Bicycle Dynamics Simulator

Design Team

Kyle Becker, Alex Bonin, Sam Bruce
Steven Healey, Lukas Tubby

Design Advisor | *Sponsor* | *Donor*

Prof. Jim Papadopoulos | **Prof. Yingzi Lin** | **TDK-Lambda**

Abstract

The team is working to design and fabricate a mechanical testing platform that realistically simulates the riding forces of a bicycle in a bike lane. By mimicking real bicycle-related forces, the system will help the Intelligent Human-Machine Systems Laboratory investigate bicyclist safety and the effectiveness of different bike lane designs. The team's device has been designed in a way that has never been attempted. The device moves the ground supports laterally beneath the rider, identically to real bicycle wheels. To achieve this, motor-driven wheels are mounted perpendicular to the bike's frame. These motors accelerate the entire bike horizontally, allowing for small lane shifts and slaloms. As the rider turns the handlebars, these motors will drive the front wheels to roll in the direction of the turn. This effect will allow the rider to balance through steering. The rear wheels will be controlled by the angle of the bike frame and will lag behind the front wheels.

For more information, please contact j.papadopoulos@neu.edu.

The Need for Project

An industrial engineering capstone team needs a mechanical testing platform for their virtual reality bicycle simulator.

The need for this project arises from an industrial engineering (IE) capstone team's project. The IE team's goal is to design a better bicycle lane for the Boston bicycle infrastructure. In order to quantify safety levels of different bicycle lane designs, the IE team will put test subjects into a virtual reality world and simulate various traffic scenarios. The IE team has asked the mechanical engineering (ME) team to assemble a mechanical testing platform that replicates realistic bicycle riding and meets all of their testing specifications—please see section 1 of the main report for more details on the IE team specifications.

The IE team has asked the ME team's device to mimic the actual forces involved in cycling and to incorporate the elements of realistic steering, including the necessity for leaning as well as countersteering. This level of realism is required to make sure that the lane designs that the IE team come up with can safely accommodate all realistic bicycle maneuvers as well as to make physiological response data more robust. The IE team will be able to convert data they receive from sensors on the system into positioning data in the simulator, so that they can accurately determine where the bicycle is within the lane.

The Design Project Objectives and Requirements

The goal of this project is to simulate the forces felt by a rider maneuvering in a bicycle lane.

Design Objectives

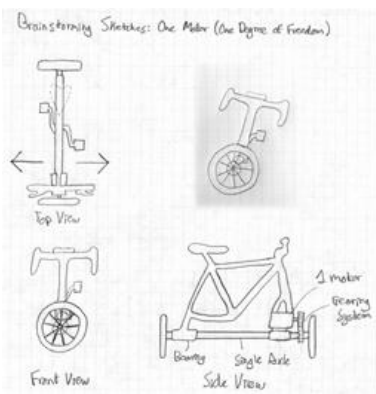
The objective of the mechanical design is to maximize realism of the virtual reality simulator. The system needs to be able to make the rider feel as though they are actually riding a bicycle; whatever speed the rider is riding at, the system needs to be able to replicate the relative stability of a bicycle going at that speed. The system must also respond as quickly as possible to mimic the instantaneous response of real bicycle riding, and must have the same degrees of freedom to be able to simulate the different bicycle maneuvers.

Design Requirements

The system must be able to simulate turns and/or slaloms with a lean angle of 25 degrees from vertical at a speed of up to 15 mph. In addition, it must be able to vary the simulated speed based upon the pedaling speed of the rider—this includes speeding up, slowing down, as well as stopping. The system must also be able to accurately replicate the motion of a real bicycle, including the necessity to countersteer before initiating a turn/lean (please see section 2.1.1 of the report).

Design Concepts Considered

The team developed several candidate design concepts that met the given requirements.



Preliminary Sketch

The team considered multiple design concepts. In one concept, the front wheel would be mounted perpendicular to the bike frame and the back wheel would be replaced by a pivot at the ground. This allows turning of the bike and limited lateral motion. The new front wheel would be driven by a motor controlled by turning the handlebars. A variation of this design is to replace the pivot with another wheel, allowing the entire bike to move laterally (but sacrificing the ability to turn the bike). This can be seen in the sketch to the left.

