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Synchronization of Two Flywheels for Stable Balancing Control of One-wheel Transportation Vehicle : Gyrocycle

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Abstract : This paper presents the simple method for synchronizing the motion of two flywheels located in a one-wheel transportation vehicle called Gyrocycle. The vehicle balances itself by the gyro effect induced by two flywheels inside the Gyrocycle. Asymmetry between two flywheels reduces gyro effect and causes the unstable balancing performance at last. In this paper, a simple method is proposed to synchronize the motion of two flywheels. Experimental studies are conducted to confirm the proposed synchronization method.

Keywords : one-wheel mobile robot, gyro effect, synchronization, two flywheels, gyrocycle

1. Introduction

The main purpose of mobile robots is aimed to navigate for surveillance in the field and to deliver objects in the office building. The majority of mobile robot research is about localization and mapping for autonomous navigation tasks.

The other aspect of mobile robot research is to use them as transportation vehicles like electric automobiles. Passengers can ride mobile robots to commute short distance in the urban area. One of successful transportation vehicles is Segway which is based on the balancing mechanism with two wheels [1].

Many researches on two-wheel mobile robots have been presented [2-5]. From the small size to the large size, two-wheel mobile robots have been presented with various control methods. A two-wheel transportation vehicle of which driver can sit and drive is implemented [5].

Currently, two-wheel mobile robots are transformed to a single-wheel mobile robot. Research on a single-wheel robot has been pioneered by Y. S. Xu for a long time [6]. Fruitful research outcomes about a single-wheel mobile robot, Gyrover have been summarized as a book [6]. Other research activities on a single-wheel mobile robot can also be found in the literature, but they are not many [7-11].

Most of researches on single-wheel mobile robots are about controlling the balancing angle and navigating on the plane. Since the integration of hardware inside the wheel is not easy, the main goal of a single-wheel mobile robot is the implementation for the successful balancing performance.

In our previous research on a single-wheel mobile robot, several models have been developed. A history of implementing Gyrobo has been presented in the paper [9]. A neural network control technique is applied to control the balancing angle as well as trajectory tracking tasks [10]. One of difficulties of implementing a single-wheel robot is the mechanical design to have a symmetrical structure in the body and to generate enough gyro-effect to raise the whole system up. Another difficulty is to obtain an accurate balancing angle from the available sensors.

In the control point of views, a difficulty comes when the tilted angle of the flywheel keeps increasing in one direction to generate gyro-effect to maintain balance. This behavior causes instability of the system since the flywheel cannot tilt 360 degrees. To solve this problem, the gain scheduling method with different gains selected for several ranges of balancing angles is applied [11].

In this paper, the same control concept of a single-wheel mobile robot is applied to a larger sized single-wheel mobile robot to carry a person. Since Gyrocycle is designed to carry a human operator, it has different design specifications. One typical design is that Gyrocycle has two flywheels to generate more gyro-effect to maintain the balance as shown in Fig. 1.

We have observed the unstable balancing performance after a certain period of time due to the unsynchronized motion of two flywheels [11]. Two flywheels are supposed to behave in a synchronized way, but they have unsynchronized motion after a while. This behavior occurs due to the asymmetry between two flywheels.

In this paper, a simple method is proposed to make the motion of two flywheels synchronized. Instead of synchronizing mechanically, compensation for the unsynchronized motion is done by software programming.

Fig. 1 Gyrocycle

2. Gain Scheduling Control Schemes

One of important control specification for the stable balancing performance of Gyrocycle is to regulate the angle of the flywheel, θ. The system goes unstable as the flywheel keeps leaning in one direction trying to make the system balance. This behavior can be prevented by making the flywheel converge to zero through the gain scheduling method for different ranges of balancing angles [11].

The ultimate goal of the Gyrocycle is to make the lean angle of the system, β be zero. Not only the PD control method but a compensating term, β_e from a gain scheduling method is used together to solve this problem.

Therefore, the lean angle error becomes

$$e_\beta = \beta_e + \beta_d - \beta \qquad (1)$$
$$\dot{e}_\beta = \dot{\beta}_d - \dot{\beta}$$

where β_d is the desired lean angle and β_e is the compensation factor obtained from the gain scheduling table.

Then the PD control method can be formed to generate tilt torques for the right and left flywheels. Synchronizing factors can be multiplied to make two flywheels behave synchronously. Tilt torques of the flywheels become

$$\tau_L = K_L(k_{LP}e_\beta + k_{LD}\dot{e}_\beta) \qquad (2)$$
$$\tau_R = K_R(k_{RP}e_\beta + k_{RD}\dot{e}_\beta)$$

where τ_L is the tilt torque for the left flywheel , τ_R is the tilt torque for the right flywheel, $k_{LP}, k_{RP}, k_{LD}, k_{RD}$ are PD controller gains. K_L and K_R are synchronizing factors of left and right wheels respectively. Those synchronizing values are obtained from the difference of two tilt angles, $e_\theta = \theta_R - \theta_L$ and selected differently with respect to the value of e_θ. The idea is to bind the angle difference, e_θ from deviating from each other. Fig. 2 shows the synchronizing control block diagram.

