Vision-based Control and Stabilization of an Inverted Pendulum

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Motivation

o The inverted pendulum model is used in many scientific and engineering applications, including Segways, rockets, robotics, and even to model the human body.

o Systems used in laboratories to study the behavior of an inverted pendulum traditionally use a built-in sensor (a potentiometer) to control the pendulum. Such sensors, when used in real-world inverted pendulum applications, are susceptible to malfunctions and interference, which would render the user incapable of controlling the system.

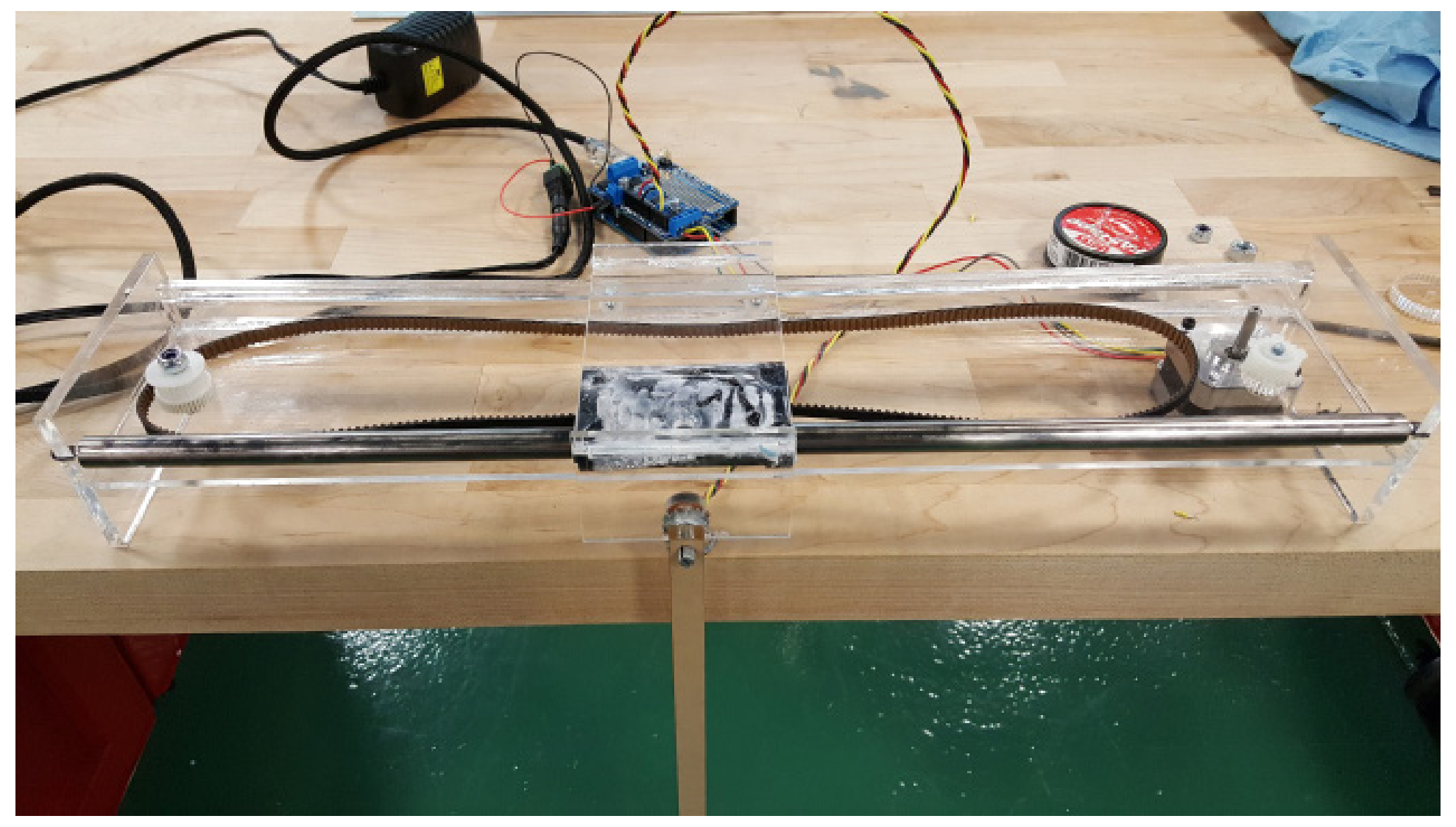
o A system controlled by a sensor placed outside the system itself would be robust to malfunctions in internal sensors. Such a backup control mechanism would be invaluable for applications of inverted pendulums for which stability is critical, such as humanoid robots, self-balancing transport systems, autonomous drones etc.

