Model-based Control of Small-scale Surface Vessel

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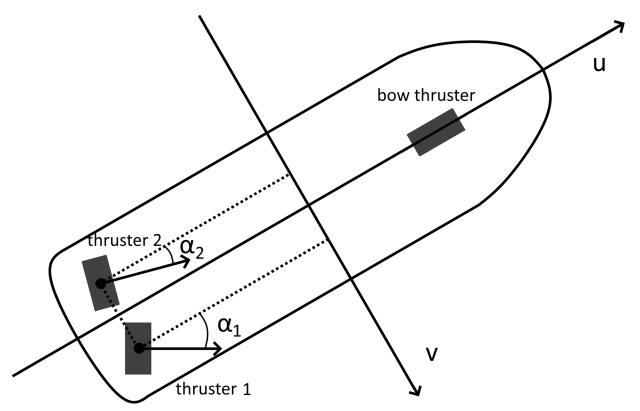
Introduction

The purpose of the project was to investigate automation of marine vessels. This was done using a small-scale ship. The project was a collaboration between Linköping university and ABB.

Main objectives

- Evaluation of a model proposed in a previous project
- Estimate the model parameters and potentially develop the model further
- Develop methods to control the boat autonomously.

The boat is actuated using three thrusters. Two azimuth in the aft and one static in the bow.



Overview of the system

Model

The model is non-linear and of greybox-type with inputs and states:

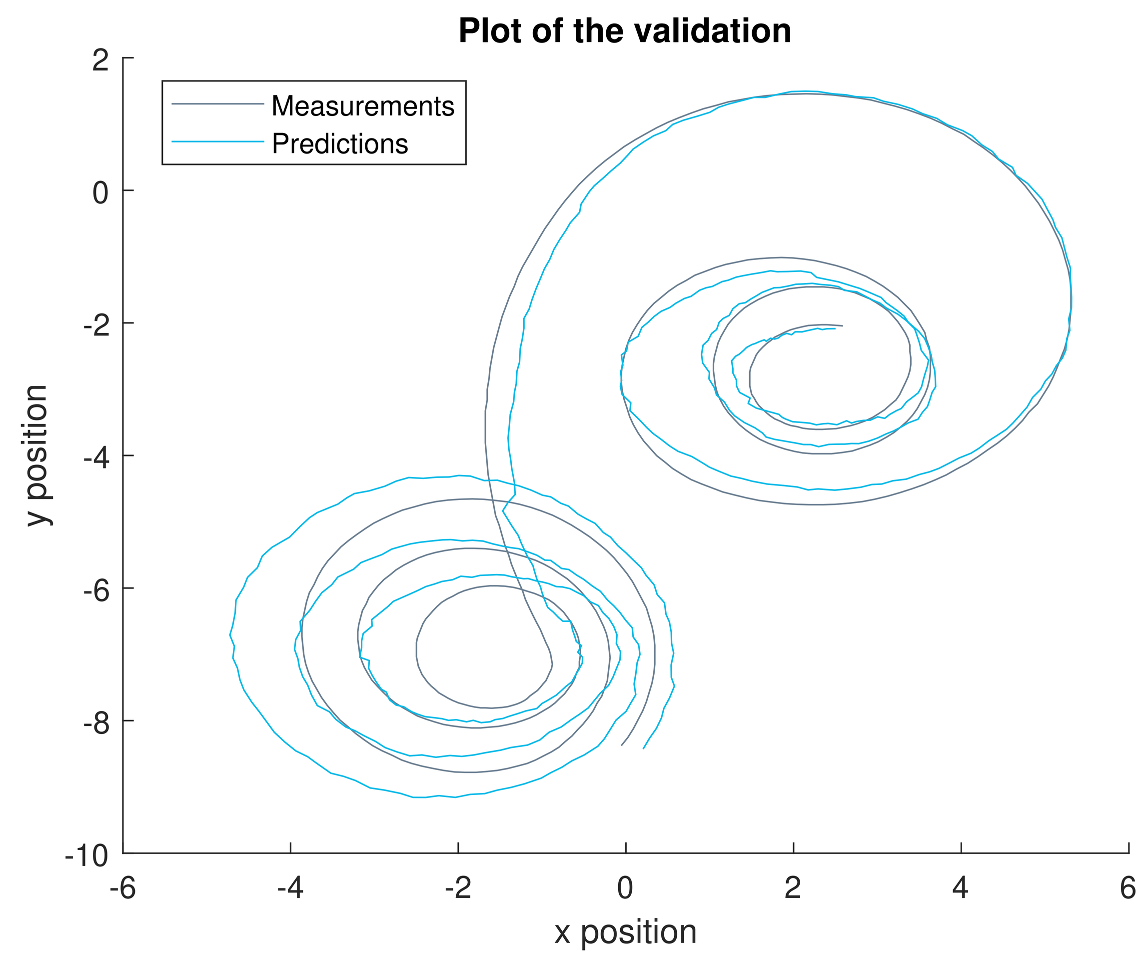
Inputs

$$\begin{bmatrix} n_1 \\ n_2 \\ n_t \\ \alpha_1 \\ \alpha_2 \end{bmatrix} = \begin{bmatrix} \text{RPM of thruster 1} \\ \text{RPM of thruster 2} \\ \text{RPM of bow thruster} \\ \text{Angle of thruster 1} \\ \text{Angle of thruster 2} \end{bmatrix}$$

States

$$\begin{bmatrix} x \\ y \\ \psi \\ u \\ v \\ r \end{bmatrix} = \begin{bmatrix} \text{Lateral position} \\ \text{Longitudinal position} \\ \text{Yaw angle} \\ \text{Surge speed} \\ \text{Sway speed} \\ \text{Yaw rate} \end{bmatrix}$$

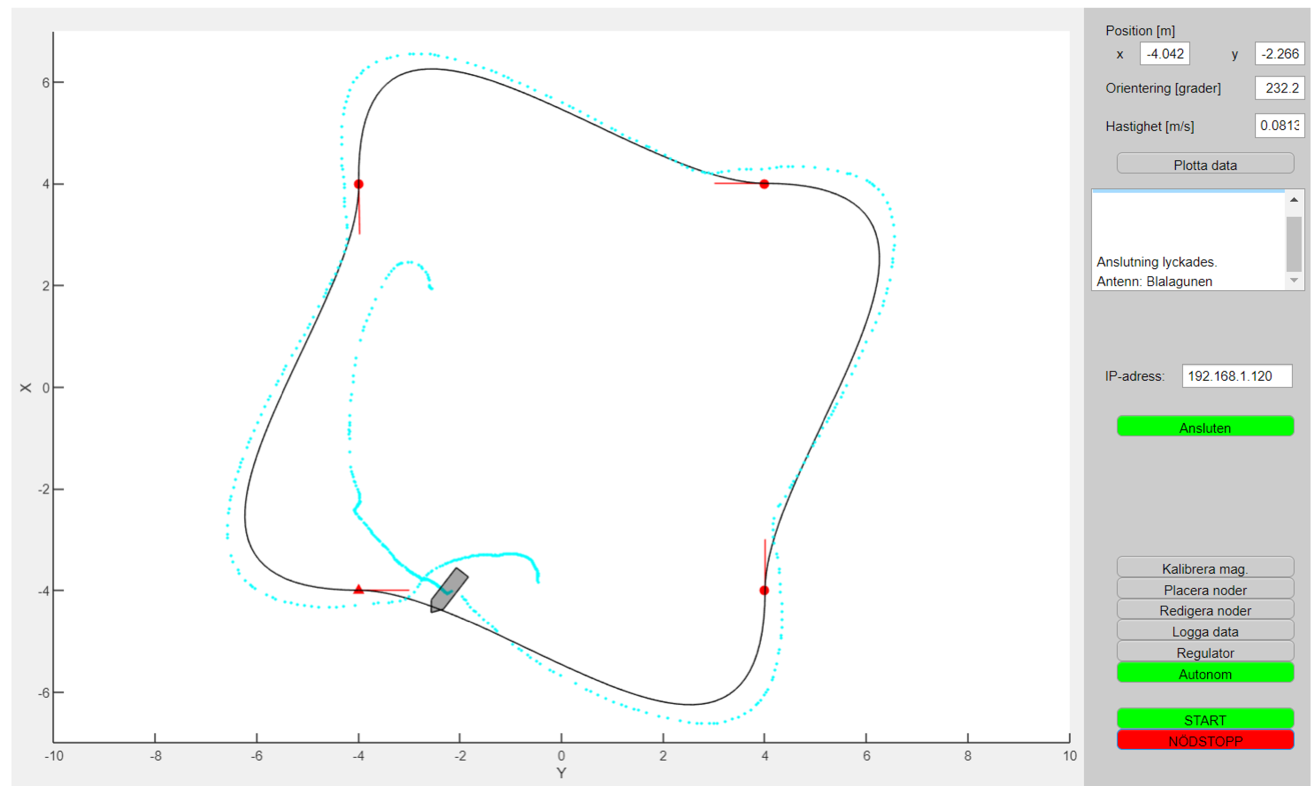
The model also includes a number of unknown, time-static, parameters that were estimated using data collected from a long test drive aimed at revealing as much as possible of the ship's dynamic properties. The unknown parameters were estimated using the MATLAB function `nlgreyest` with the acquired data. The purpose of the model is to predict the vessel's state at a given time horizon as is shown in the figure:



