Autocycle: Design, Construction, and Validation of an Autonomous Bicycle

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Background

Bike-sharing systems are one of many proposed solutions to mitigate climate change. In these systems, citizens can easily borrow or rent a communal bike, making biking more convenient, reducing automobile usage, and decreasing an individual's carbon footprint.

Problem Statement

Bike-sharing systems, although good in theory, face several issues, including:

- An insufficient number of bike hubs to be convenient
- Poor distribution of bicycles across hubs

Team Autocycle hopes to increase the utility of bike-sharing systems by developing an effective self-driving bike. This way, bikes can autonomously travel to a user and back to its bike hub after use.

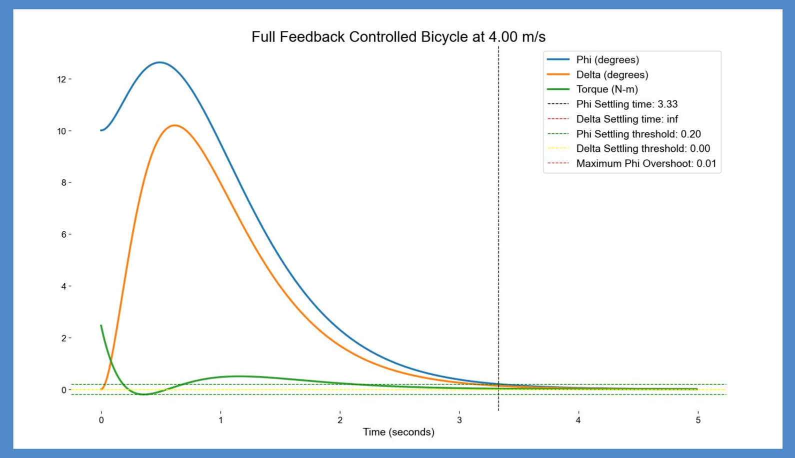
Research Questions

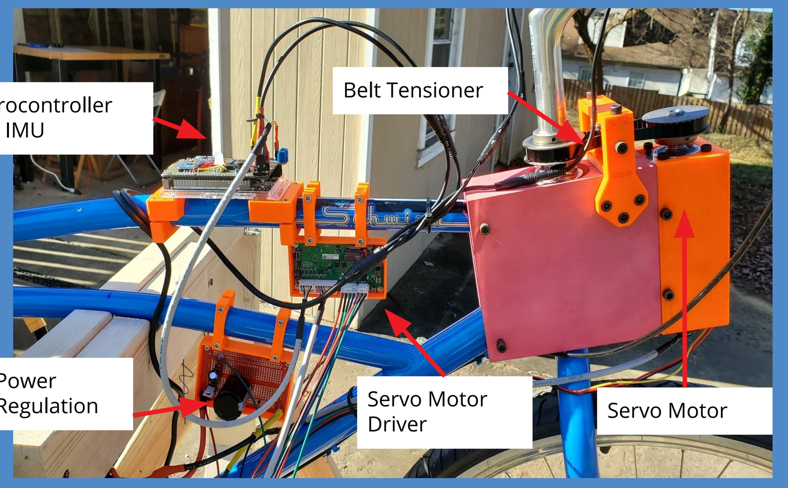
- What are the most effective control methods for achieving stability and steering in a bicycle?
- How can these methods be best combined with navigation technology to implement an autonomous bicycle for use in a bike sharing system?

Methodology

Controls & Stability

In order to remain upright on only two wheels while also following a specified path, the Autocycle requires an active control system. After surveying several options previously proposed in existing literature (shown on the right), and testing them via a custom numerical simulation, the team has proceeded with developing a Full State Feedback controller to track the desired roll and steering angles.





The control scheme is executed on board the prototype by an Atmel SAM family microcontroller, with actuation being accomplished by means of a hacked commercial mid-drive electric motor providing forward motion and a dedicated brushless servo exerting torque on the handlebars through a timing belt (shown on the left). State information for use in the controller is found by applying a Kalman filter to data from a six Degree of Freedom Inertial Measurement Unit, as well as the encoder output from the steering torque motor.