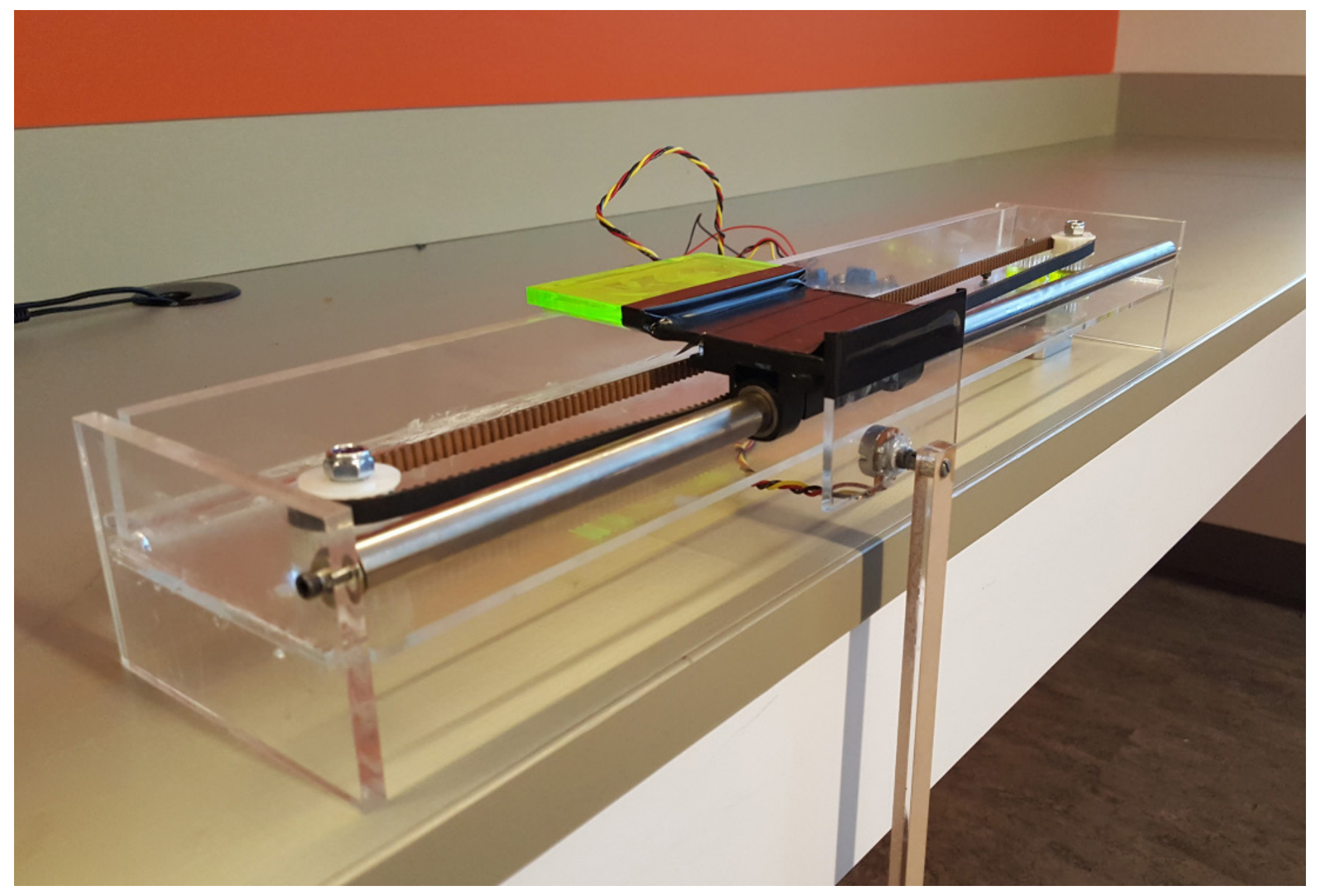
o Furthermore, this redesign could be used in instances requiring the control of an object using an external sensor, such as an assistive robot that helps elderly patients walk by tracking their motion using its camera

Abstract

o This project proposes an inverted pendulum system that can be controlled by an externally placed sensor, specifically a smart camera. By using the visual feed from the camera, the orientation of the inverted pendulum can be monitored in real-time, and the data required to stabilize it can be extrapolated from the visual feed.
its camera to determine when to provide support.

