with absorption system in order to bring down to costs and effectively to control it [17-19].

2. Electromagnet Robot with a Four-wheel Drive

2.1 Analysis of control environment for robot-driving

The robots should be able to move regardless of the external force due to the connected power line in order to perform stable motion. While the robot climbs up a vertical cliff, The minimum torque is identified by formula (1) [3, 10].

$$\mathrm{T} \geq \frac{(F_1+F_2)\cdot R}{N} \times B \times S \quad (1)$$

In formula 1, F1 and F2 include the weight of the electromagnet robot and device's weight attached by the robot. R is the radius of the robot wheel and N is the number of electric motor. B is a deceleration ratio. S means a safety ratio.

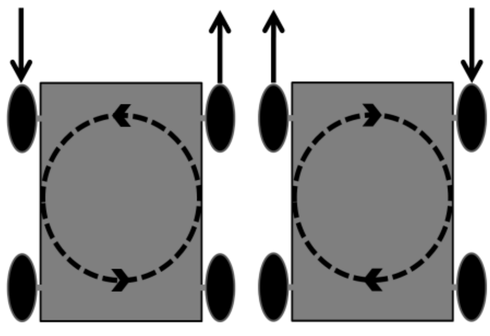

Fig. 1. Driving way (A)

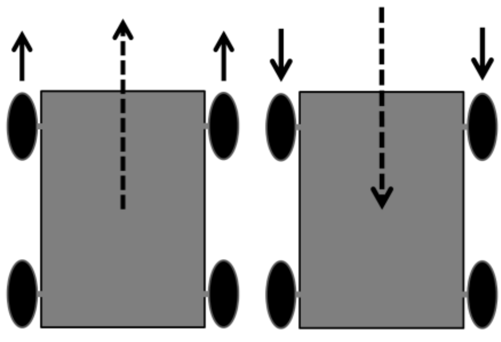

Fig. 2. Driving way (B)

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2.2 Steering system of the electromagnet robot

This study adopted two robot-driving methods as Fig. 1, 2 in order to sustainably move the electromagnet robot. The robot is able to be controlled by difference rotational speed between right and left sides. It is necessary to know the position change according to the rotational speed of the left and right side, to move the robot with 4-wheel-drive with electromagnet to desired position. We can calculate it using the moment center of rotation as a reference at the flat surface. The kinematic model for calculating the position of a 4-wheel-drive electromagnet robot is shown in Fig. 3 [3, 10].

The kinematic model's formula is based on formula 2 if the electromagnetic robot is not assumed to slide down the direction, $V_{LFy}, V_{LBy}, V_{RFy}, V_{RBy}$. Formula 2 includes V_F and V_B having the movement speed of the robot of forward and backward wheels and V_L, V_R indicating the robot movement speed. Movement position, $A'(A'_x, A'_y)$ from starting point, $A(A_x, A_y)$ is able to be formulated as formula 3. θ and θ' indicate the direction of the robot's forward and backward movement. Angle of rotation, δθ and radius rotation, R is formula 4, 5 and it can be calculated with wheel speed, the electromagnetic robot width, L, ravel time, T[3, 10].

$$\begin{aligned} V_L &= V_{LFy} = V_{LBy} \\ V_R &= V_{RFy} = V_{RBy} \\ V_F &= L_{LFx} = V_{RFx} \\ V_B &= V_{LBx} = V_{RBx} \end{aligned} \tag{2}$$

$$\begin{pmatrix} A'_x \\ A'_y \\ \theta \end{pmatrix} = \begin{pmatrix} \cos(\delta\theta) & -\sin(\delta\theta) & 0 \\ \sin(\delta\theta) & \cos(\delta\theta) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} R\sin(\theta) \\ -R\cos(\theta) \\ \theta \end{pmatrix} + \begin{pmatrix} A_x - R\sin(\theta) \\ A_y + R\cos(\theta) \\ \delta\theta \end{pmatrix} \tag{3}$$