Performance of the model

GUI

In order to ease testing and troubleshooting a GUI was developed.



GUI in use

Control

Controllers

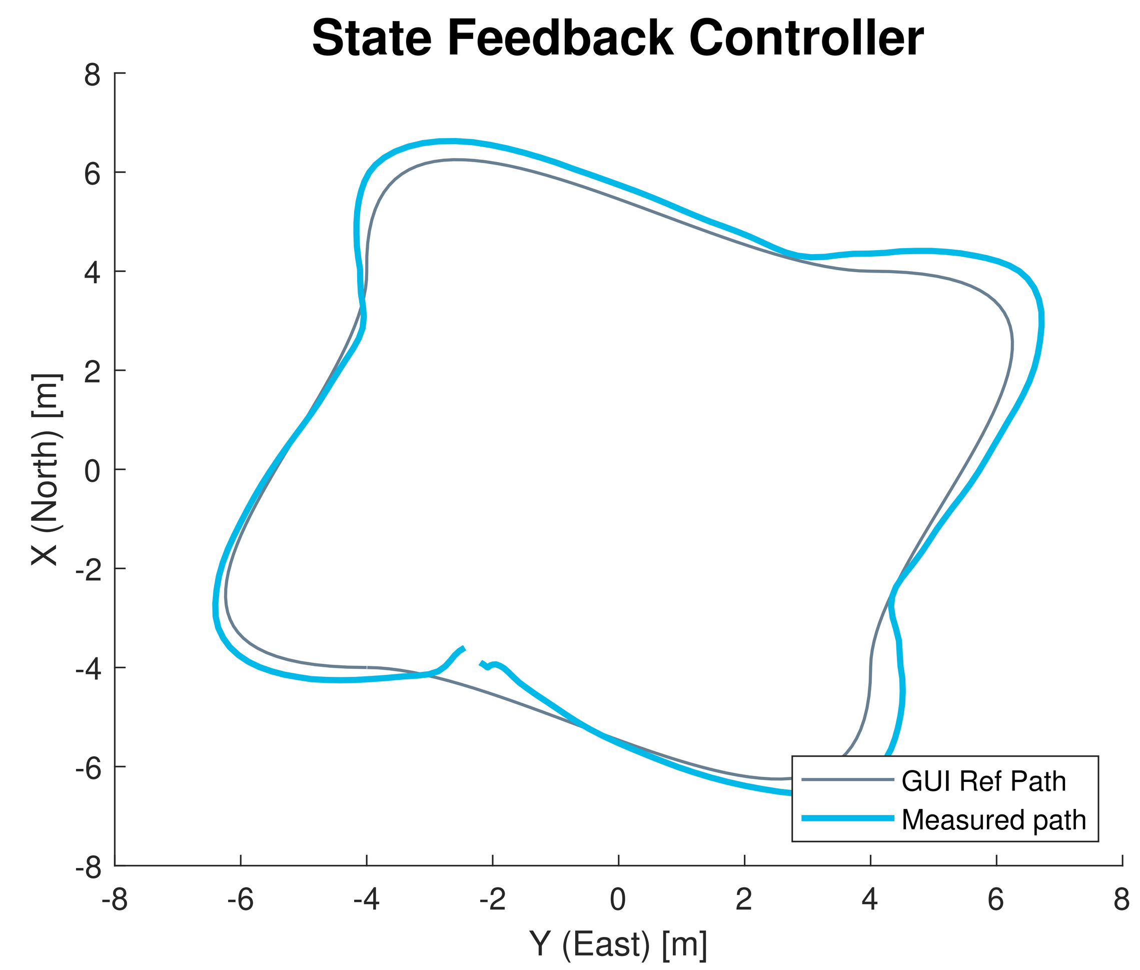
1. State Feedback (basic)
   (a) Feedback based on bicylce model
2. Model predictive control (advanced)
   (a) Linearisation w.r.t. reference-path
   (b) Quadratic program
   (c) Python library OSQP