Mechanical System

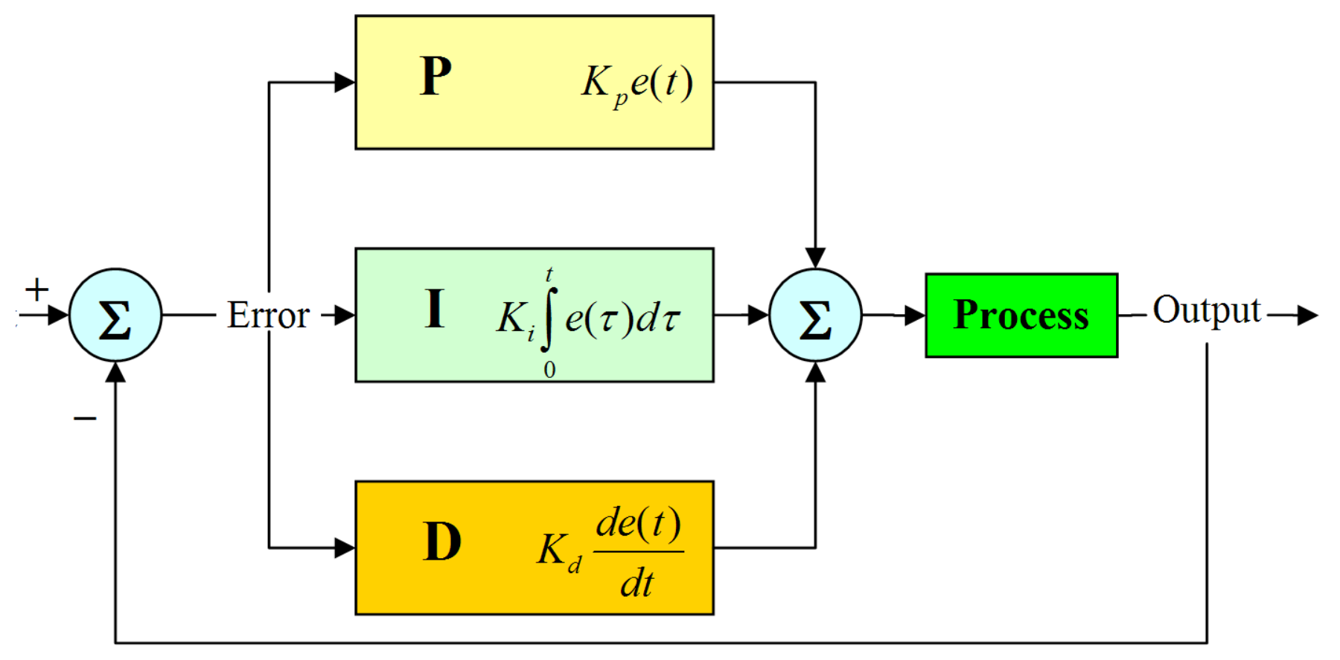




o The approach taken for this project was to first build an inverted pendulum system using a traditional built-in sensor, a potentiometer, such that the system model could be derived and a suitable control algorithm could be devised.

o The first iteration of the system (top) was found to have excess friction that hindered stable sensor readings. Thus, a second iteration (bottom) was built with less friction and more stable sensor readings.

