Appendix_1 : Model of Self-balancing two-wheel vehicle

1. Mechanical part

Working principle of self-balancing two-wheel vehicles using flywheel: The self-balancing two-wheel vehicle will be equipped with a flywheel and a DC motor that creates torque for the flywheel. When the vehicle is tilted off-balance, the vehicle's torque moment tends to pull the vehicle down. At that time, the engine will turn the flywheel, creating a corresponding torque acting on the car in the opposite direction of the vehicle's inclination (against the torque moment). Therefore, the two-wheel vehicle is pulled back to a balanced position.

The wheel part of the bike uses children's bicycle wheels. The chassis is constructed of aluminum. The front wheel of the two-wheel vehicle is fixed, so the two-wheel vehicle can only go straight. Accordingly, we only focus on the problem of controlling vehicle balance when the vehicle is moving straight, and when the vehicle is affected by external forces.

The size of the vehicle is shown in Fig. 1 as follows:

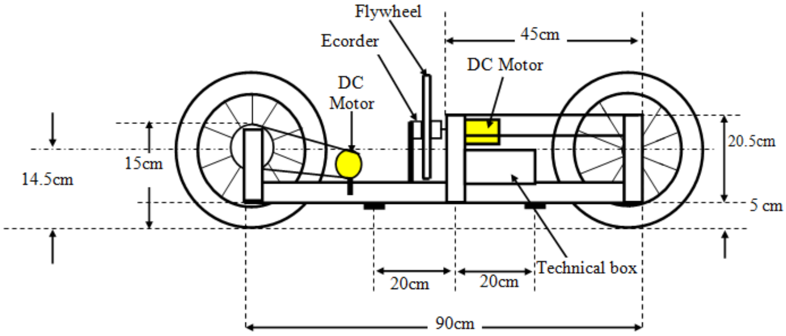


Figure 1: Size of the self-balancing two-wheel vehicle

a. Balancing mechanism

The balancing mechanism consists of a DC motor that creates a torque for the system and a flywheel with large inertial torque. The motor transmits torque through the flywheel via a coupling, with a gear ratio a = 1. The motor is rigidly mounted to the frame of a two-wheel vehicle through a screw system.

Size of flywheel:

- Outside diameter $D_n = 0,26\ m$
- Inside diameter $D_t = 0,22\ m$;
- The thickness of the flywheel rim: $t_n = 0,021\ m$;
- The thickness of the inner rim of the flywheel: $t_n = 0,005\ m$

The actual shape of the flywheel is shown in Fig. 2 as follows:

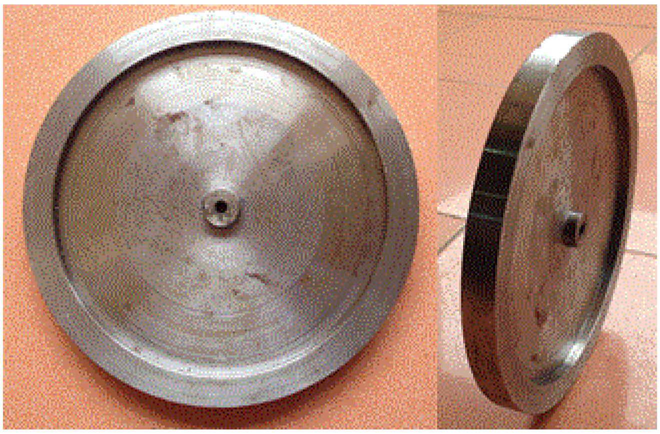


Figure 2. The actual shape of the flywheel

Choice of DC dc motor: The shape of a direct current electric motor is shown in Fig. 3 as follows:

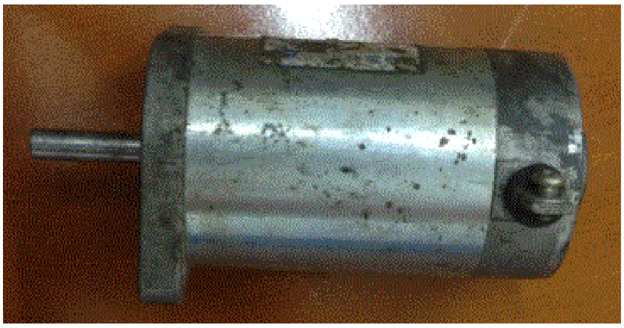


Figure 3. DC motor

DC motors have the following parameters: 100w-15v-3400 rev/min

b. Backward and forward movement control system

The system uses a DC motor. This motor pulls the vehicle back and forth through the chain drive system with a gear ratio of 1: 1. The control system forwards and backward is shown in Fig. 4 as follows:

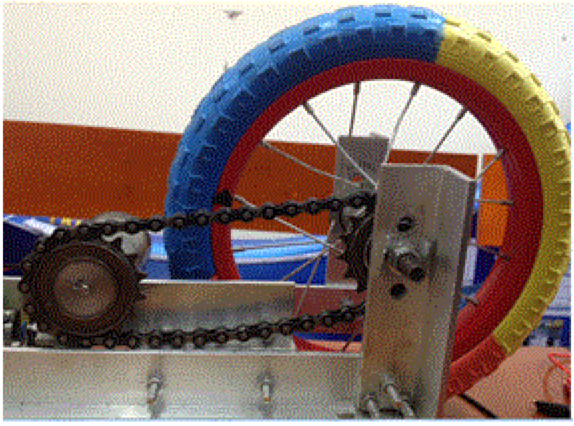


Figure 4. Backward and forward control system of two-wheel vehicle

2. Electrical part

The function of the balance control system is to maintain the vehicle balance. The system has two inputs: one is from the tilt angle sensor (tilt angle and angular velocity of the vehicle), and the other is from the speed sensor attached to the flywheel motor. The output of the system is to maintain the tilt angle of the two-wheel vehicle to 0.

a. Microcontroller

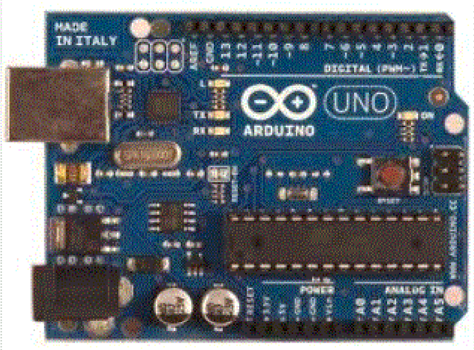


Figure 5. Arduino

We chose the Arduino board that uses Atmel's 8-bit megaAVR processor family with the board shape shown in Fig. 5. These processors (with the two most popular chips, ATmega328 and ATmega2560) allow the programming of complex control applications. It is equipped with a powerful configuration with ROM, RAM and Flash memory, digital I/O outputs, many of which are capable of outputting PWM signals, analog signal reading ports, and delivery standards. Next, there are diversities such as UART, SPI, TWI (I2C).

Processing power; clock speed: 16MHz; EEPROM: 1KB (ATmega328) and 4KB (ATmega2560); SRAM: 2KB (Atmega328) and 8KB (Atmega2560); Flash: 32KB (Atmega328) and 256KB (Atmega2560)

b. H bridge

In order to power the dc motor that drives the flywheel, we use the H-bridge circuit shown in Fig. 6 as follows:

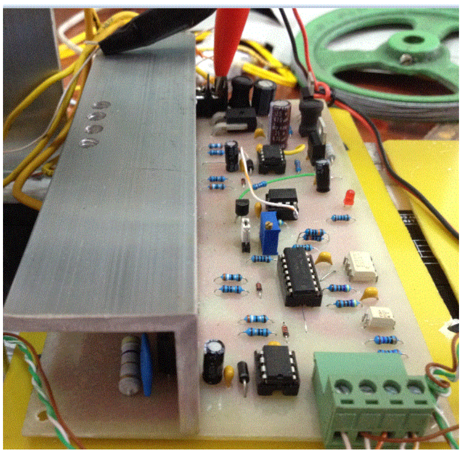


Figure 6. The H-bridge circuit

c. Power supply

The power supply system must have enough power and voltage to keep the two-wheel vehicle running for a long time. However, the mass of the power supply system needs to be small so as not to affect the weight of the vehicle. Therefore, we chose the power system, including 2 batteries 12V – 2,2 Ah connected in series to obtain a 24V 4,4Ah source. This power system also supplies power to the vehicle's forward and backward control. The actual shape of the power supply is shown in Fig. 7 as follows:

Figure 7: Power supply

d. Tilt angle sensor

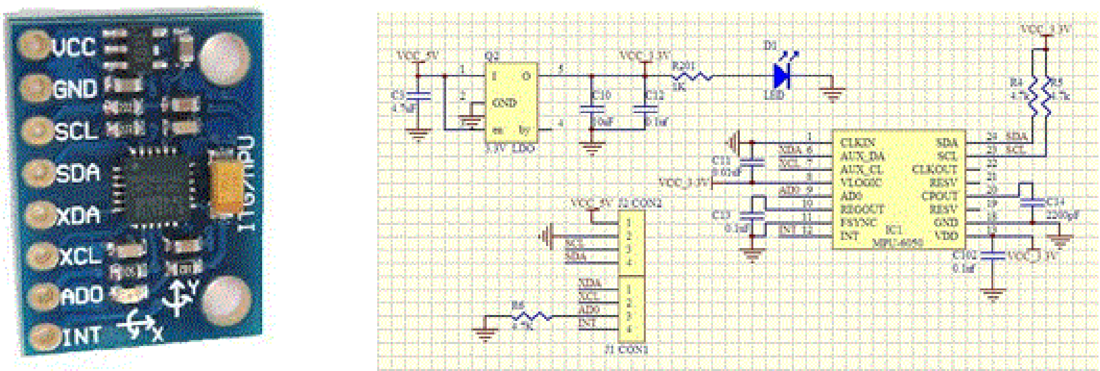
We use the tilt angle sensor GY-521 6DOF MPU-6050 with the following specifications: MPU-6050 module (3 angular axes + 3 acceleration axes); Chip: MPU-6050; Power supply: 3-5V; Standard of communication: I2C; Chip 16bit AD converter, 16-bit data output.

