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The Transmission Design of a Human Powered SAGWAY

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Abstract

In this study, a double-wheel self balanced unicycle is proposed. Because of the shortage of energy resource and parking space in city, the idea of this light-weight electrical aid personal unicycle can hopefully be used in future transportation system. The unicycle has the features of small longitudinal length, with two coaxial wheels and pedal by human with electric control system to balance the unicycle. It is known that when the rider rides the unicycle, the paddle force disturbs the balance of the vehicle. This unbalance force comes from the gravity center is not at the point of the ground contact points of the vehicle. To balance the unbalance force, two servo-motors to drive the two wheels are used. The unbalance condition is detected by sensors. A transmission mechanism to combine human power and electric power is designed. Planetary gear set is considerable to be the basic concept of transmission mechanism design. The sequence of study processes would be helpful to design the layout of the transmission about chassis, bike frame, and wheels. The mechanism design could link up the mechanical system with the motors and electro-control system.

Keywords— SEGWAY, Human powered, Transmission design

1 Introduction

SEGWAY[1] is a very interesting unicycle. Since it starts to sell on the market, there were several unicycles had been invented (such as I-Boot [2], Toyota's Winglet) and manufactured. In addition to product invention, there were several papers had been published such as Baloh and Parent [3] and Lee, Kim, Kim 及 Kwak[4]. The power of SEGWAY is from electricity, therefore, the motor of the SEGWAY and the energy storage capacity of the batteries should be large enough to make the SAGWAY can have long driving distance. The larger motor and larger capacity of the battery is, the heavier the weight of the SAGWAY. It is noted that the weight increase due to the motor and battery is an important factor to reduce the range of the cruising distance of SAGWAY. In order to reduce the weight and increasing the cruising range of the SAGWAY, in this study, a human powered SAGWAY is developed. The

basic concept of the human powered SAGWAY is a hybrid electric bicycle, which combines the human power and electric power together. The electric power is used as the balance force to stabilize the pay load of the unicycle at upright position. The pedal force from human is the main force to move the bicycle around. Like SEGWAY, there are several gyros to detect the posture of the unicycle and the unicycle is balanced by servo motor. The overall figure of the new designed unicycle is shown in Fig. 1[5].

As shown in Fig. 1, the unicycle is composed of a pedal, handle bar, a transmission, two servo motors, one small support wheel and two parallel driving wheels. It is noted that the force comes from servo motor not only to keep the rider at upright position but also need to help the rider climbing up the hill.

Therefore the power of the servo motor has to be combined with the human power from pedal. It is also noted that the human pedal force is a unstable force due to the motion of the rider's body. Therefore, How to combine two kind forces together is a very important task.

In this study, the concept of the human power SYGWAY is also introduced. To drive the unicycle, a transmission system is designed. It is find that the human powered SYGWAY is a very interesting way to design a human power bicycle.

Figure 1: Design of Human powered SAGWAY[5]

2 Configuration of the system

As shown in Fig. 1, the unicycle is composed of a pedal, a handle bar, a transmission, two servo motors, one small support wheel and two parallel driving wheels. To move the vehicle forward, the rider only needed to pedal the pedal of the vehicle. To turn the unicycle, the rider can turn the handle bar, an encoder in the handle bar is used to detect the turning angle of the handle bar and send the signal to the controller of the transmission system. The controller received the signal and following the signal to make the speed of left wheel and right wheel in different speed to turn the unicycle. The posture of the unicycle is detected by position sensor and angular encoder. The small front wheel does not contact with the ground in regular using condition. However, when in all man power driving mode, the unicycle is same as a tricycle.

As discussed in above section, a transmission should be designed (the configuration of the transmission is shown in Fig.2) to control the servo motors to do the job as wished. The mechtronic configuration of the power system of this study is shown in Fig. 3. In Fig. 3, the controller is the brain of the system. The transmission is one of the important mechanical parts to combine the powers comes from both human and servo motors. The human pedal force is input to the transmission system from the pedal (the configuration of the pedal system is same as the system used in a bicycle) as shown in Fig. 3. This pedal force is combined with the forces from left motor and right motor than transfer to the left and right wheels of the unicycle. It is noted that there is an unbalance force comes from the backward or forward motion of the unicycle. The posture of the unicycle has to be adjusted by the motion of two wheels which driven by two servo-motors. It is noted that the balance torque of keeping the rider at the upright position is a variable torque. Therefore, to balance the torques from motors are always varied. As shown in Fig. 3, when all the position sensors (acceleration, angular encoder and Gyroscope etc.) detecting the motion of the unicycle, the controller control the left and right motors to drive the left and right wheels to keep the unicycle in balance position.

In addition to mixing the man power and the electrical power, it is also very important not to transmit the forces come from the motor to enter the pedal system to make the rider feel uncomfortable at the time the man stop to

paddling. An isolation of pedal and motor is needed to be designed.