$$\delta\theta = \frac{(V_R + V_L)t}{L} \tag{4}$$

$$R = \frac{L}{2} \cdot \frac{V_R + V_L}{V_R - V_L} \tag{5}$$

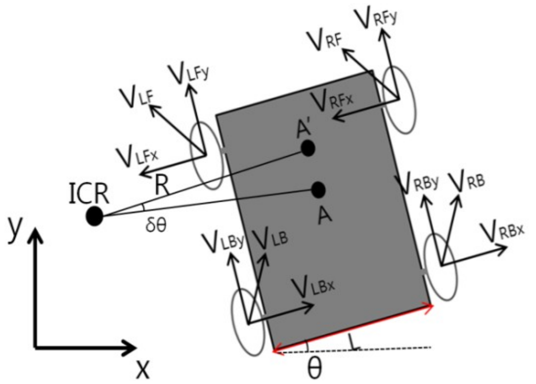

Fig. 3. The electromagnetic robot kinematic model

2.3 The structure of the electromagnet robot

The purpose of this study is based on electromagnet attachment system while using electromagnet making powerful tension on both sides of the center of the robot body to keep sustainable distance between robot and iron plate. Further, both sides of robot body have BLDC motors generating powerful torque to 2EA. The electromagnet

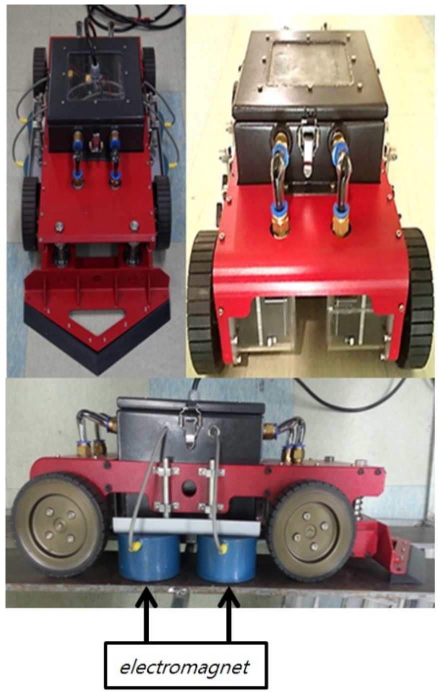

Fig. 4. The structure of the electromagnet robot

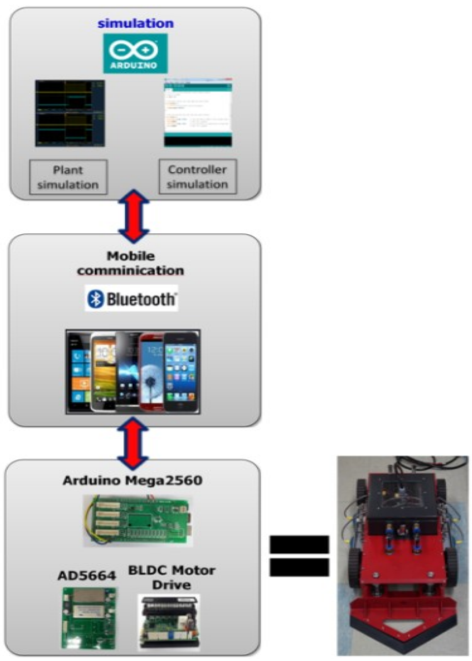

Fig. 5. The system components of the robot

robot is made of urethane wheel for improving frictional force and the body of the robot includes a controller and a motor driver. The weight of the robot is about 35Kg [17-19].

2.4 Entire system configuration.

The system configuration of the electromagnet robot follows Fig. 5 and external power is used to power motor and electromagnet. In addition, battery is used to power Micro Controller Unit for the control of the electromagnet robot. Bluetooth communication is used for the driving control of the robot to connect MCU and smart phone. And, the robot is controlled by the real-time serial data transmission of the smart application. Further, the robot equips the control device such as motor 4EA, motor drive 4EA and AD5664 chip for sophisticated robot motion [17-19].

