

Learning Inverse Dynamics with Gaussian Process Regression



Cleveland State University
Washkewicz College of Engineering
Department of Mechanical Engineering
Mechanics and Control of Living Systems Laboratory
Titus Lungu, Eric Schearer Ph.D.

Objective: Use Gaussian Process Regression (GPR) to learn inverse dynamics of a pendulum and infer a system model to use for control, based on observations. This can allow for an adaptable control policy which is preferred when controlling complex, hard to model systems such as a human arm.

Current Work

- Create a pendulum simulation in MATLAB using torques to drive a rod (*Figure 1*).
- Use torques, angular positions, and angular velocities from a simulation (taking pendulum from 0 to π radians) to train the GPR algorithm so that it learns the system model (*Figure 2*, 0-3 seconds).
- Use the learned model to control the pendulum along a new trajectory (π to 0 radians) (*Figure 3*, 3-6 seconds).

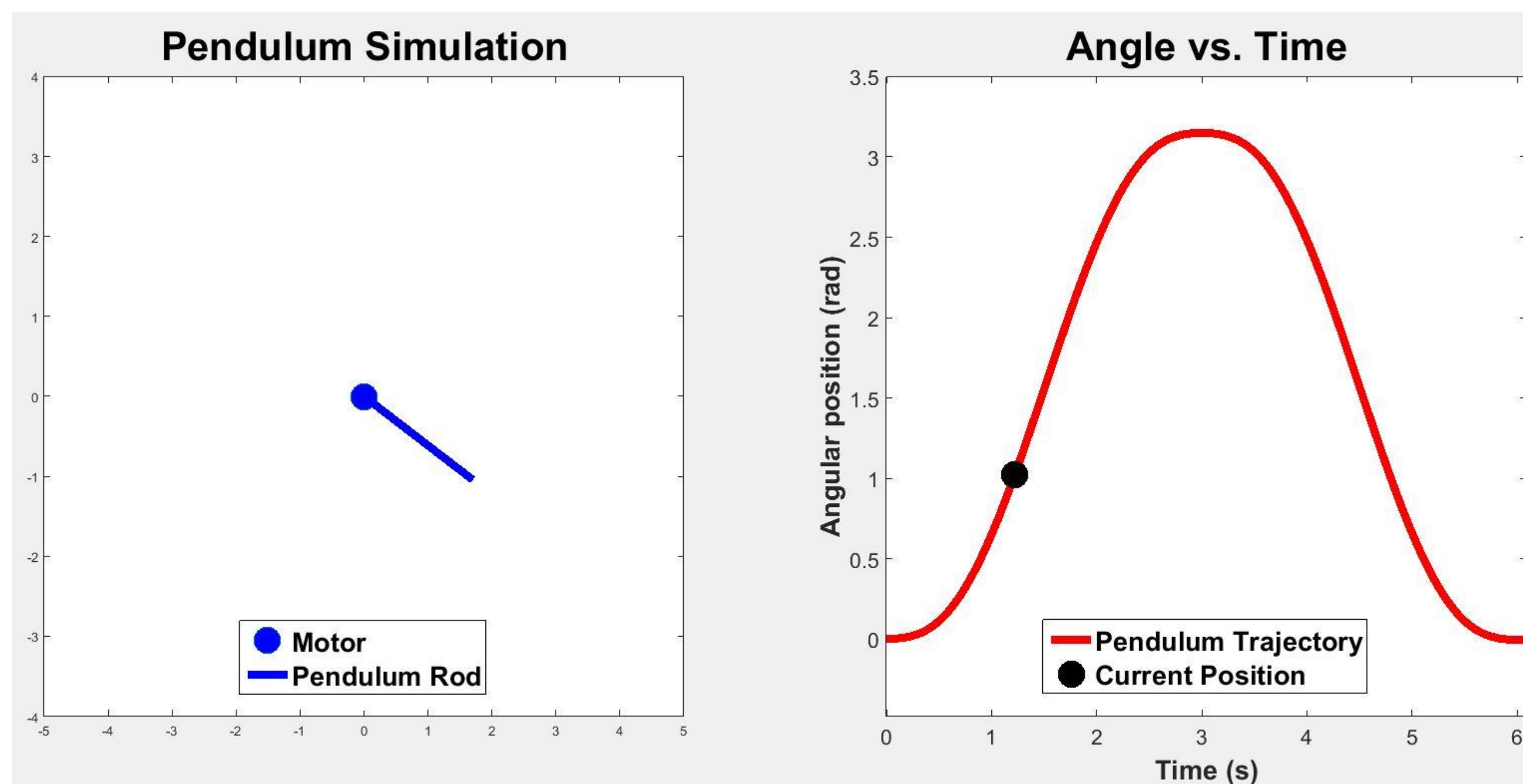


Figure 1: Pendulum Simulation

Gaussian Process Regression^{1, 2}

- Inputs of angular position and velocity (with sensor noise) and outputs of torque are used to train this GPR model.
- GPR assumes normal distribution of data and assigns a mean and covariance to define the system and learn the model:

$$f(x^1), \dots, f(x^n) \sim \mathcal{N}(\mu, \Sigma)$$

$$\Sigma = C(x^p, x^q) = \exp \left[-\frac{1}{2} \sum_{d=1}^D \frac{(x_d^p - x_d^q)^2}{w_d^2} \right],$$

where w_d represents hyperparameters such as length scale, signal variance, and noise variance