3 Configuration of Transmission

There are three driving modes of present design: (1) Mixing the man power and electric power mode, (2) All electric power mode, (3) All man power mode. In all man power mode, the small wheel of the front(as shown in Fig.1) will contact the ground to make the system as a tricycle. The layout of the transmission of the unicycle is shown in Fig. 4.

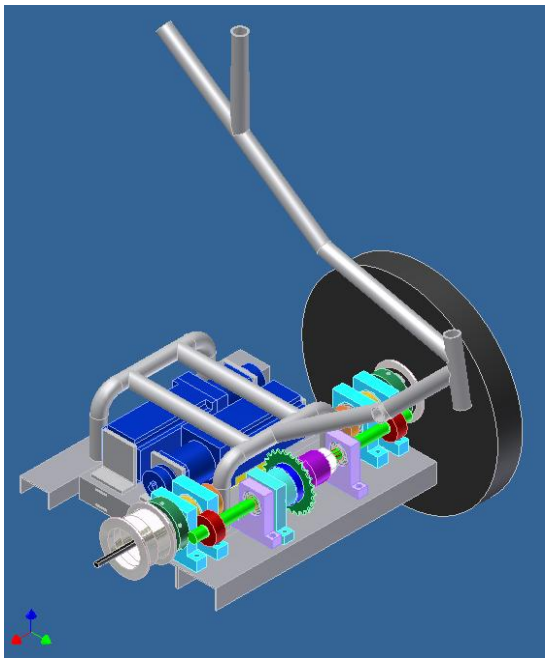

Figure 2: Configuration of transmission

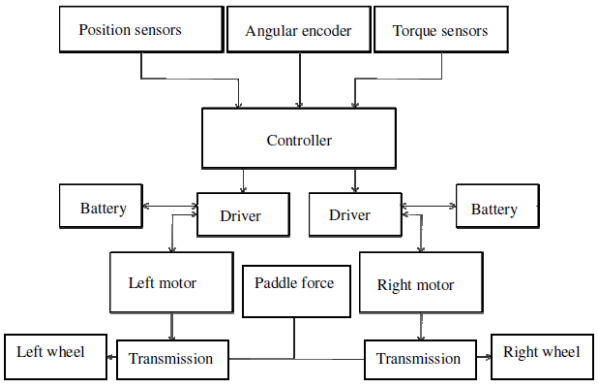

Figure 3: The block diagram of the power system

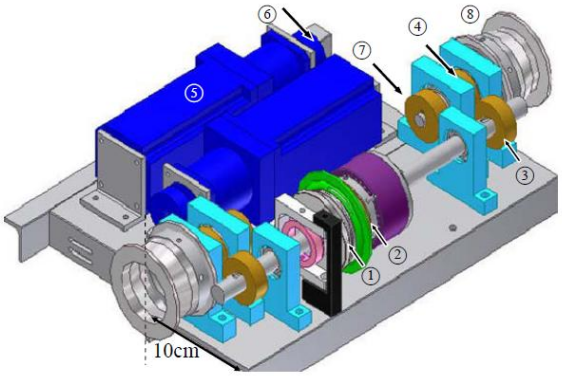

Figure 4: Lay out of the transmission

There are two kinds of force flow.:(1) Pedale force comes from human's legs, (2) Electric forces from two servo-motors. The pedale torque transfers from padle through front sprocket to the rear sprocket ① of the roller chain and through the clutch② to the sprocket ③ of the timing belt. By using the timing belt, the sprocket ④ is driven by the sprocket ③ and passed the torque to the planet gears of the planetary gear train ⑧. The torque of the right servo motor ⑤ output the torque to the sprocket ⑥. Then the torque goes to the sprocket ⑦ and the sprocket ⑦ is connected to sun gear of the planetary gear train ⑧. It is noted that the left wheel has similar force transmission path as right wheel, except the torque of electric motor comes from right motor (in front of motor ⑤ as shown in Fig. 4). The pedal force and electric power is combined by the planetary gear train.

To prevent the torque of servo motor feed back to pedal to make the rider feels uncomfortable, the clutch② is used. The use of the clutch is not only to isolate the motor torque from pedal, but also to translate the torque to wheels to balance the unicycle. Therefore, when applying the clutch, the clutch releases the contact with the sprocket ① and fixes the shaft which connected with clutch.

4 Selection of planetary gear train

The planatary gear train can be designed by using a simple equation. It is costly to manufacture our own gear train. The comercial planetary gear train is slelected to fit our use. Before selection, the requirement of the gear train must be set up. Due to there are a lot of degree of freedoms to select as

shown in Fig. 4. The force flow of pedal force to wheels, which is from ①,②,③,④,⑧ than to wheel. The torque of the right servo motor is from ⑤ to ⑥. Therefore, there are three places can be used to change the speed ratio for pedal force. One is from pedal system, the secons is from ③ to ④ and the third is planetary gear train. Therefore, the planetary gear train is the first part to be determined. Sunrace X-RF8 internal hub with 8 speed reduction ratios is choosed due to it is the only gear train with wide gear ratio we can find in the market. The photo of the internal hub is shown in Fig. 5. This internal hub composed of three planetary gear train to compose it's 8 speed. In this study, only one speed is enough to control the system. We fixed the gear ratio by weld the gear ratio control bar to a fix the gear ratio.