Resolution of angular velocity (ω): ± 250, 500, 1000, 2000 [°/s] equivalent 1°/s = 1.3,14/180 [rad/s].

Resolution of angular acceleration: ± 2; ± 4; ± 8; ± 16g (g= 9,81 m/s^2 is the gravitational acceleration).

Standard os circuit jacks: 2,54mm.

Shape and diagram for acceleration sensor Gyro GY-521 6DOF MPU6050 are shown in Fig. 8 as follows:



a. Shape of the sensor *b. Circuit diagram of the sensor*

Figure 8: Acceleration sensor Gyro GY-521 6DOF MPU6050

e. Speed sensor

To determine the flywheel's rotation speed, we use a Sharp Encoder with the following specifications: Encoder Sharp 100 pulses; Mass: 100 [g], Power supply: 5 [VDC], 2 phases A, B; Shaft diameter: 6 [mm]; Outer diameter: 45 [mm]; Speed: 5.000.000 [pulses/minute]. The Sharp Encoder shape is shown in Fig. 9 as follows:

Figure 9: Speed sensor

h. Backward and forward control system

The backward and forward control system has the function of controlling the two-wheel vehicle running backward and forward.

H- bridge circuit drives the motor backward and forward

To control the supply of DC motors, we use the H-bridge circuit shown in Fig. 10 as follows:

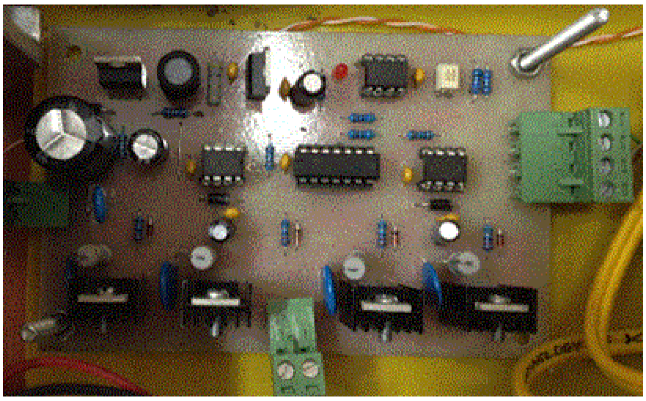


Figure 10: H-bridge circuit for driving the motor backward and forthward

Remote control system back and forth

To drive the vehicle back and forth, we use the remote control module, shown in Fig. 11 as follows:

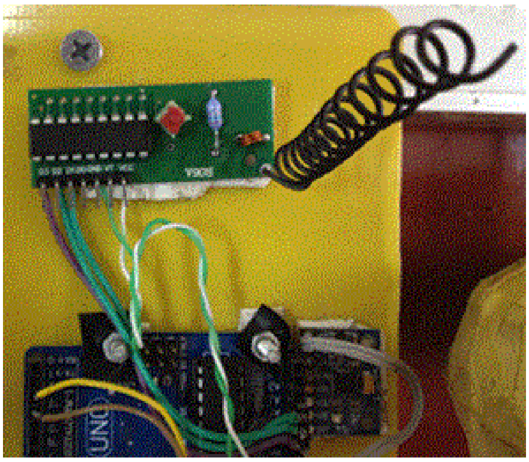


Figure 11. Remote control system connected to Arduino

Appendix_2: Determine the parameters of a two-wheel vehicle model

The two-wheel vehicle model is shown in Figure 1 as follows:

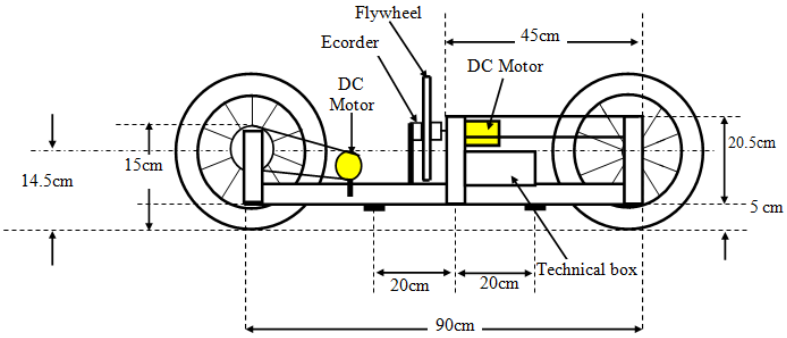


Figure 1: Size of the self-balancing two-wheel vehicle

1. Determination of flywheel parameters

Focus height of flywheel: $h_2 = 0,205m$

Size of flywheel:

- Outside diameter $D_n = 0,26\ m$
- Inside diameter $D_t = 0,22\ m$;
- The thickness of the flywheel rim: $t_n = 0,021\ m$;
- The thickness of the inner rim of the flywheel: $t_n = 0,005\ m$

Moment of inertia of the flywheel

- The flywheel is made of steel, with a relative density $\rho = 7850\ Kg/m^3$.

- Weight of outer rim of flywheel $m_n = \pi t_n \frac{\left(D_n^2 - D_t^2\right)}{4}\rho$ = 2,485 kg.

- Weight of inner rim of flywheel m_t = $\pi t_t \frac{\left(D_t^2\right)}{4}\rho$ =1,491 kg.

- Total flywheel mass: $m_2 = m_n + m_t$ = 3,976 kg.

- The moment of inertia of the flywheel is:

$$I_2 = \frac{1}{2} m_n \frac{\left(D_n^2 - D_t^2\right)}{4} + \frac{1}{2} m_t \frac{D_t^2}{4} = 0,03289\ \text{kg.m}^2$$

The actual shape of the flywheel is shown in Figure 2 as follows:

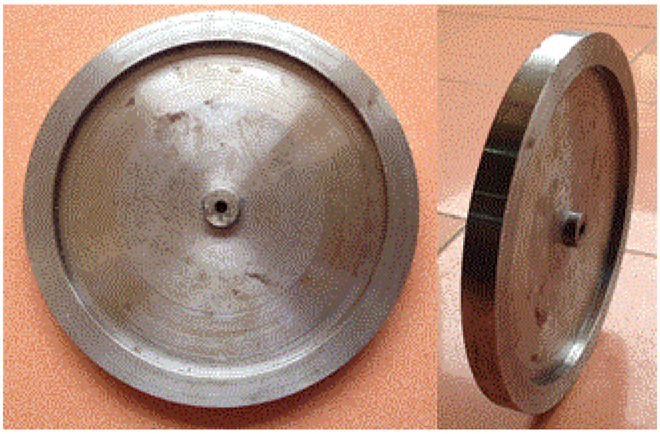


Figure 2. The actual shape of the flywheel

2. Calculation of DC motor parameters

The shape of a direct current electric motor is shown in Figure 3 as follows:

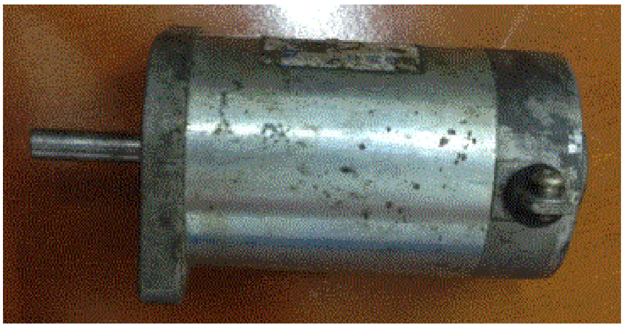


Figure 3. DC motor

The basic parameters are shown on the marks of the engine include:

No.	Parameter	Value	Unit
1	P	100	W
2	U	15	V
3	V	34000	Rev/min

To determine the remaining parameters of the motor, we perform calculations and experiments according to the following link: https://www.sccs.swarthmore.edu/users/06/adem/engin/e58/lab2/

Our results are as follows:

Table 1. Parameters of DC motor

No.	Parameter	Value	Unit
1	Transmission	1:1	
2	K_e	0,045	V.s/rad

3	K_m	0,045	N.m/A
4	ω	355,86	Rad/s
5	R	0,54	Ω

3. Calculation of model parameters

- Vehicle weight is determined by weighter: $m_1 = 10,024kg$

- The height h_1 and moment of inertia of the vehicle I_1 is determined based on vehicle structure based on the following references:

Reference 1: Jason M. Gallaspy, John Y. Hung*, "Gyroscopic Stabilization Of An Stationary Unmanned Bicycle", https://www.coursehero.com/file/31059355/bicycle-paperdoc/

Reference 2: H. Sato and T. Namerikawa, "Modeling and Robust Attitude Control of Stationary Self-sustaining Two-wheeled Vehicle" Proc. of the SICE Annual Conference 2005, pp.2174-2179, Okayama University, Okayama, JAPAN, August 8-10 2005., DOI: 10.1299/kikaic.72.2130