3. I-PID Control Way

Reference [12-16] indicate I-PID control theory. The general system of the dynamic equation is a function of input $\mathrm{u(t)}$ and output $\mathrm{y(t)}$. And, a differential equation is as shown in formula (6) [12-16].

$$\mathrm{f}(y^{(m)}(t), y^{(m-1)}(t), \cdots \dot{y}(t), y(t), u^{(l)}(t), \cdots, \dot{u}(t), u(t)) = 0 \tag{6}$$

Formula (6) follows formula (7) [12-16].

$$y^{(n)}(t) = F(t) + \alpha u(t) \tag{7}$$

In formula (7), n is 1 or 2. And, α is decided by a designer. $\mathrm{F(t)}$ is $\mathrm{y(t), u(t)}$ and the higher order differential function of it. And, it is an unknown term including all of control object information. Further, as substituting random time input $\mathrm{u(t)}$ and measured value $y^{(n)}(t)$, you can calculate $\mathrm{F(t)}$. IF you calculate $\mathrm{F(t), u(t)}$ is as shown in formula (8), for sustainable input in closed loop control system. In particular, n=2 follows formula (7) [12-16].

$$\mathrm{u(t)} = \frac{1}{\alpha}(-F(t) + \ddot{y}^{*}(t) + K_{p}e(t) + K_{I}\int e(\tau)d\tau + K_{D}\dot{e}(t)) \tag{8}$$

$y^{*}(t)$ is an object signal that control object should follow formula (8) and following error is as shown in formula (9) [12-16].

$$\mathrm{e(t)} = y^{*}(t) - y(t) \tag{9}$$

K_P, K_I, K_D is a general PID controller gain. You can prove formula (10) if you substitute $\mathrm{F(t)}$ to formula (7) [12-16].

$$\alpha\mathrm{u(t)} = (-\ddot{y}(t) + \alpha u(t) + \ddot{y}^{*}(t) + K_{P}e(t) + K_{I}\int e(\tau)d\tau + K_{D}\dot{e}(t)) \tag{10}$$

Formula (11) indicates the error equation of the close-loop response [12-16].

$$\ddot{e}(t) + K_{P}e(t) + K_{D}\dot{e}(t) + K_{I}\int e(\tau)d\tau = 0 \tag{11}$$

The substitution of Laplace transform follows as formula (12) [12-16].

$$\mathrm{g(s)} = S^{3} + K_{D}S^{2} + K_{P}S + K_{I} \tag{12}$$

K_P, K_I, K_D is formulated by formula (12). $\mathrm{F(t)}$ in formula (8) is unknown quantity. So, formula (7) should be needed for this calculation. in this regard, $\mathrm{h(t)}(> 0)$ and $\mathrm{u(t-h)}$ are used for it as below formula (13) [12-16].

$$|F(t)| = \ddot{y}(t) - \alpha\mathrm{u(t-h)} \tag{13}$$

Estimated value $\mathrm{u(t-h)} \cong \mathrm{u(t)}$ is merely used for above calculation. While formula (13) substitutes formula (8), real controlling input follows formula (14). And, it is called I-PID controller [12-16].

$$\mathrm{u(t)} = \frac{1}{\alpha}(-\ddot{y}(t) + \alpha u(t-h) + \ddot{y}^{*}(t) + K_{P}e(t) + K_{I}\int e(\tau)d\tau + K_{D}\dot{e}(t)) \tag{14}$$

4. Driving Control Experiment

4.1 Experiment and simulation on electromagnet gap and attachment ability to electricity.

The electromagnet specifications of this paper follow Table 1. Changes in current from electromagnet 1EA gaps follow as shown in Fig. 6. These changes reduce the attachment ability and climbing ability of the robot. As a result, a strong controller is designed through I-PID control as above Fig. 7. The electromagnet in Fig. 7 is composed of R and L elements and R is 24 Ω, R=24Ω and L is 270mH, L=270mH and $K_P = 10, K_I = 50, \alpha = 1$. And, 1msec is used for delay time.

