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Turning Motion Control of a Spherical Robot Based on a Gyroscopic Actuation: G-Sphere

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Abstract— **In this paper, a small spherical robot called G-Sphere is introduced. G-Sphere is equipped with a gimbal system that induces the gyroscopic force by one flywheel and two motors. G-sphere is designed to aim for navigate in its terrain by avoiding obstacles. Therefore, generation and control of various motions become essential in addition to maintain balance. A gyroscopic motion control method for the typical motion of turning 90 degrees is presented. The feasibility of turning motion control is evaluated by the experimental studies.**

I. INTRODUCTION

Navigation is one of the most important functions of mobile robot systems. There are three major methods for the mobility of the robot system to move one location to another such as wheels, legs, and spherical body. Mobility with wheels and legs is the major utility for the robot to navigate.

In other aspects, however, rolling mobility with spherical bodies is an interesting mechanism and its control becomes quite challenging.

The spherical robots can navigate with three degrees of freedom that can show a good maneuverability. Since all the hardware components such as electrical parts and sensor parts are sealing with the cover, the robot can be protected from the unexpected collision with the obstacle. Unlike wheeled or legged robots, spherical robots can navigate seamlessly under the harsh environments such as water.

For the purpose of the stable navigation of such a spherical rolling robot system, driving and steering mechanisms must be well defined and controlled. Various rolling mechanisms of the spherical robot have been presented based on different actuations such as wheel and steering axis structure, two-wheeled design, rotor momentum, pendulum motion, center of mass shift mechanism, and a deforming method [1]. The steering control of aforementioned robot systems requires complex and expensive structures.

Therefore, in this paper, G-sphere is presented as a novel mechanism aiming a simple and cost-effective system. G-sphere has one flywheel and two motors to induce the gyroscopic force. The rolling motion can be generated by means of the pendulum mechanism of the gimbal system inside the robot. For the navigation of the robot, steering control should be manipulated. To test the feasibility of steering control of the robot, 90 degrees turning motion is implemented by regulating the gyroscopically induced torque. Experimental studies are provided to confirm the proposal.

II. MECHANISM

A. G-Sphere

G-Sphere is designed and implemented as a non-holonomic and under-actuated system as shown in Fig. 1. One flywheel can rotate with a flywheel motor. The direction of the angular momentum can be controlled by a gimbal motor. The attitude of the flywheel can be observed by an ARS(Attitude Reference System) sensor system. The robot can be controlled with the PC.

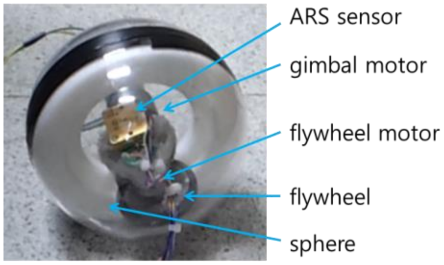

Figure 1. G-Sphere robot.

B. Driving Mechanism

As a driving mechanism for the robot, a rotating pendulum or a non-rotating flywheel can be used. Manipulation of the rotating flywheel is more difficult than the non-rotating one although it shows more power efficiency. By controlling the swing motion of the flywheel, forward and backward motions can be generated.

C. Turning Mechanism

The high rotating flywheel produces an angular momentum and the momentum is controlled by the gimbal motor of the robot to induce the gyroscopic torque as follow

$$\boldsymbol{\tau} = \mathbf{H} \times \boldsymbol{\Omega} \tag{1}$$

where, $\boldsymbol{\tau}(\mathrm{Nm})$ is the gyroscopically induced torque, $\mathbf{H}(\mathrm{Nms}\ /\ \mathrm{rad})$ is the angular momentum of high rotating flywheel, and $\boldsymbol{\Omega}(\mathrm{rad}\ /\ \mathrm{s})$ is the tilt rate of the gimbal.

Turning motion of the robot is the yawing motion of the robot in the coordinate system. When the tilt angle of the flywheel is nearby 90 degrees, the gyroscopically induced

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torque can be a yaw-dominant state. When the flywheel is placed nearby the zero degrees, the turning effect of gyro is difficult to expect.

Therefore, the fast motion in the yaw direction must be generated when the tilt of the flywheel is changing direction nearby 90 degrees as shown in Fig. 2.

