Minireach: Autonomous Forklifts

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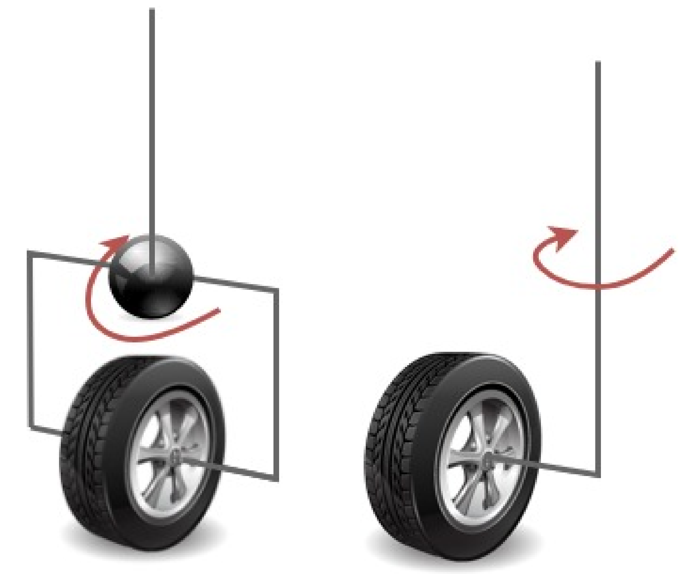
Abstract

This project has further developed a concept of autonomous forklifts in collaboration with Toyota Material Handling Europe in Mjölby. Previous projects have designed and produced two downscaled (1:3) forklifts of so-called Reach type for development purposes, referred to as *Minireach* forklifts (Figure 1a). The long-term goal with the project is to investigate opportunities and difficulties with the development of autonomous forklifts.

(a) *Minireach* forklift



(b) Drive wheel offset (left: initial model, right: physical forklifts)

Figure 1

Extension of Simulation Model

The development of the Minireach concept is mainly model-based, i.e. with limited access to the physical forklifts. This development principle requires accurate models of the system. The previous model used in the simulation environment had a severe difference compared to the physical system; the drive wheel on the real forklift had a small axial offset and was therefore not centered below the steer servo rotational axis (Figure 1b). This drawback gave the model a different behavior and hampered accurate development.

The offset was introduced in the model and the model was then validated. While extending the model, further model errors were detected, e.g. incorrect setting of maximum rotational speed of the steer servo. When validating the offset implementation, tests were conducted so that this parameter could also be tuned (Figure 2).

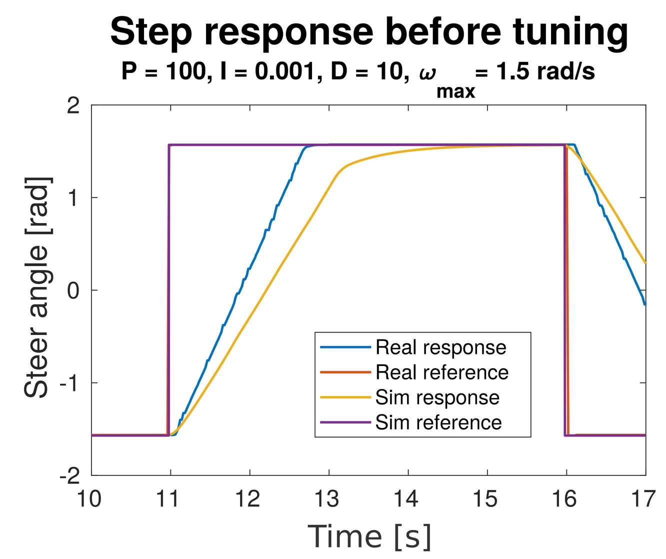


Figure 2: Tuning of controller parameters and maximum rotational velocity for steer servo.

Development of State-Space Model

In order to design a robust and reliable controller following a calculated path with high precision, development of a state-space model was necessary. The purpose of the state-space model is predicting position in a 2D-map with linear and angular velocity as inputs to the model. An accurate model of the system can be used to implement feed forward or model predictive controller functionality in the design of the controller.

The model was developed with system identification using measurements of the linear and rotational speed and the position of the real truck. For verification the positions from simulations in Simulink with the state-space model were compared to the measured positions (Figure 3). The results were also compared to tests in the robotic simulation software Gazebo with identical inputs in order to demonstrate the deviation in simulation environment.