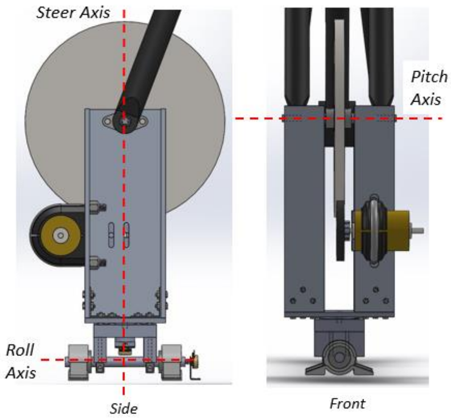
After completing a decision matrix, the final design was chosen as a bicycle with two sets of sideways-facing wheels driven independently to permit yawing of the bicycle frame. These wheels also allow for lateral movement of the bike. This lateral movement will recreate the accelerations felt when riding a bicycle, and yawing of the frame will allow for more-realistic dynamics and rear-wheel lag. Please see section 3 of the report for further details on preliminary design concepts.

Recommended Design Concept

The final design includes wheels powered by two motors that accelerate the bike laterally with linkages that recreate the motion of the front and rear wheels.

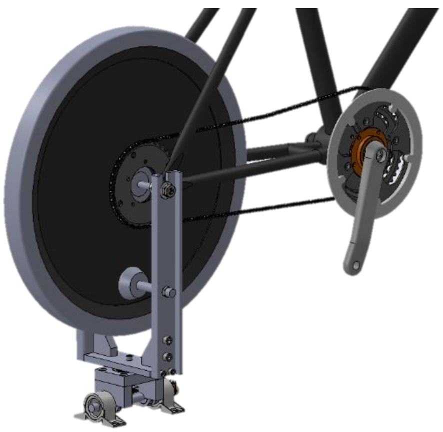
Design Description

The team pursued the two motor design that recreates the full experience of small turns and balancing without forward speed. The design includes transverse wheels at the front and back, each with a motor to drive the bike laterally. Using wheels to accelerate the bike provides a relatively inexpensive solution to recreate the base acceleration felt by a rider in a slalom or lane change. The design breaks down into three major subassemblies: front linkage, rear linkage, and carts. The front and rear linkages replace the front and rear wheels respectively. These linkages are also instrumented to control the motors based on frame and steering angles. The cart assemblies establish a mount for the motors and wheels.



Front Linkage

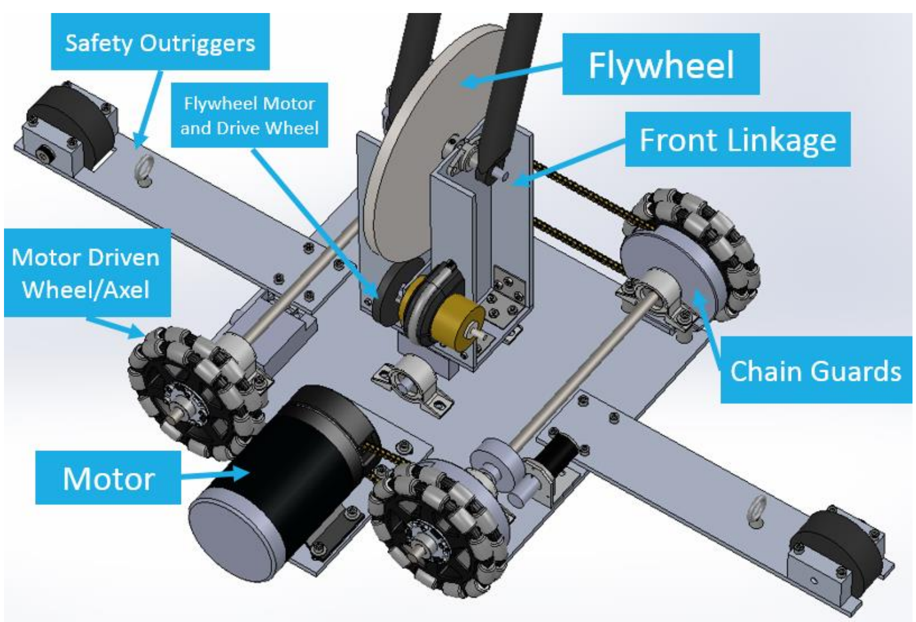
Since the front linkage replaces the front wheel of the bike, it must have the same freedom of motion as a bike wheel. The required motions include turning of the front forks, leaning of the entire linkage, and pivoting of the front linkage at the axle of the front wheel. Since the front linkage was designed to mimic the motion of the front wheel, the design will feel realistic. This includes the addition of a flywheel between the front forks. The spinning flywheel recreates the gyroscopic (self-steering) effects of the spinning front wheel. Since the front linkage was designed to mimic the front wheel, steering will feel the same as on a real bike.


