The Fourteenth International Symposium on Artificial Life and Robotics 2009 (AROB 14th '09),
B-Con Plaza, Beppu, Oita, Japan, February 5 - 7, 2009

Yawing Control of a Single Wheel Robot

BuHwan Ahn , JongMyung Hwang , JuBum Son and JangMyung Lee

Dep. Of Electronics and Electrical Engineering
Pusan National University
Busan, Geumjeong Gu, 609-735, Republic of Korea.
(Tel : 82-51-510-1696; Fax : 82-51-514-1693)
(abssky@pusan.ac.kr, h_kafka@pusan.ac.kr, sonjb81@pusan.ac.kr, jmlee@pusan.ac.kr)

***Abstract*:** The yawing control of a single wheel robot has been proposed to control the rotation angle of the single wheel robot according to the motor torque and rotation velocity. Most researches on the single wheel robot so far focus on the balance control in roll and pitch directions. With this balance control, the robot can move forward and backward for hours and it can go to the desired position finally. However, the robot can not avoid obstacles while it is keeping the balance and moving forward and backward. To provide the obstacle avoidance capability, the left or right rotation control, that is, the yawing control is added to the single wheel robot. With this additional function, the single wheel robot can be used as an autonomous carrying device even though it is operating in an environment shared by people. In this research, the yaw direction control algorithm is developed with the single wheel robot simulator and applied for the real robot. The effectiveness of the yawing controller and control algorithm has been demonstrated through the real experiments.

***Keywords*:** unicycle robot, roll, pitch, yaw, position, balance, angle, rotation control

I. INTRODUCTION

Recently single wheel robots consisted of motor and controller are coming. This robot called the unicycle robot.

Yaw direction rotation controls means, while standing still or movement the obstacle appears on the front, or, robot converts direction of yaw axis for changes the angle θ of the body. Yawing controls are same meaning to yaw direction controls.

Until currently single wheel robots of existing research and development are has many with difficult in Yaw direction rotation controls.

In order to rotate a direction or evade an obstacle, unicycle robot engineer have to research on the method which yaw direction rotary control systems are a kinetic efficiency.

The key issue of this paper is to develop the optimum movement tracking routine without external force to take the rotation of the robot body.

The unicycle robot will be used later at the recreational area where service, dining etc., and medical treatment which assists the old person and disabled person. So the field of research is very high value of the unicycle robot.

II. Analysis of yawing rotation angle

2.1 Relationship of ω and α from Rolling motion

Angular velocity is rotated angle per unit time, and definition θ_1, θ_2 are initial angle and rotated angle, t_1 and t_2 are initial time and after rotated time.

$$\varpi = \frac{\theta_2 - \theta_1}{t_2 - t_1} = \frac{\Delta\theta}{\Delta t} \quad (1)$$

$$\omega = \lim_{\Delta t \to 0} \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt} \quad (2)$$

Angular acceleration defines to changing angular velocity per unit time and consisted of average angular acceleration $\bar{\alpha}$ with momentary angular acceleration α.

$$\bar{\alpha} = \frac{\omega_2 - \omega_1}{t_2 - t_1} = \frac{\Delta\omega}{\Delta t} \quad (3)$$

$$\alpha = \lim_{\Delta t \to 0} = \frac{\Delta\omega}{\Delta t} = \frac{d\omega}{dt} \quad (4)$$

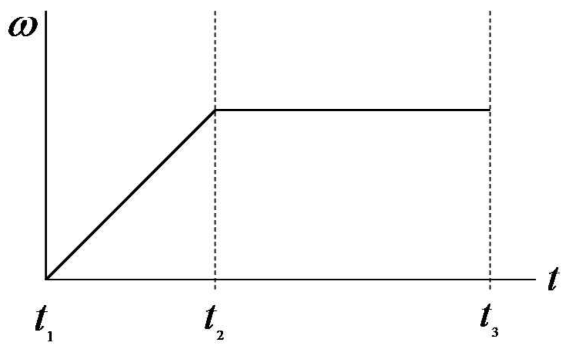
By (1) and (2), and (3) and (4), when rigid body (rotation disk) rotates, disk angular velocity and angular acceleration becomes same value from all points. In order to know α of the rigid body which it specifies, we must calculates ω.

The ω and the α refers from the paper are the momentary angular velocity and the momentary average angular average acceleration angular. But average terms are attached the word `average' which is before. The rotation torques from the disk's roll motion and standstill motion are vectors which has a size and a direction. Therefore, ω and α which consists torque are also vectors.

