DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Dynamic Modelling and Control of Cable-Driven Hyper-Redundant Manipulator

Arundathi Shaji Shanthini
Supervisor: Prof . Sarah Spurgeon

Motivation and Objectives

Robotic manipulators that mimic the motion of snakes are highly desired for the **high maneuverability and accessibility properties.** A robotic arm developed by OC Robotics is at Here East in an attempt to automate close-range measurements and inspection of aerodynamic structures using cutting-edge imaging techniques like photogrammetry. This project contributes to this research effort through the following **objectives**:

Develop and implement a mathematical model → Design and test control strategies that will control the end-effector position
Analyse the robustness of the control system configuration ←

System Description

The cable-driven hyper-redundant manipulator (CDHRM) is **hollow-core structure with passive joints** each **driven by wire ropes** that are controlled by motors at the base. **Each link is controlled by 3 cables** placed equidistant to each other around the link. Close-range measurements require precise end-effector path tracking. The fact that the end-effector position is indirectly controlled by motor rotation via the cables is what makes modelling and simulation of the system difficult.

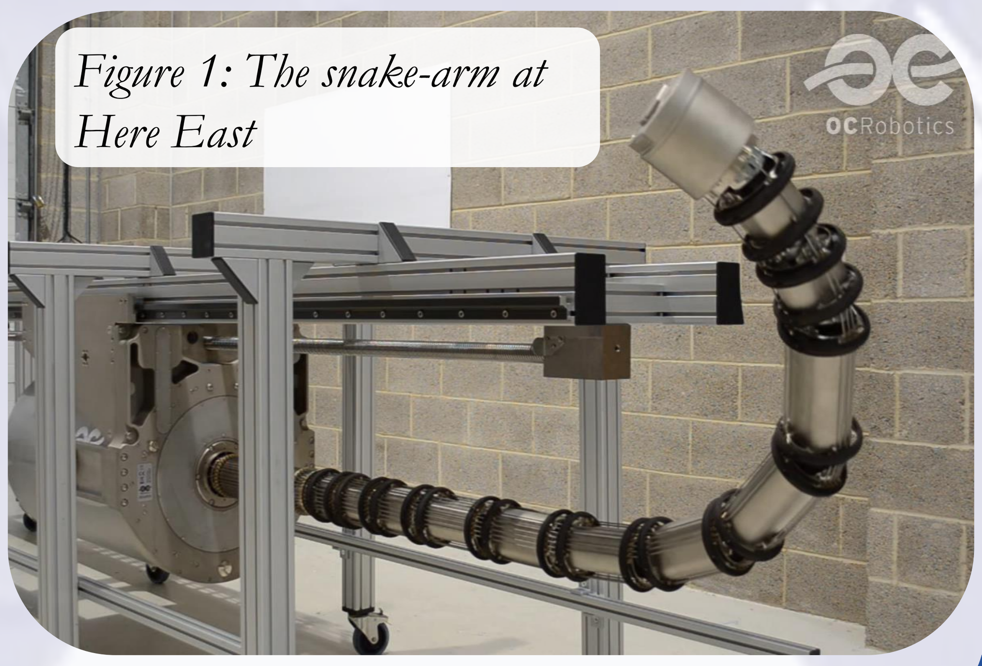
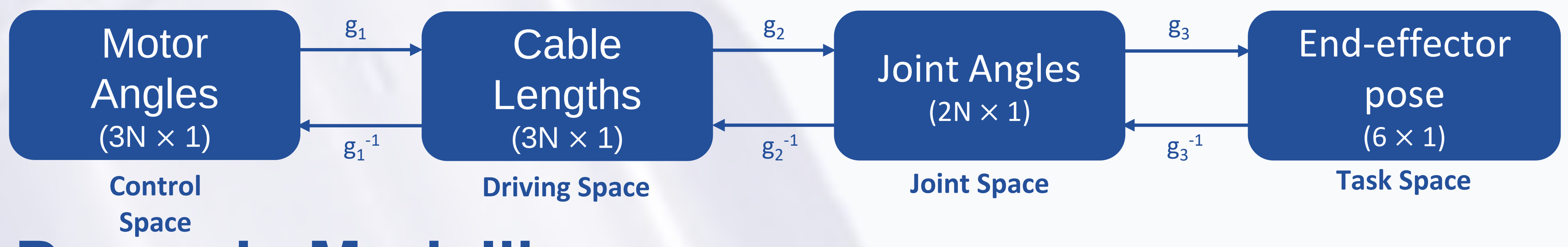


Figure 1: The snake-arm at Here East

Modelling the System

Kinematic Modelling

The kinematic modelling of the system was used to convert the reference end-effector position value to the reference motor angle of rotation value. This meant mapping between the following 4 spaces:



Dynamic Modelling

The dynamic model of the snake arm itself was derived as for a generic robot manipulator with 2 passive joints between 2 links.

$$M(\theta)\ddot{\theta} + C(\theta,\dot{\theta})\dot{\theta} + F_v\dot{\theta} + g(\theta) = \tau - J^T(\theta)F_e$$

Control System Design

The control system design developed is depicted by Fig. 2 which shows that a feedback plus feedforward strategy is used to control the angle of rotation of motor which then indirectly controls the end-effector position. Forward dynamic equations are used to then trace back the actual end-effector position achieved and to study the tracking errors obtained for it.