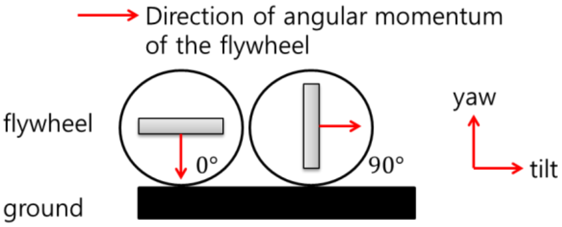


Figure 2. Direction of the flywheel.

The motion plan for the turning motion is designed as follow.

Step 1. Move the flywheel nearby the 90 degrees.

Step 2. Turn the direction of the flywheel.

III. EXPERIMENT

The experimental setup is shown in Fig. 3. The overall control for the proposed method is done through a RS232 communication port. The power for the robot is supplied by the outer power unit. In the PC, MATLAB software is used to run a test program.

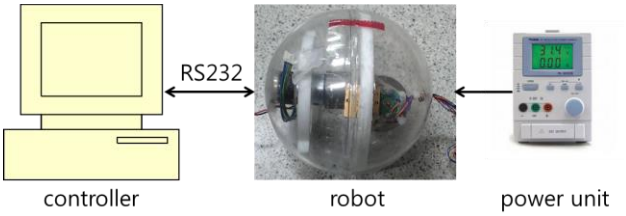


Figure 3. Experimental setup.

Initially, by nature, the designed robot has about 25 degrees tilt angle of the flywheel. Steps for the turning motion are listed in Table 1 and implemented in the controller.

TABLE I. TILT MOTION PLAN

Time(sec)	Motion of the tilt
0	Initial condition: about 25degrees
0.2	Goes to the 90degrees
0.6	Goes to the -45degrees

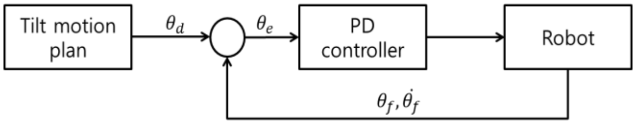


Figure 4. Control block diagram.

As a control scheme for the Table 1, PD-controller is used as Fig. 4. Experimental images are shown in Fig. 5.The robot successfully turned 90 degrees.

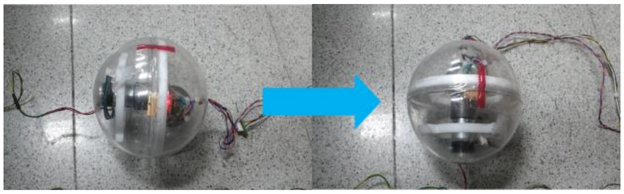
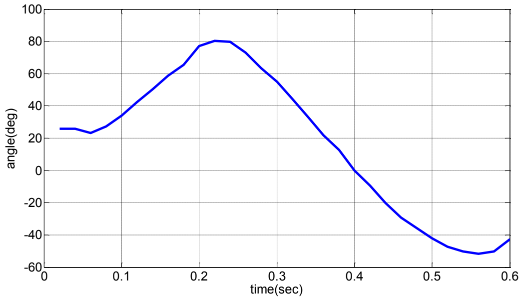
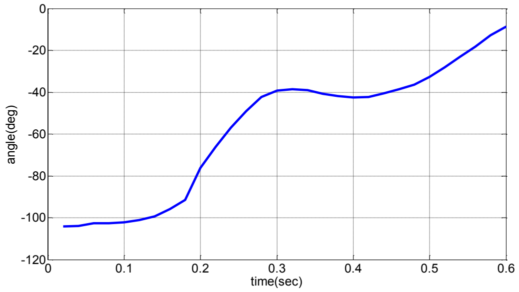


Figure 5. Performance verificaiton.

The corresponding plots are shown in Fig. 6. When the tilt motion is given as Fig. 6 (a), the turning motion of Fig. 6 (b) is successfully generated. From zero seconds to 0.2 seconds, the flywheel goes up to the 90 degrees.



(a) Tilt input.



(b) Yaw output.

Figure 6. Input and output of the system

IV. CONCLUSION

G-sphere has been designed and implemented. The turning motion of the spherical rolling robot is generated by controlling the gyroscopic force. Experimental studies confirmed that the proposed method made the robot turns 90 degrees.

REFERENCES

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