AUTONOMOUS BICYCLE

Electrical Subsystem

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Summary

This report includes all the electrical parts of the autonomous bicycle. Not only how we design the circuits but also how we choose the components and the datasheets of them are also included in the appendix.

Motivation

The goal of this project is to design and fabricate a bicycle that can self-stabilize. To accomplish this, we need to have a model of bike and a controller to keep the bike stand upright. This controller should receive state data of the bicycle and give out corresponding output to keep it from falling. At the same time, we'll have a propulsion motor to make the bike move forward. Such a bicycle will be able to be ridden by people who do not know how to ride a bicycle or who cannot stabilize it themselves.

Inputs

Potentiometer

The steering wheel of the system will be actuated using a DC motor. The current position (angle) of the motor, hence the steering wheel, is required to be measured for several reasons:

1- Model input: The system model requires the presence of the angle of the steering wheel. Since it is a part of the dynamics of the system, the current position of the steering wheel will affect how the system should react.

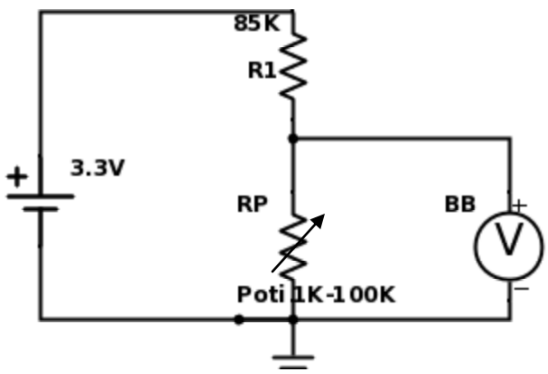
2- Feedback: If the system requires a certain angle, feedback of the angle to system is essential to reduce position error. That also will affect how the system should react.

There are several methods for obtaining the current position of the steering angle. Measurements could be taken either from the steering rod, or from the motor. There would be a difference between the two measurement methods of the actuation was not direct, or if the axes of both the motor and the steering rod were not coaxial. In the current design, the motor is coaxial with the steering rod, therefore there will be no difference.

Measurements of the angle can be obtained by one of two transducers: Potentiometer or encoder.

Characteristics	Potentiometer	Encoder
Angular Range	Limited to number of turns	Infinite
Resolution	Essentially infinite	2^x (x= 0-15)
Maximum error	0.1°	One increment
Interface with Computer	Analog	Digital (serial communication)
Measurement interface	Contact	Non-contact
Peripherals	Voltage divider circuit (Hardware)	Communication and counting algorithm (Software)

The choice of the transducer was done by a previous group. Their choice was using a potentiometer, since there was an interface problem between the encoder and the computer.



There are required peripherals for the potentiometer to be able to interface with the computer. The computer cannot read resistance value; however, it can read analog voltage value. The peripheral is called a voltage divider, which transforms the changing resistance value of the potentiometer to voltage.

The voltage divider circuit consists of four components:

1- Power source: required to run the circuit. It is chosen to be 3.3V, the same supply voltage as the computer.
2- Output (BB): this is the output voltage of the circuit to the computer.
3- Constant resistance (R1): required for to achieve voltage division.
4- Potentiometer (RP): the angular transducer.

The model for the computer to determine the angular position of the steering wheel:

$$\emptyset = 170 - \frac{340V_{BB}}{1.74}$$

Where φ= steering wheel angle in degrees (°)
V_{BB} = output voltage of the voltage divider in volts (V)

Backlash=0.1°

Error = 0.529 mV

IMU

The IMU is a sensor that outputs the attitude of system it is attached on using accelerometers and gyroscopes. The IMU used in the circuit is the Microstrain Inertia – Link. The purpose of using such a sensor on the bicycle is to measure the bicycle’s lean angle and lean angular velocity. These state data are needed in the dynamics control to keep the bicycle upright.