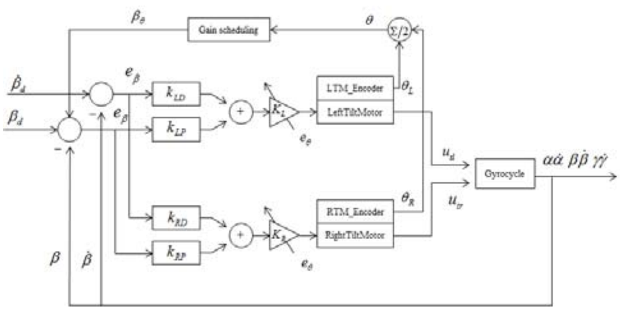

Fig. 2 Control block diagram

The synchronizing factors are found empirically and listed in the Table 1. There are four cases depending upon the difference angle between two flywheels and the direction of movements. The critical angle value is set to 8 degrees. The direction is determined by the sign of applied torque signals.

Table 1. Synchronizing factors

Gimbal / Conditions	K_L (Left)	K_R (Right)
e_θ >8 degrees, τ >0	1.2	1
e_θ >8 degrees, τ <0	0.8	1.2
e_θ <8 degrees, τ >0	0.8	1.2
e_θ <8 degrees, τ <0	1.2	1

3. Gyrocycle System

The structure of Gyrocycle is described in Fig. 3. Gyrocycle consists of three parts: a main wheel, flywheels, and a body. Hardware including a controller and sensors are located on the top of the system. The flywheel is located inside of the main wheel. The batteries are located at both steps to make the body symmetrical. One of important design is how to suppress vibration caused from the flywheels. The vibration causes the ill sensing results and this affects the balancing control performance of Gyrocycle.

There are three motors for Gyrocycle. The flywheel motor keeps the flywheel rotating. The tilt motor controls the angle of the flywheel system, which is the only control input to the system. Finally, the drive motor is required to move the system forward. The flywheel rotation and the tilting motion induce the gyroscopic effect. The main control hardware is DSP and the sampling time of the controller is 100Hz. The speed of the flywheel is set to 5,400 rpm.

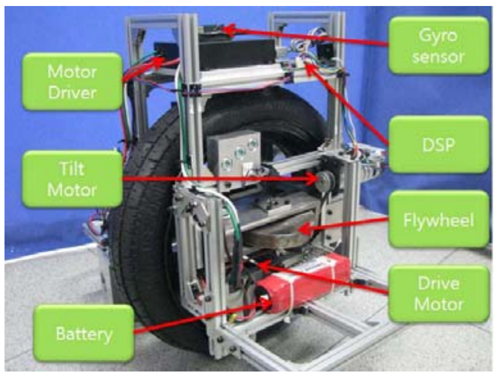

Fig. 3 Gyrocycle structure

4. Experimental Results

Experimental studies of the balancing control performance are demonstrated as shown in Fig. 4 and the corresponding plots are shown in Figs. 5-7. We see from Fig. 4 that Gyrocycle maintains balance well as time goes. Gyrocycle does not fall down until power is shut down.

However, the heading angle of Gyrocycle of the last figure of Fig. 4 is a little bit tilted as compared with the first figure. This is because of the dynamical movement trying to stay upright position by the flywheels during the balancing control performance. Gyrocycle tries to make balance by moving the whole body in roll direction through tilting the flywheels. This causes vibration to the system.