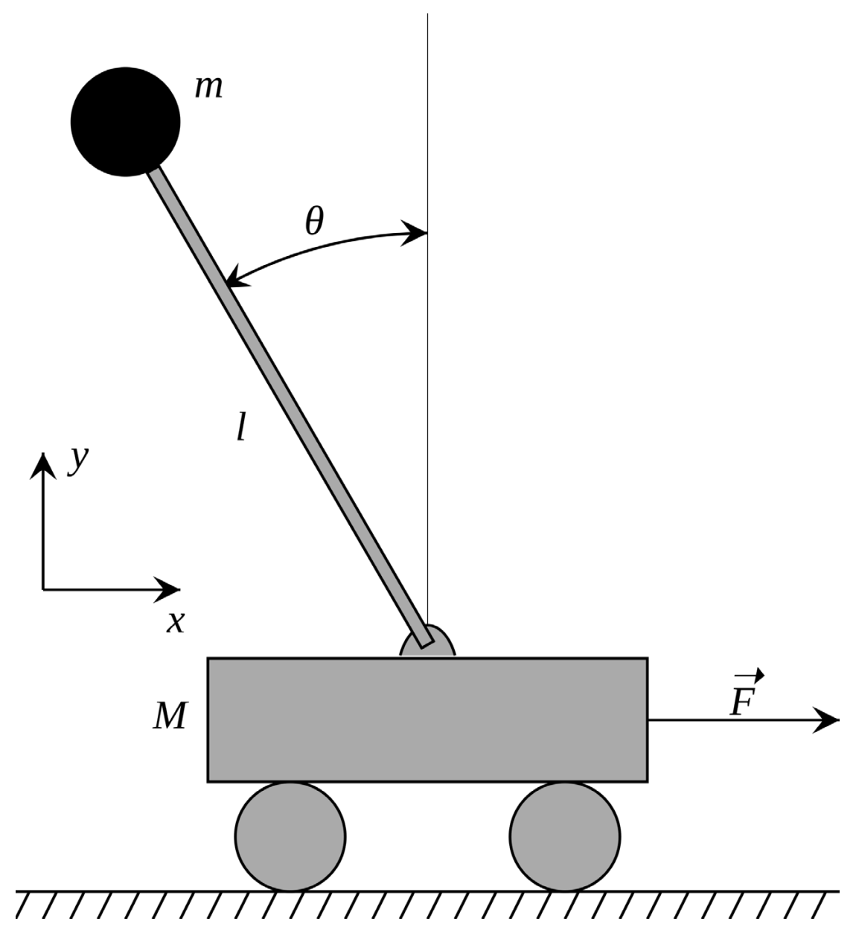
Control Software



o A Proportional-Integral-Derivative (PID) control algorithm was used to stabilize the inverted pendulum.

o This calculates the force needed to balance the pendulum using its angular orientation. Tuning the PID gain parameters requires a well defined system model.

Modelling the System



o In order to use PID control, a precise mathematical model for the inverted pendulum system must be derived. Our first approach to modelling the system was to use basic physics principles (angular acceleration of the pendulum about its pivot). This resulted in the following transfer function for the system:

$$\frac{\theta(s)}{F(s)} = \frac{\frac{-1}{Ml}}{s^2-(\frac{M+m}{Ml})g}$$

o The PID gain parameters for this transfer function did not succeed in stabilizing the pendulum, indicating that this model did not account for all the real-world imperfections (friction, mechanical constraints etc.) of the actual inverted pendulum system.

o The system model was derived using experimental data instead. However, since the pendulum was not stable in its inverted configuration, system input/output data could not be collected.

o Thus, the normal configuration of the pendulum was used to collect data, and the system model for the inverted configuration was extrapolated using the relationship between the theoretical transfer functions for the two configurations.