2.2 Principle of motion for yawing Disk

[Fig.1.] the yawing Disk which (affixed in DC motor)

The [Fig.1.] is the disk actual object features what is actually affixed in yaw direction rotary simulators.
When DC motors operates initially t_1 second, the disk accelerates to make specific speed at specific time during t_2 second time. And it arrive scheduled speed, the motor move uniform motion.
When the uniform motioning disk arrive programmed time t_3, the motor stop rolling motion and the electric power shut down.
That moment, the torque will occur in proportionately in with angular acceleration. Consequently robots frame rotate by the force F of the vector product propensity occurs. If there's no noise, it shows simply in speed graph of DC motors, like the [Fig. 2.].



[Fig. 2.] Speed quality graph of DC motors

The [Fig. 2.] appears from t_1 seconds until t_2 seconds to show a precipitous slope price and the motor accelerated motion. But from t_2 seconds until t_3 seconds motion shows without speed changes of DC motor.
In ideal state or free space, we know α and $\bar{\alpha}$ like the [Fig. 2.] almost the same. So, we have the rule of (5).

$$\bar{\alpha} \cong \alpha \tag{5}$$

Uses (5) constraint condition, dividing speed levels of 16 steps of DC motor. And we calculate the torque τ each 16 steps of speed changes.
The disks rotation time and stop time designed respectively in 10 seconds.

$$f = \frac{\omega}{2\pi} \tag{6}$$

$$\omega = 2\pi f \tag{7}$$

Therefore rotational frequency f is rotated frequency per unit time (usually, meaning rpm), it means one rotation same as 2π radian rotations. So, it defines with (6) and (7).
Consequently angular acceleration α and the torque τ are figuring out with (8) relationships.

$$\alpha \propto \tau \tag{8}$$

By using (8) equation, it will be able to derivation the equation (9) of rolling motion from Newton's 2nd law.

$$\tau = mR^2\alpha \tag{9}$$

The (9) shows that mR^2 is the inertia from rolling motion.

The (5) ~ (9) theories will be able to define about the rolling disk torques.

$$\tau = \left(\sum m_i R_i^2\right)\alpha \tag{10}$$

When deriving (10), we used a fact that angular accelerations are same to rotating in the fixed axis.

$$\sum m_i R_i^2 = m_1R_1^2 + m_2R_2^2 + m_3R_3^2 + \cdots + m_nR_n^2$$

From (10), it will be able to define (11) and I is the disk inertia moments.

$$I = \sum m_i R_i^2 \qquad (11)$$

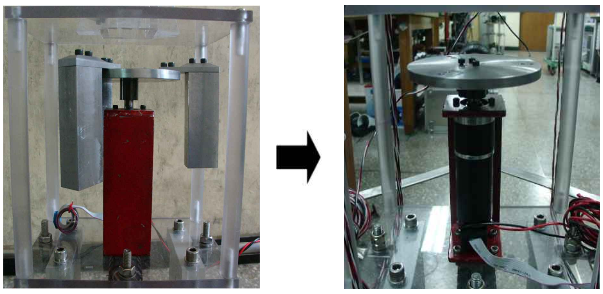
Unites with (10) and (11), defines (12).

$$\tau = I\alpha \qquad (12)$$

Similarly (9), as (12) that corresponds to the law of Newton's 2nd laws of movement can derive and can be used as the definition of torque τ.

III. Experiment

1. Yawing control techniques



[Fig. 3.] Yawing Disk of the changes

The [Fig. 3.] shows a disk initially form and a postscript form. The Maxon Motor attached the Yaw axis, features are changed because the maximum continuous torque specification is 181mNm, and the optimal load of the weight is 1.7Kg in uniform velocity system. Initially the disk weight is 3.5Kg, it was too weighty. After reduce weight, the disk weight is 1.4Kg. Right figure of the [Fig. 3] shows the disk for the optimum rotation torque.
After changing the load of the motor by 1.4Kg, experiment direction rotating of left and right. To get the rotation torque, repeat switching high-speed rotation and an instantaneous resting state of the disk.

The [Table. 1.] listed rotation angle of the robot body step by step for change yawing rotation motor RPM value. The 0x008f value is the maximum motor RPM character, so it is representative value.