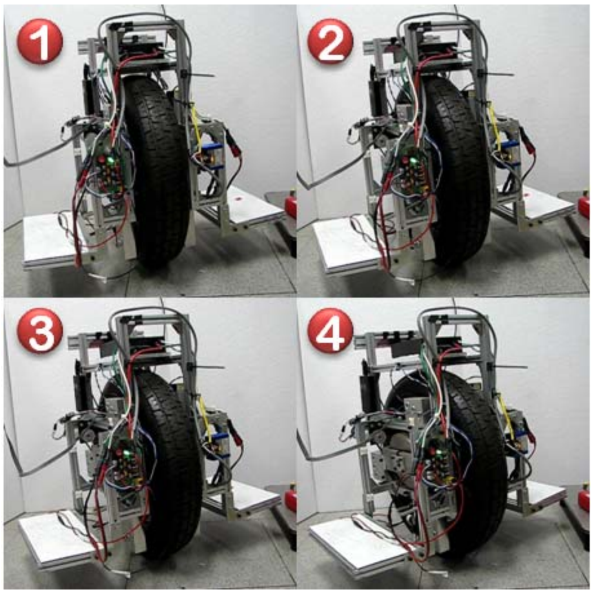

Fig. 4 Balancing performance of Gyrocycle

Fig. 5 shows the lean angle of Gyrocycle. We clearly see that the angle is well maintained within the error of 0.01 radian. The angles of flywheels are also plotted in Fig. 6 and 7. Both angles are converged to the same angle direction which indicates that both flywheels are synchronized. The difference between the left and the right flywheel angles calculated from Fig. 6 and 7 is about 2 degrees, which is all right since we set the critical angle value to 8 degrees as in Table 1. The threshold degree of 8 degrees is found empirically.

Without the synchronization control, Gyrocycle falls down after balancing for a while. This is because two flywheels rotate in same direction at the beginning and eventually opposite direction such that the gyroscopic effects are cancelled each other inducing zero effect. A simple synchronization control method solves this problem.

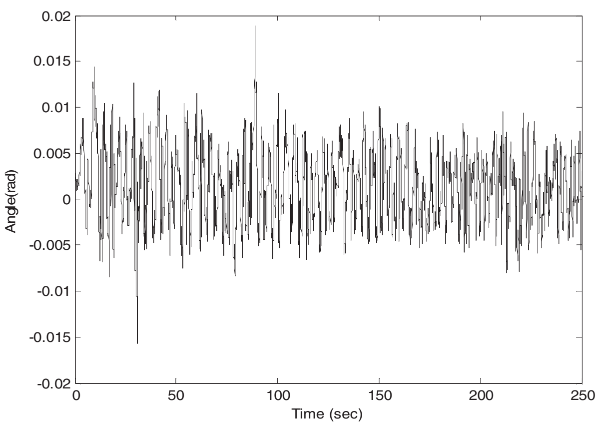

Fig. 5 Lean angle of Gyrocycle

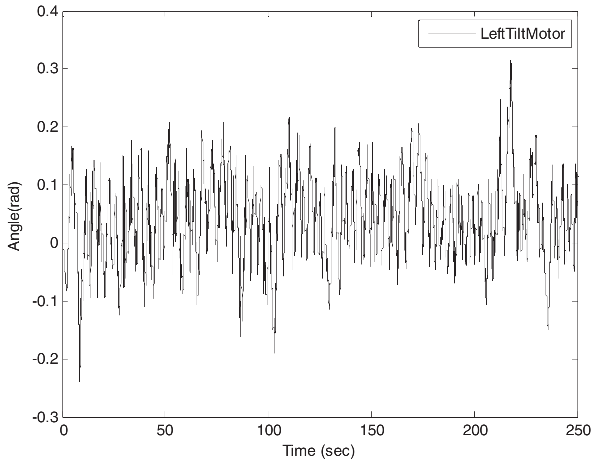

Fig. 6 Angle of the left flywheel

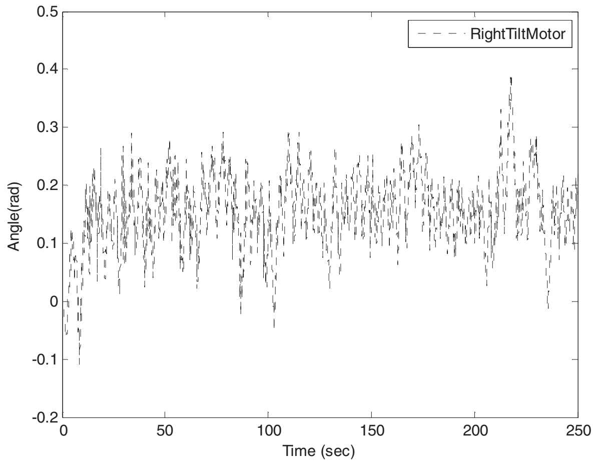

Fig. 7 Angle of the right flywheel

5. Conclusion

In this paper, a simple synchronization technique is applied to a single-wheel personal vehicle, Gyrocycle. The problem of the unsynchronized motion between two flywheels has been solved by the simple synchronization technique for two flywheels. A simple gain tuning for tilt torques of flywheels solves the problem although values are empirically found. As a result, Gyrocycle maintains balance as long as power is on.

However, there are many things to be done. Not only balancing control but also driving control of Gyrocycle should be performed. Therefore, a future research topic is to control both balancing and navigation of Gyrocycle on the plane.

Acknowledgements

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