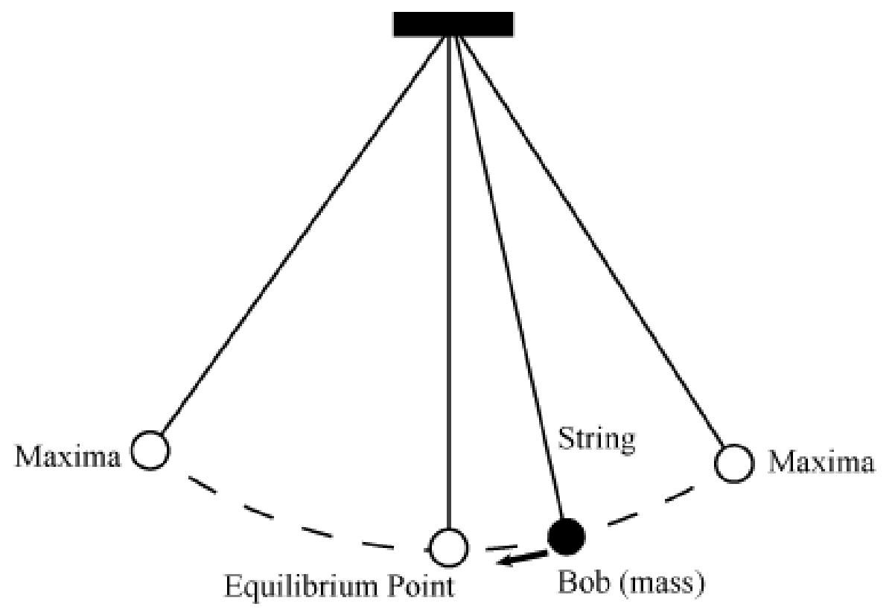
$$\frac{\theta(s)}{F(s)} = \frac{\frac{-1}{Ml}}{s^2-(\frac{M+m}{Ml})g}$$

Transfer function for the inverted pendulum

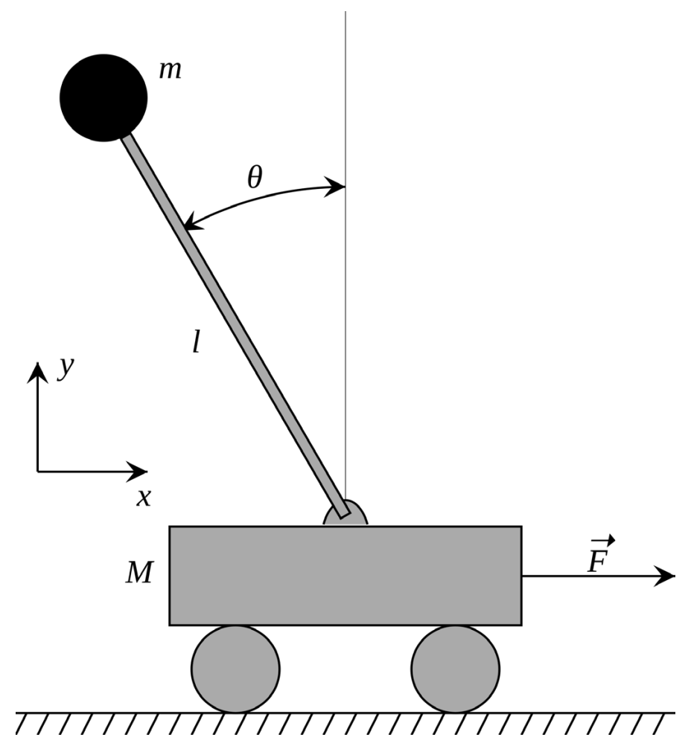
$$\frac{\theta(s)}{F(s)} = \frac{\frac{-1}{Ml}}{s^2+(\frac{M+m}{Ml})g}$$

Transfer function for the non-inverted (simple) pendulum

Results and Discussion



1st equilibrium: Θ = 180°



2nd equilibrium: Θ = 0°

$$\frac{\theta(s)}{F(s)} = \frac{0.0016}{s^2+1.745s+30.98}$$

$$\frac{\theta(s)}{F(s)} = \frac{-0.0016}{s^2-1.745s-30.98}$$

o Using the relationship between the two system models, the transfer function for the inverted pendulum was derived as above and used to calculate the PID gain parameters required to control the pendulum.

o The PID control algorithm thus derived was only able to stabilize the inverted pendulum for very small deviations from the vertical.

Conclusion

o The first stage of the project, the design and construction of the inverted pendulum system, was successfully completed.

o In order to proceed to replacing the built-in sensor, the inverted pendulum must be made robust to larger disturbances.

o Once such a system is obtained, work on the latter half of the project (using a camera to stablilize the pendulum) may be begun.

Next Steps

o Devise a PID control algorithm that can stabilize the pendulum perfectly. In order to accomplish this, a better system model must be derived, or an inverted pendulum system that has less mechanical imperfections must be used.

o Use the visual feed from a smart camera to determine the angle of deviation of the pendulum and control the pendulum using this data.

o Integrate system into existing robotic platforms such as drones.

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