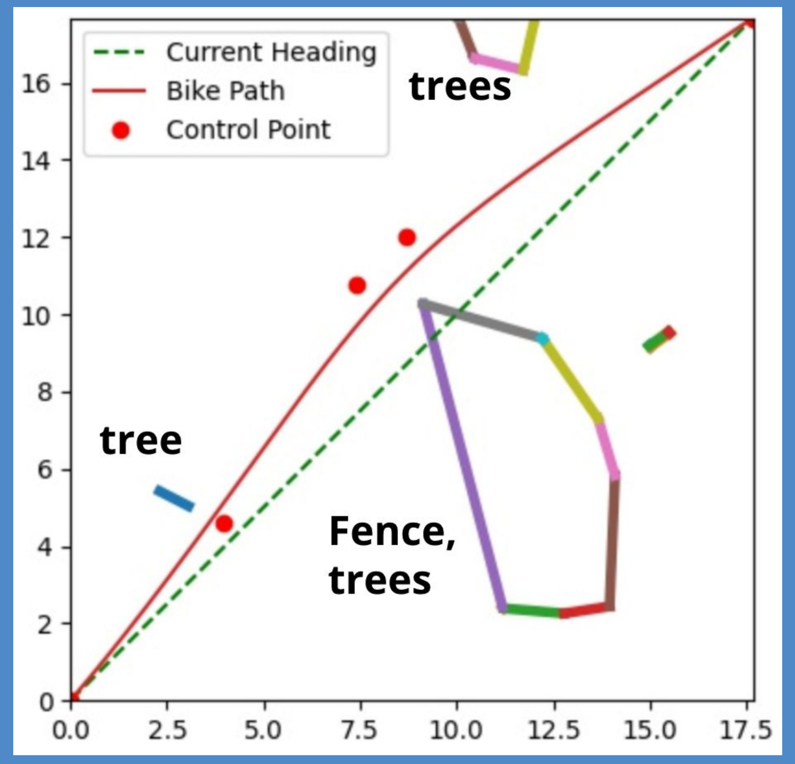
Construction

The Autocycle prototype uses a modified bicycle frame with custom components that allow a controller to manipulate the bicycle's handlebars and speed during testing. Sensor and motor mounts were designed in SolidWorks. Mock-ups were 3D printed to identify any necessary design revisions prior to final manufacturing.

To prevent the prototype from falling over when moving at an unstable speed, a system was developed that could deploy a second set of stabilizing wheels (shown on the right). This system utilizes frame-mounted linear actuators, 3d printed parts, and steel machined at the Instructional Fabrication Lab.

Navigation

The Autocycle prototype must be able to avoid obstacles along its path in addition to keeping itself upright. A LiDAR provides a "view" of the area in front of the prototype, with depth information to map the position and distance the prototype is from objects (shown on the right).



In conjunction with object detection from the LiDAR, cameras and a GNSS system will be integrated in the future. The onboard cameras will feed image information into an object classification algorithm to determine the type of objects (cars, humans, stop signs, etc.). Typing data will be mapped to detected obstacles and a path will be plotted to avoid obstacles giving special instructions for specific object types. Finally the GNSS system will be used in the correction of the prototype's estimated position and to update the desired destination.

Results So Far

On the Stability side, our team has successfully assembled a prototype capable of sensing all of the necessary input states and output this information to the necessary actuators. We have repeatedly tested our system, rapidly iterating based off data collection to improve our state estimation, control system, and mechanical design.

On the Navigation side, our team has implemented a ROS pipeline connecting the object detection and path planning algorithms. Experimental testing of the pipeline resulted in objects being detected and a correctly planned path.

Future Research

Future Goals:

- Upright stabilization over 100 feet
- Straight-line stabilization
- Turning maneuvers
- Integrated local navigation
- Fully integrated navigation

Bike Improvements:

- Integration of zero-speed stability system
- Centralization of electronics onto PCB
- Increased data storage capability
- Integration of navigation system and cameras

Acknowledgements, References, & Glossary

Thank you to our mentor Dr. Gomez, the Gemstone staff, and the University for enabling us to develop our research.

Want to learn more? Visit autocycle.io!

References & Glossary