Changes in current are able to be identified by PID control and open loop system as shown in Fig. 8. The open loop system makes vibrations due to disturbance. The PID system reduces vibrations more than the open loop system. However, this experiment explores that the response speed of the PID system is slow more than the open loop system

Table 1. Electromagnet specifications

diameter*high	kilogram-force (kgf)	voltage (V)	current	weight (kg)
D100*60H	350	24	1A	2.2

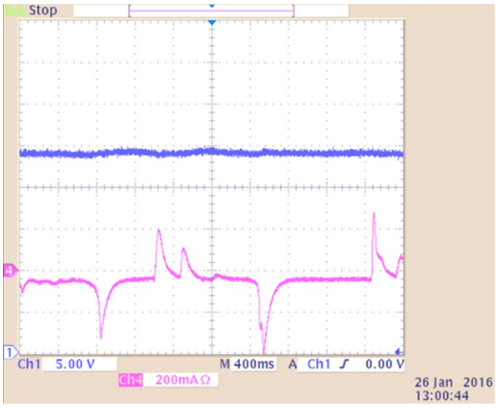

Fig. 6. Changes in current from electromagnet gaps

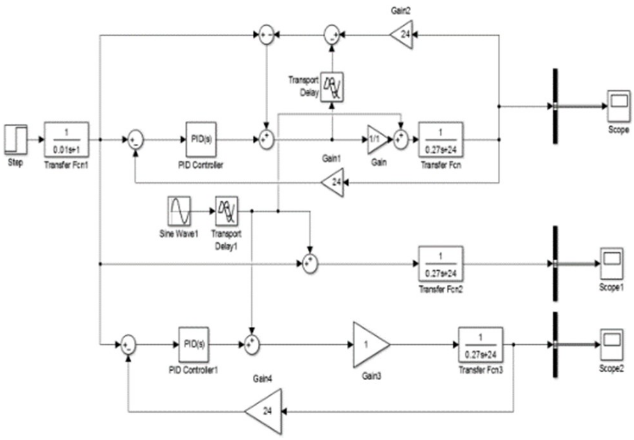

Fig. 7. I-PID control simulation block diagram

but, output on electromagnetic disturbance is stable as using I-PID control. This paper finds that response speed has been improved and the Gauss-measured value from electromagnetic gaps follows as shown in Fig. 9.

The result of experimental measured value is applied to the electromagnetic robot and a structure made of metal such as offshore plant iron plate is designed for the experiment and the plate thickness is 10mm. I inverted and made the robot stand up in order to identify its attachment

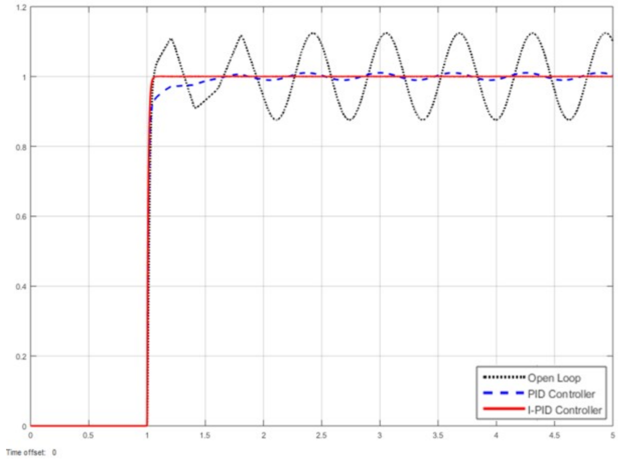

Fig. 8. Output characteristic

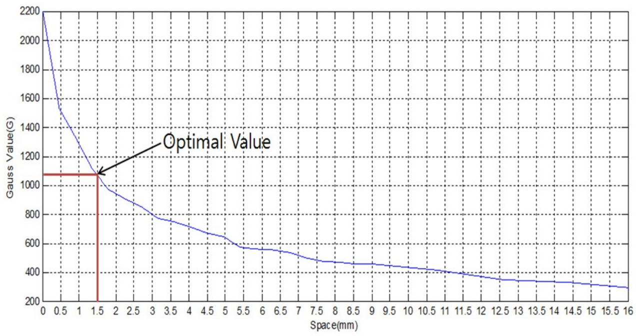

Fig. 9. Gauss value from different electromagnetic robot gaps

Fig. 10. Experimental plate made of iron

ability for the plate as shown in Figs. 11, 12 and 13. Fig. 11 indicates that BLDC motor load is the highest due to the robot weight and gravity.