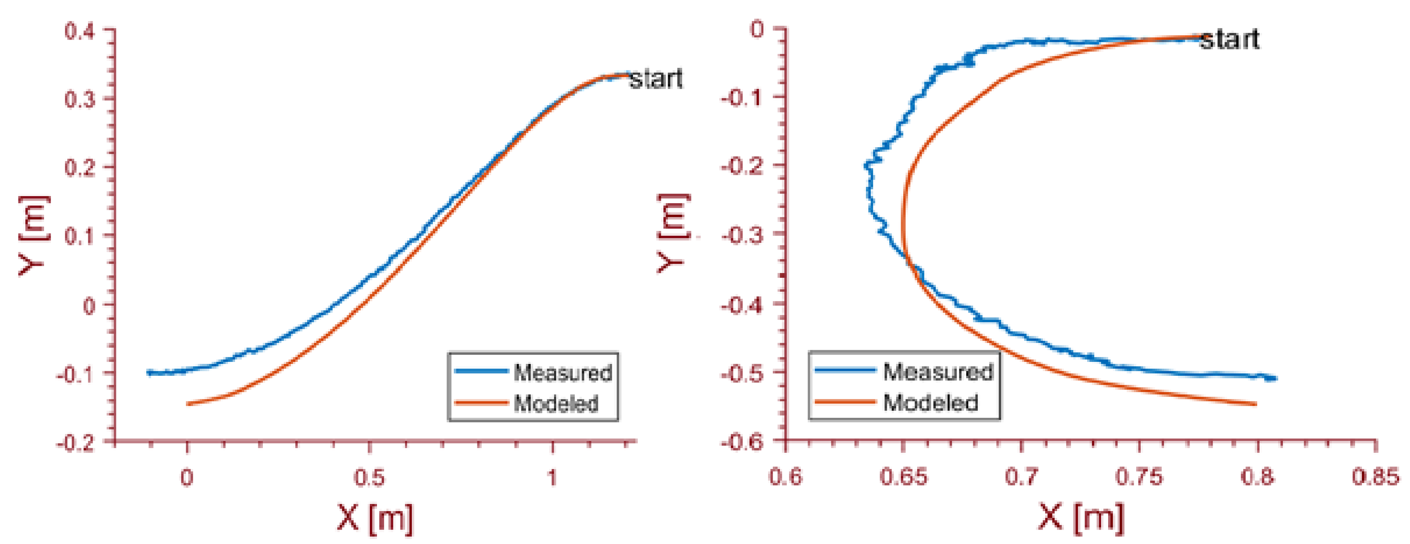


Figure 3: Comparison of position from the simulated state-space model and from the real truck with identical input signals.

Improvements to High-Precision Controller

The forklift must be able to position itself straight ahead of the pallet in order to pick it up. To accomplish this the forklift needs a good high-precision controller and good short-range planner. The forklift has been upgraded with a dynamic speed controller that sets the forward speed depending on the last errors and the curvature of future curve. This allowed for a more aggressive angular speed controller. The planner has been changed to make the forklift more robust and unnecessary turns has been removed (Figure 4). An investigation about the possibility of adding a feedforward element to the controller has been performed and shows promising results.

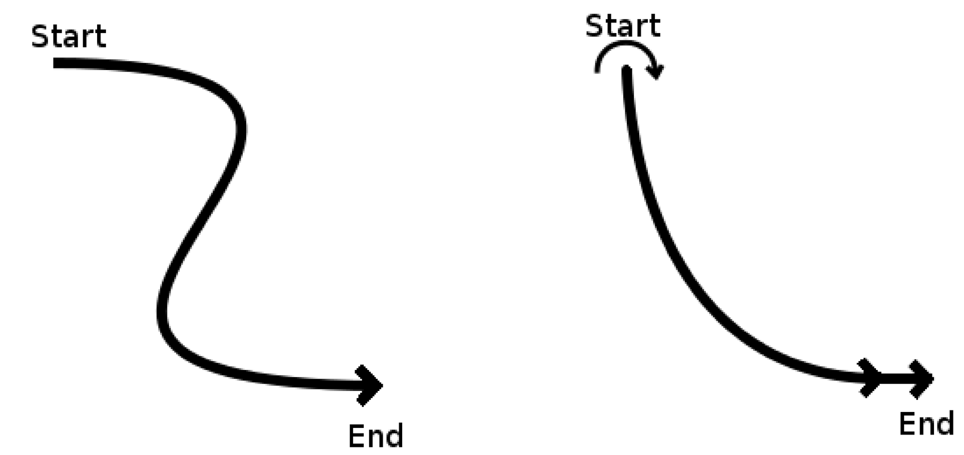


Figure 4: To the left, the previous curve is shown. To the right, the improved curve is presented.

Controller Test Results

Average simulation results following the updated curve in Fig. 4:

- Position error, x-direction: 1.23 mm
- Position error, y-direction: 7.74 mm
- Angular error: 0.59°

Conclusions

The project has achieved improvements in three different areas. The model used in the simulation environment has been improved to behave more like the physical system by introducing an axial drive wheel offset in the model. Further, a state-space model has been developed using system identification which allows for more advanced control principles to be developed. Finally, improvements have been made to the high-precision controller to enable more robust control when the forklift is following reference paths.

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