These three planary gear trains are combined to get higher gear ratio than single one. However, these three gear trains can be presented as a simple gear train by some equivalent parameters. The gear ratio of the internal hub can be written as:

$$\omega_0 = \omega_r R_r - \omega_s R_s \quad (1)$$

In above equation, ω_0 is the rotation speed of rim (it is the wheel in this study). ω_r is the arm velocity (Man power input speed), R_r is the equivalent radius of arm, ω_s is the sun gear velocity (servo motor input speed), R_s is the equivalent radius of sun gear. To selected the gear ratio to make the reduction ratio of motor input to wheel is smallist, the equivalent radius of arm is 1.3 and equivalent radius of sun gear is 0.3. The Eq. (1) can be written as:

$$\omega_0 = 1.3\omega_r - 0.3\omega_s \quad (2)$$

Above equation is the speed relation between the wheel, pedal input and servo motor input.

Figure 5: Photo of Sun Raise XRF8

5 Determine the gear ratio of the timing belt and the chain sprocket

As explained in section 3, the pedale torque transfers from padle through front sprocket to the rear sprocket ① and through the clutch ② to the sprocket ③ of the timing belt. By using the timing belt, the sprocket ④ is driven and passed the torque to the planet gears of the planetary gear train ⑧. Therefore, there are three reduction ratios in this force flow line. There are three reduction stages; one is the front sprocket to rear sprocket by chain (reduction ratio is R_1). The second is the timing belt (reduction ratio is R_2) and the third is the internal hub (reduction ratio is R_3). As discuss before, the reduction ratio of the internal hub is determined by the selection of the commercial product (reduction ratio is R_r). The total reduction ratio is multiples of those three reduction ratio.

It was found by previous research, the comfortable paddling speed is below 80 rpm, and 60rpm is the best choice. In this study, the wheel diameter is 18 in.; the pedal speed is 60 rpm. If the speed of the vehicle is required as 20km/hr, than the reduction ration of R_1R_2 should be around 3. It is easily to select a chain transmission from any commercial catalog of the bicycle transmission system.

As shown in Eq. 2, the reduction ratio for motor driving the wheels to balance the unbalance force and to keep the rider in upright position is 0.3. To select the servo motor to fit the requirement of balancing the gravity center movement, the gravity movement of the vehicle when pedaling is masured. The suitable motors are selected to balance the gravity center movement.

Figure 6: The prototype of the Man powered SEGWAY

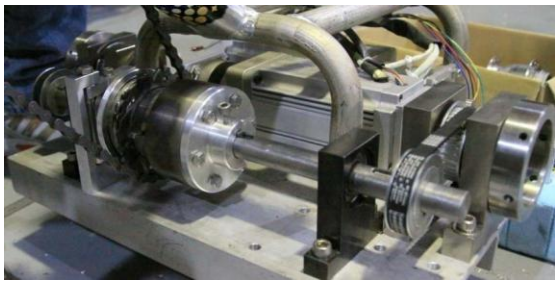

Figure 7: The View of the transmission system

6 Set up of the prototype

The prototype of the vehicle is shown in Fig. 6. The front wheel of the vehicle is not contact with the ground when the servo motors start to activate to balance the rider at upright position. Under this condition, the gravity center is right above the wheel axis. Fig. 7 is the enlarged view of the transmission system.

7 Conclusion

In this study, a man powered SAGWAY is proposed. To design a low cost transmission system for that kind of unicycle, two internal 8 speed wide ratio hubs are used to mix the man power and electric power. The pedal force is the only force to drive the vehicle, the torques from servo motor are used to balance the gravity force to keep the rider at upright position and turning the vehicle. In addition to the hub to change the speed ratio between the pedal and wheels, there are still two stages can be used to reduce the speed more. After finishing the design of the transmission system, the system is made. The test of purely man power pedaling is good.

Acknologments

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References

[1] http://www.segway.com/

[2] http://www.ibotnow.com/

[3] Michael Baloh and Michael Parent, *Modeling and Model Verification of an Intelligent Self-Balancing Two-Wheeled Vehicle for an Autonomous Urban Transportation System*, The Conference on Computational Intelligence, Robotics, and Autonomous Systems, Dec. 2003, 380-450

[4] D. Y. Lee, Y. H. Kim, B. S. Kim, Y. K. Kwak, *Dynamics and Control of Non-holonomic Two Wheeled Inverted Pendulum Robot,* the Eighth Int. Symp. on Artificial Life and Robotics (AROB8th, '03), January 2003, 415-418,

[5] Dein Shaw, Y.S. Deng, etc, "Green City-Design of Personal and public transportation and their relationship', NSC report, 2009

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