Fig. 11. Robot in upright

Fig. 12. Robot in climbing the plate

Fig. 13. Robot in 180 rotation

If the robot would not generate suitable tension, it can be slipped and detached. In doing so, this experiment confirmed that the robot operated properly without falling. Also, it identified the stable distance between the robot, the plate and the fastest movement in the robot by the smallest friction between the robot and the plate. However, when the electromagnet is less than 1.5 mm, high tension is occurred and the electromagnet bracket of the robot is bent and adhered completely to the iron plate. The robot can make a straight-line motion on the iron plate if the robot keeps the gap, 1.5mm. Nevertheless, powerful tension makes friction too much and it does not enable the robot

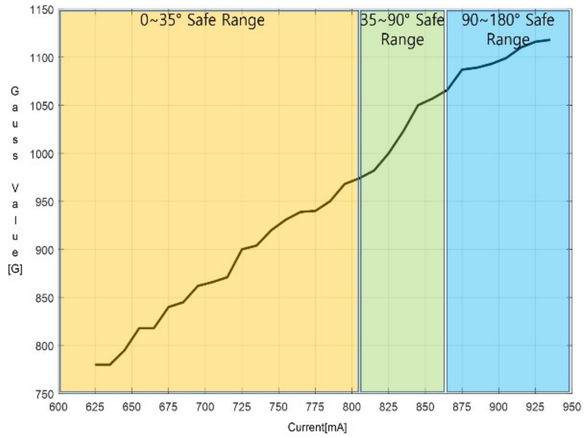

Fig. 14. Gauss value from the current changes with 1.5mm gap

Table 2. Gauss value from the current changes with 1.5mm gap

Safe range	mA	G	Safe range	mA	G
10~35°	625	780		785	950
	635	780		795	968
	645	795		805	974
	655	818	35~90°	815	982
	665	818		825	1000
	675	840		835	1023
	685	845		845	1050
	695	862		855	1057
	705	866		865	1066
	715	871	90~180°	875	1087
	725	900		885	1089
	735	904		895	1093
	745	920		905	1099
	755	931		915	1110
	765	939		925	1116
	775	940		935	1118

to naturally move itself. When we supply the current according to the angle to the robot by controlling the current of electric magnet, we can control the tension of electric magnet. For the smooth motion of the robot in this paper, the graph of the experimental results was obtained by controlling the current with 1.5mm gaps as shown in Fig. 14, Table 2.

The robot can perform rectilinear and rotational motion on iron plate of 10~35° slope in Fig. 14, 10~35° safe range(yellow area). However, the robot is easy to fall when it takes external shock on the big slope like side of the ship in this range. The robot can move rectilinear and right-left motion smoothly on iron plate of 35~90° slope in 35~90° safe range(green area). Even though the tension is strong on iron plate of 90~180° slope, it can switch direction softly in blue area 90~180° safe range(blue area). Further, above data helps to find a section where the robot to go straight ahead and make left and right direction without any drop.

5. Conclusion

The purpose of this paper focuses on I-PID application for the electromagnetic robot with a four-wheel drive which can climb up and down on an iron plate. As shown in Fig.14, the Gauss value and current measure of the electromagnet are directly proportional to each other. So, I-PID controller can control electromagnetic current in order to make the robot climb on the plate. Further, this study finds that the robot keeps the distance between it and the plate as using electromagnet. In this regard, BLDC motor is able to be maximized in its speed and minimized in its load — in particular, production costs are lower. Low friction late also helps the robot to make stable movement and workers can control it very easily — the robot does not any other device. The continuous study of the robot will replace worker's roll in cleaning vessel body with this robot.

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