Rear Linkage

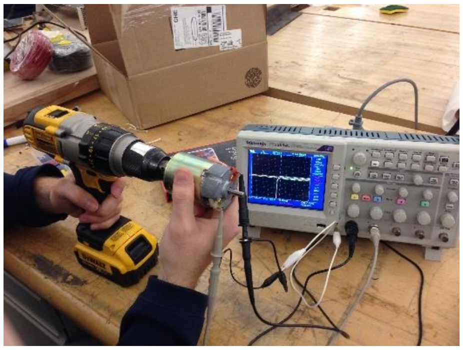
The rear linkage has similar requirements to the front linkage since it also recreates the motion of a bike wheel rolling on the ground. The rear linkage also includes a flywheel but for different reasons. The flywheel in the rear is larger and heavier since it is used to provide resistive pedaling. The pedals of the bike are connected to the flywheel to create effects similar to an exercise bike. The hand brake will be connected to this flywheel to provide realistic braking.

The carts connect the wheels and the two linkages. They also include mounts for the motors and the transmission system. The angle of the handlebars will be measured to control the lateral velocity of the front cart via a PID controller. Since there are carts in the front and rear of the bike, they move independently. This allows the rear wheel to trail behind the front wheel similar to a real bike.

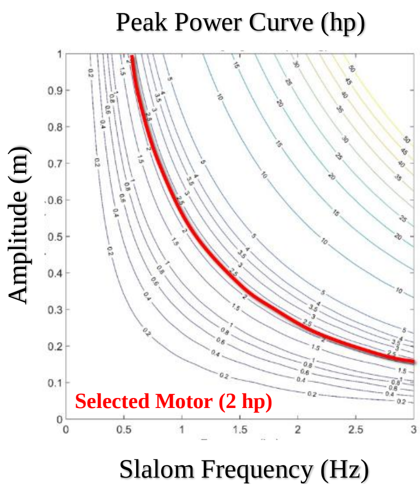
Each of the subassemblies recreates the wheel behavior of a real bike to produce a simulator with as much realism as possible.



Cart Design



Tachometer Testing



Analysis:

The team employed dynamic, structural, electrical, and control analyses to make critical design decisions. To determine motor power requirements, the optimal gear ratio, and the forces for structural analysis, the team modeled a bicycle as an inverted pendulum moving in a slalom. From the model, a motor with sufficient power was selected and the transmission was optimized. Using the loads from the model, stress analysis was performed using hand calculations and finite element analysis. The team used Euler's equations of motion to determine the front flywheel inertia and rotational speed to maintain realistic gyroscopic torques on the handlebars.

The transfer functions for our electrical and mechanical systems were calculated. The time constants of the bike, sensors, and motors were compared to confirm that the overall system response was sufficiently fast. Simulink, Maple, and testing were used to tune the final PID controller gains. Several electrical components were also designed using Simulink. A low pass filter and a voltage amplifier for the tachometers were optimized. The filter was tested experimentally and proven to successfully remove the noise from the signals. For more details on analysis, please see section 6 of the main report.

Financial Issues

Initial prototyping cost is high, but productizing would reduce cost greatly.

The cost of the prototype is expected to be about $6000. However, because of a generous donation of two DC power supplies from TDK Lambda, the overall cost to Northeastern has been reduced to around $2500. Prices were also reduced by the team personally fabricating mechanical components. In production, this unit would be dramatically less expensive.

Recommended Improvements

A larger budget with more design time would lead to a more robust system.

An optimal design would allow for a harness to be the main safety feature. To properly implement, a large steel frame would be designed to keep the rider from falling at any point during the simulation. This design was not implemented due to time and cost constraints.

Additionally, the design should incorporate higher quality motors. The current motors are not designed for rapid speed control. The team's bicycle simulator design would benefit from high quality servo motors and speed controllers. This would simplify control of the bicycle and allow for more precise turning with a lower time constant.