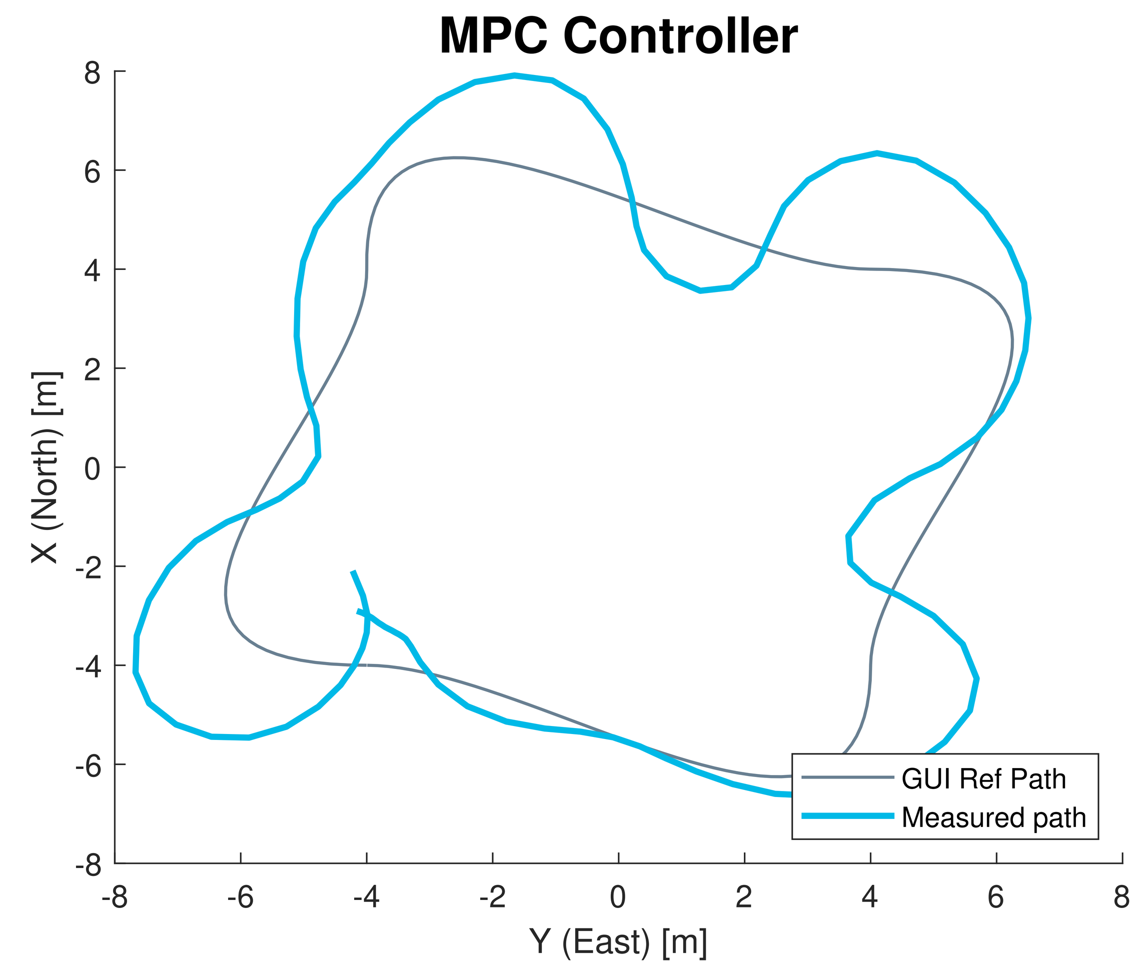
MPC

$$\dot{x}_{MPC} = A_{MPC}\, x_{MPC} + B_{MPC}\, c_f$$

$$x_{MPC} = \left[d_e\ \psi_e\ u\ v\ r\right]^T, \qquad c_f = \left[F_{1x}\ F_{1y}\ F_{2x}\ F_{2y}\ F_t\right]^T$$

$$J_n = \frac{1}{2} C_f^T P C_f + q^T C_f, \qquad s.t: A\, C_f \leq b$$





Performance of the controllers

The result is that the State Feedback works well while the MPC, which is theoretically superior, is functional but not particularly good. The project suggests several potential causes for the behavior, but the remaining time was insufficient for implementation.

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