Actuators

There are two parameters that require control. The method of controlling these parameters will be through motors. The first parameter required to be controlled is the forward motion of the bicycle. The second parameter required to be controlled is the steering angle of the front wheel. The two motors are attached to the front wheel.

Forward motion (Hub) motor

The forward motion of the bicycle is required to be controlled because unmanned testing of the bicycle will be done. Therefore a source of forward locomotion of the bicycle is required to be able to perform the tests. The requirement of the actuator is to drive the bicycle forward. A motor was already purchased for that purpose (Magic Pie 2). The magic pie motor was chosen because it is built for the purpose of driving bicycles. The motor is integrated in the wheel and is controlled be a separate controller.

Steering motor

The method of maintaining the stability of the bicycle is by changing the steering angle of the front wheel. The steering angle will be controlled by a motor whose output shaft will be connected with the fork of the front wheel.

The used motor is chosen according to several parameters:

Item	Value
Configuration	DC
Output speed	0-45 rad/sec
Rated output torque	5 N.m
Diameter	2.5 in
Optional	Encoder

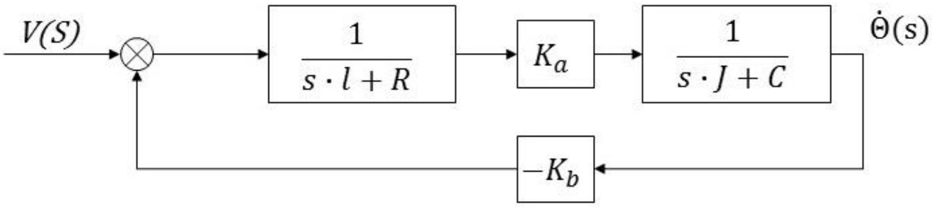
The motor is required to be DC, since the power source of the system is a 24 battery. The maximum output speed required is the maximum speed the output shaft of the motor can reach. The maximum value of 45 rad/sec is the maximum required speed for steering in order to stabilize the bicycle. The value was obtained by an experiment. The speed of the output shaft shall be continuously variable from 0 to 45 rad/sec via PWM input. The rated output torque will be the torque required to steer the front wheel.

The diameter of the motor was to be considered because of space limitations. The motor output shaft is connected to fork of the bicycle, the housing of the motor is a tube with a bore of 3 in; therefore it is required that the diameter of the motor be smaller than the tube bore for assembly. A preferable option to have in the motor that it is equipped with an encoder, however it is an option.

Steering motor model:

To be able to stabilize the bicycle effectively, the steering motor is required to be modeled for predicting its behavior. Accordingly, a suitable controller will be designed to gain the desired output.

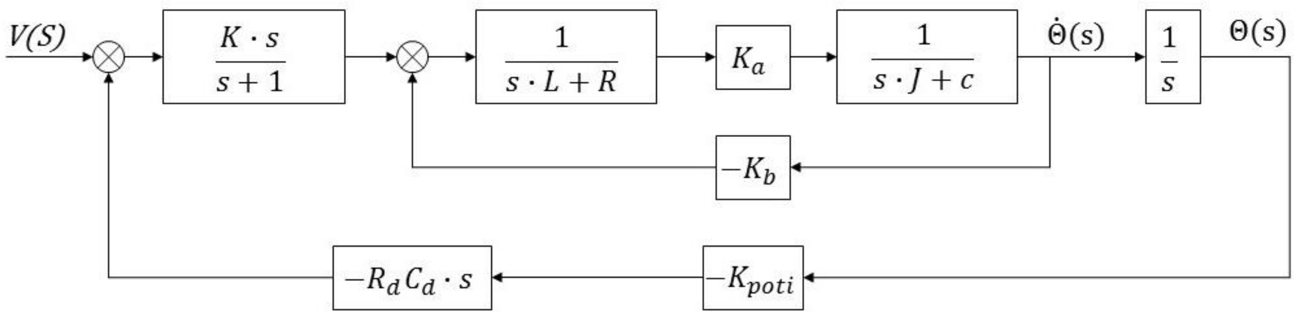
The block diagram of the motor is as follows:



Where

$\dot{\Theta}(s)$ is the steering velocity in the s-domain
V(s) is the input voltage in the s-domain
K_a is the torque constant in N.m/amp
K_b is the back emf coefficient in V/rpm
l is the internal inductance of the motor in H
R is the internal resistance of the motor in Ohm
J is the total moment of ineria of the power train in $Kg.m^2$
C is the rotational damping coefficient of the drive train in Kg/sec

The motor will be part of a feedback loop to minimize the error and control the behavior. The block diagram of the feedback loop of the motor:



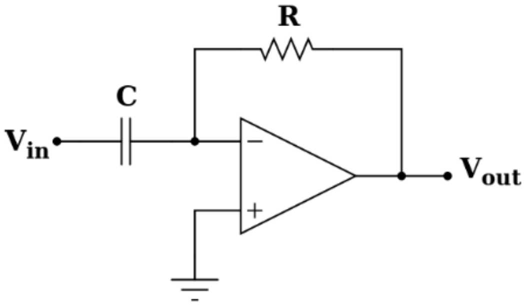
Where

$\Theta(s)$ is the steering position in the s-domain
K_{poti} is the conversion factor of the potentiometer to voltage
R_dC_d is the differentiator constant
K is the controller gain

Interfaces

Differentiator Circuit

In order to get angular velocity of the steering, we need a differentiator as an interface due to the output of potentiometer is position information. The equation and diagram of a differentiator are as following.



$$C\dot{V_{in}} + \frac{V_{out}}{R} = 0$$

$$V_{OUT} = -RC\dot{V_{in}}$$

We want the output from differentiator to be in the range of 0 to 1.8 V. Thus, we connect V_{CC}^{-} to 0.9V and V_{CC}^{+} to 1.8V to shift the output. The equation then become

$$V_{OUT} = -RC\dot{V_{in}} + 0.9.$$

When $\dot{V_{in}}$ = 0, output is 0.9; when $\dot{V_{in}}max$, output is 1.8; and when $\dot{V_{in}}min$, output is 0.

We know that $\triangle V_{max} = 1.8V$; $\triangle V_{min}$ = -1.8V; t_{min} = 1.148s so we can get $\dot{V_{in}max} = 1.567$ and $\dot{V_{in}min} = -1.567$. Plug this into the shifted equation, then we get RC ≐ 0.574. We choose R = 680 KΩ and C = 0.064 µF.

Opto-isolator

The purpose of the opto-isolator is to isolate two parts of the electric circuit from each other. This isolation is done optically by an LED and a phototransistor. The output of the circuit is connected to the LED side. When a signal reaches the LED, it will emit light. The emitted light is sensed by phototransistor. The isolation is required in our circuit in two cases. Isolating the Beagle Bone from the H-bridge. And isolating the Beagle Bone from the Hub motor controller.

H-bridge

The purpose of the H-bridge is to control the speed and direction of rotation of a motor. The H-bridge is used in the circuit to control the steering motor. PWM signal from the Beagle Bone is used to determine the speed of the motor. The direction of rotation is a separate signal from the Beagle Bone to determine the direction of rotation of the steering motor, either clockwise or counter clockwise.

DC to DC converter

The purpose of the converter is converting the high voltage of the power source (24 V) to a lower voltage (5 V), which is the rated voltage of the Beagle Bone and the IMU. Another purpose of the converter is isolating the circuit. The DC to DC converter is used in the circuit to step down voltage as a supply for the IMU.

Hub motor controller

This controller was purchased with the Hub motor. It is used for controlling the speed of the motor as well as providing feedback for the motor position. In the current circuit, the controller is used for controlling the speed of the forward motion only.

Conclusion

In this semester, the electrical part of the bicycle is completed. It was assembled and tested to work. However, the whole assembled circuit was not successfully tested to guarantee full functionality. Further developments is to test the whole circuit, as well as improve the aesthetics of the wiring. The possibility of adding new functionalities is available, such as steer by wire.