PWM Value	Motor RPM (3 times measurement)	RPM average value	Rotation degrees	Note	PWM Value	Motor RPM (3 times measurement)	RPM average value	Rotation degrees	Note
0x000f	0	0	0°	No change	0x008f	1014.0, 1016.0, 1098.4	1042.8	13°	Max
0x001f	39.9, 38.1, 40.5	39.5	0°	〃	0x009f	991.8, 985.2, 985.1	987.4	11°	Fix
0x002f	110.7, 116.0, 119.2	115.3	0°	〃	0x00af	973.4, 962.0, 976.9	970.8	11°	〃
0x003f	233.9, 253.2, 227.9	238.3	0°	〃	0x00bf	978.3, 978.4, 980.8	979.2	10°	〃
0x004f	335.8, 339.1, 321.4	332.1	0°	〃	0x00cf	980.9, 983.0, 988.8	984.2	12°	〃
0x005f	539.2, 515.1, 511.4	521.9	3°	Start	0x00df	985.4, 974.9, 980.9	980.4	11°	〃
0x006f	690.8, 763.0, 669.2	707.6	5°	〃	0x00ef	994.5, 994.4, 990.2	993.0	12°	〃
0x007f	799.2, 806.8, 772.6	792.9	7°	〃	0x00ff	990.8, 987.7, 984.2	987.6	11°	〃

[Table.1.] List of Motor RPM and rotation degrees by yawing velocity control

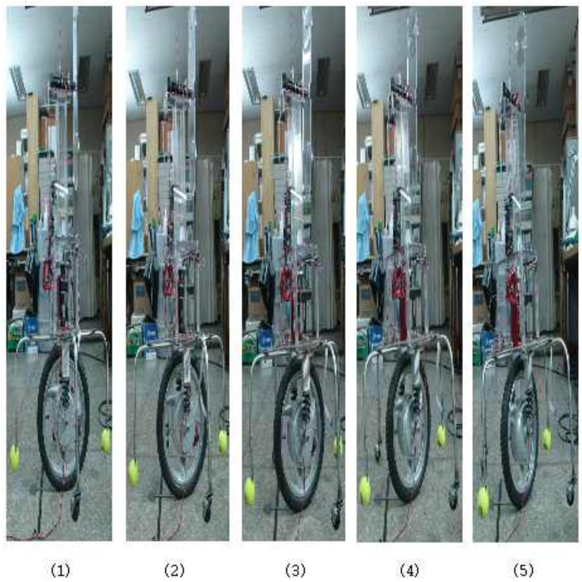
2. Yawing rotation experiment

The second experiment is to rotate unicycle body from the resting state where is not the mobile condition.

[Fig. 4.] change in the rotary angle in compliance with Yaw direction rotation wheel track movement

The [Fig. 4.] shows environment of yawing rotation experiments of unicycle robots. The left figure is not open space but rested environment. The middle figure shows 0 degree between unicycle robot and ground. This is reference point of rotation degrees. And the right figure shows after rotated degrees between unicycle robot and ground reference points.

The [Fig. 5.] shows the direction change scene of unicycle robot bodies in compliance with yawing rotation control experiment.



[Fig. 5.] Yawing rotation scenes of unicycle robots

The [Fig. 5.] shows yawing rotation scenes of unicycle robots from resting state. Yaw direction rotating motor repeat the high-speed rotation and an instantaneous resting state 5 times which change degrees. In [Fig. 5.], there are 5 pictures of unicycle body. Looking attentively, there is a black line besides robots single wheel, the rotary angle changes little by little and there is a fact that the direction is exchanged with the right side.

This rotation speed hex character of yawing motor is 0x008f whose rpm value is highest. As one rotation change robot body in 13 degrees right sides, totally 65 degrees right sides by 5 times continuous rotations.

IV. CONCLUSION

This research and experiment to control the rotation of the physically instable unicycle robot with appropriate degrees of rotation could get the desired direction of rotation.

The future directions of research is more smooth rotation of the yawing control, and more efficient rotation by acquiring the value of torque, consequently position control could be the more stable and the more robust.

V. ACKNOWLEDGEMENT

This work was supported by Korea Science and Engineering Foundation (KOSEF) Grant R01-2007-000-10171-0 funded by the Korean Government (MOST).

REFERENCES

[1] M. Iwase., "An Assistant System for Riding a Unicycle" International Journal of ARM VOL. 8, NO. 1, March 2007

[2] Yongsheng Ou., "Balance Control of a Single Wheel Robot",Conference on Intelligent Robots and Systems, October 2002

[3] Jinseok Kim., "The Posture Control of One-wheel Unicyle Robot Using Partial Feedback Linearization", Journal of the Korean Society for Precision Engineering, Vol. 24, No. 4, April 2007

[4] Sheng Z. and Yamafuji K., "Stability and Motion Control of a Unicycle (1st Report: Dynamics of a Human Unicycle and its Modeling by Link Mechanism)", JSME, International Journal, Series C, June, 1995