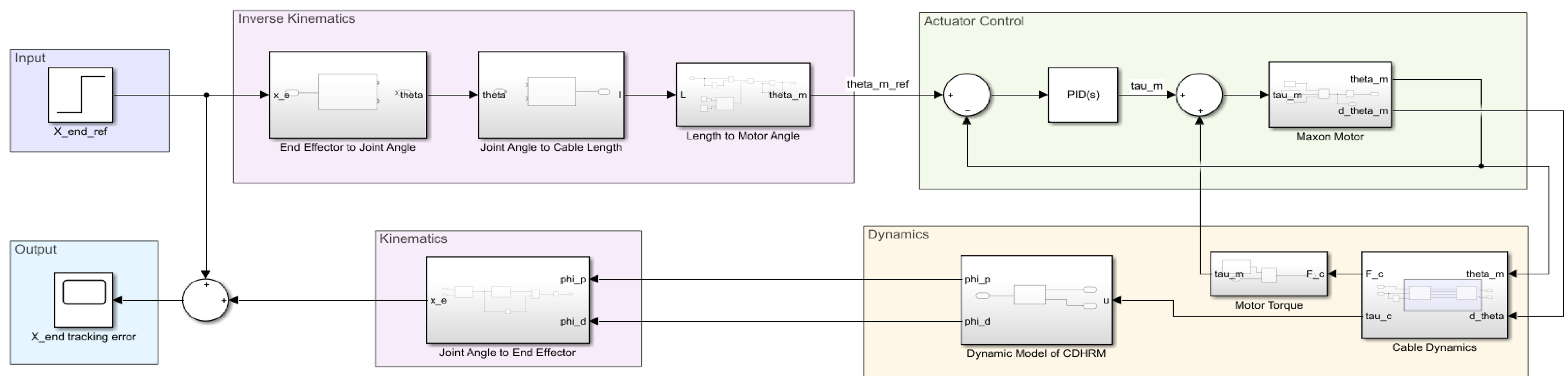
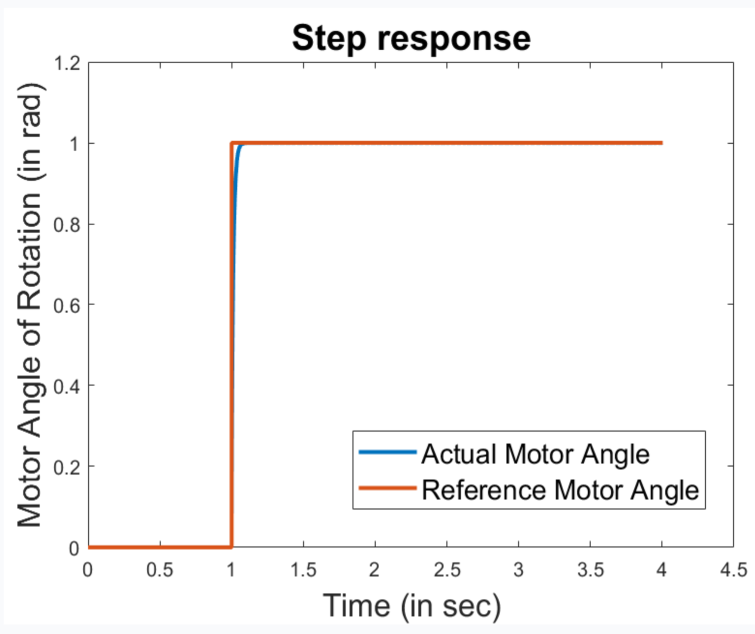
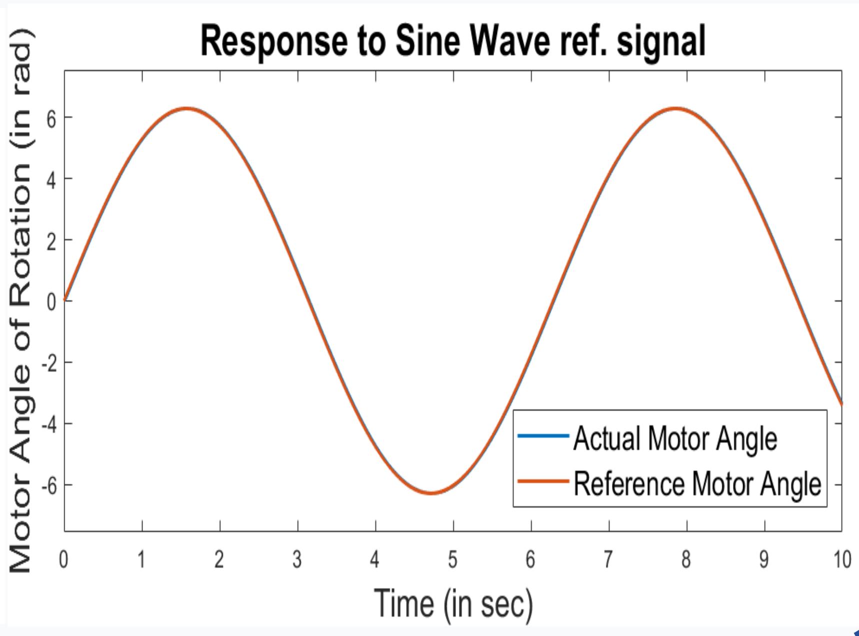


Figure 2: The control system design for end-effector position control

Preliminary Results

While this is still work in progress, tracking response of modelled motor was simulated and following responses were observed. Excellent tracking was observed however this has to be retuned as this is pure feedback response and the actual system has a feedforward response as well.





Analysis of Robustness

Analysis of robustness of the control system is to be tested by using varying values of:

- **End-effector mass** which is included in the dynamic model by the term $J^T(\theta)F_e$ in the model equation.
- **External disturbance** as an extra term F_{ext}

Conclusions

From the simulation it can proven that while control of the end-effector position is challenging it is achievable.

Further Work

- Validation of the dynamic model behaviour with actual robot.
- Implementation and comparing actual performance to that of the simulation.