- The original pendulum simulation only produces training data for the GPR. In a more complex system, the training data would be recorded via sensors in the real world and the GPR would learn the system model from this data. Afterwards, the GPR model would be able to control the system.

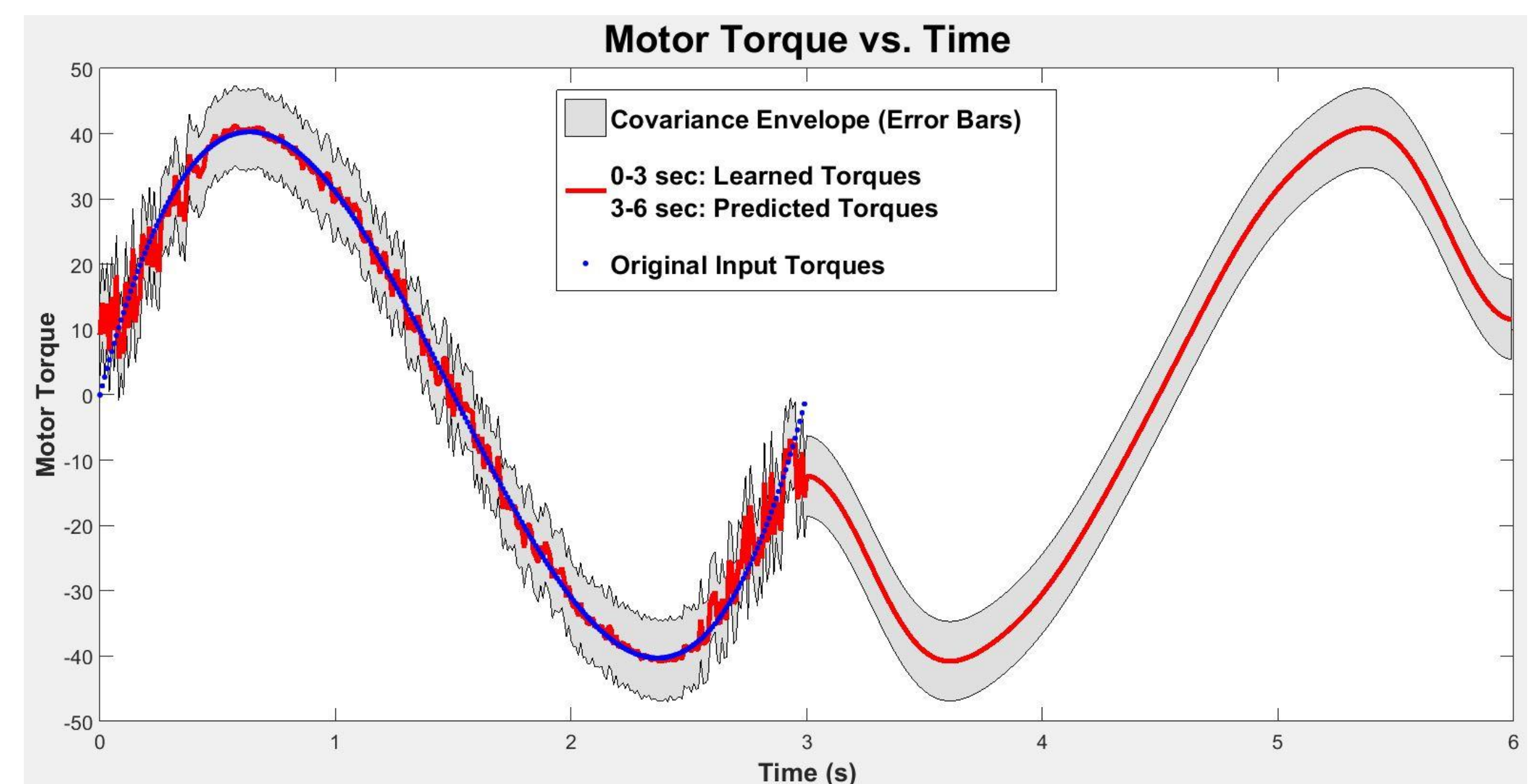


Figure 2: GPR Learning Model for Pendulum Torque

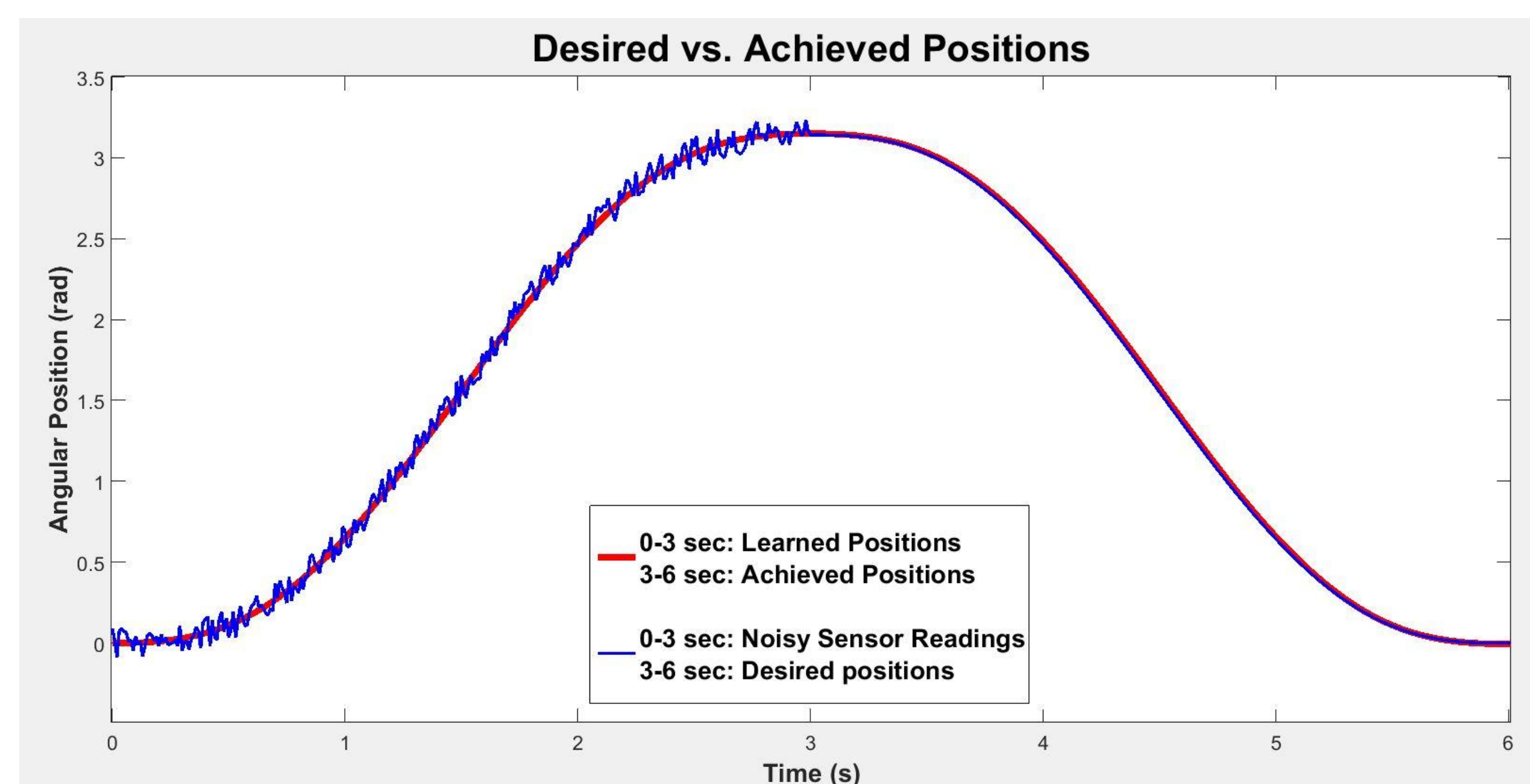


Figure 3: Positions Achieved with GPR Control

Results

- GPR learned the inverse dynamics of the pendulum by using the relationship between the torques and the positions and velocities, then calculated the torque required to achieve new positions and velocities (*Figure 2*).
- GPR predictions were very accurate compared to the desired positions (*Figure 3*).

Future Work

- Use feedback and GPR model to change the pendulum motion per user's intent.
- Use GPR to control a computer arm simulation.
- Use GPR to improve control of Functional Electrical Stimulation (FES) neuroprosthesis, which restores movement to paralyzed arms via implanted electrodes.

¹Rasmussen, Carl Edward., and Christopher K. I. Williams. Gaussian Processes for Machine Learning. Cambridge, MA: MIT, 2006. Print.

²www.gaussianprocesses.org