Precision Control of Forklift

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Introduction

The increase in automation in load handling places greater demands on the forklift's ability to perform precise and efficient maneuvers, without any help from an operator. The lifting maneuver is one of the critical parts of an autonomous forklift, since it has to be precise and fast without introducing oscillations. Therefore the aim of this project was to develop and evaluate an autonomous lift in simulations and on a real forklift.

Left picture: The simulated lift process.
Right picture: A forklift of model BT Reflex RRE250.

Project Goals

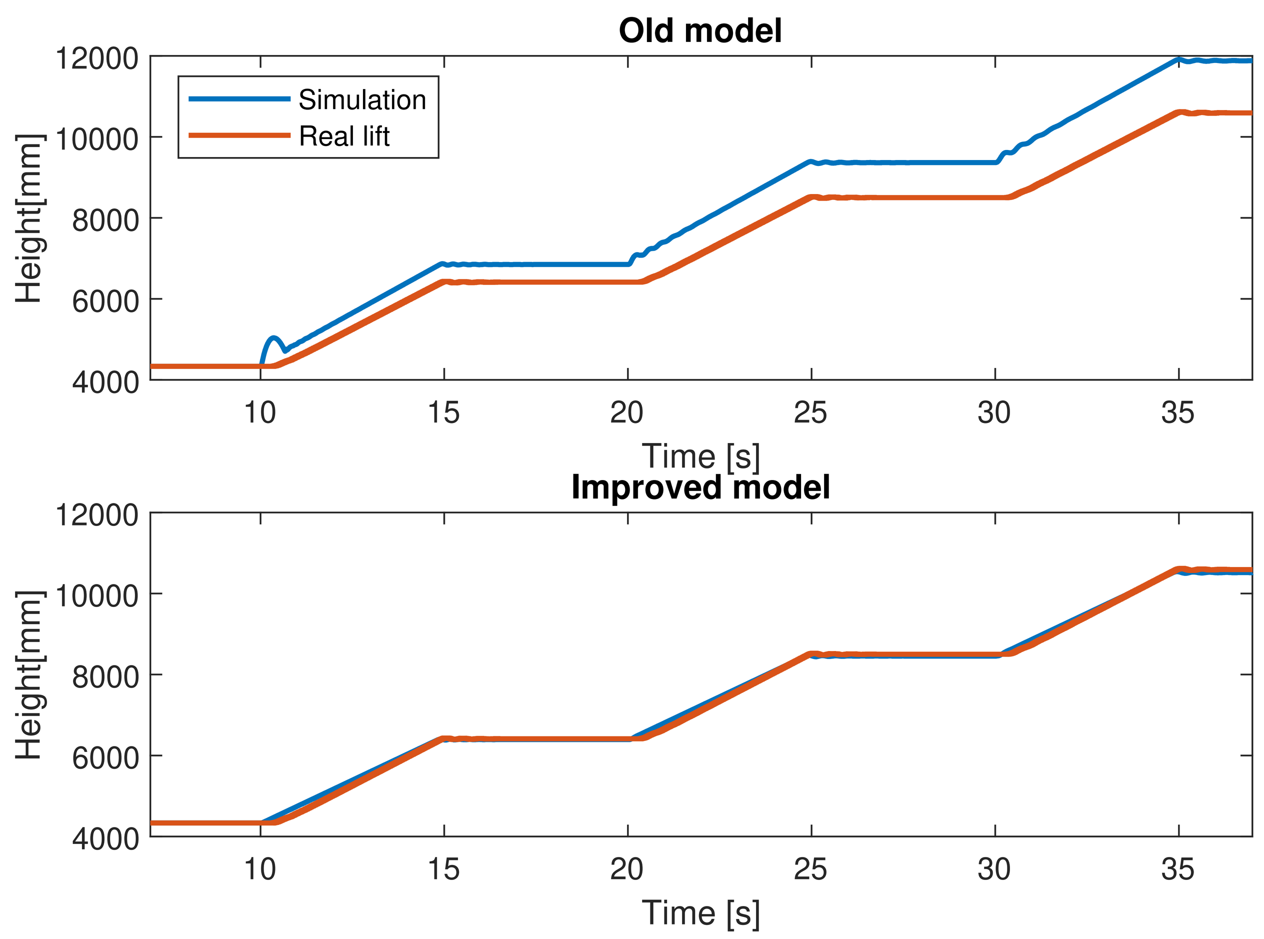
- Evaluate and develop Toyota's current model of the forklift.
- Implement a precision controller that minimizes oscillations, energy consumption and lift time, using information about the load and lifting height.
- Examine the required performance of an IMU to describe the dynamics of the lifting process.

Modeling

The model has been improved in three main areas.

- *Efficiencies* - Efficiencies have been introduced to the motor and pump models, such that the model reflects the limitations of the real forklift.
- *Hydraulics* - A pressure compensator and a pressure relief valve have been added to model the hydraulic flows better.
- *Mechanical* - A linear torsion spring and a non-linear torsion damper have been added to describe the oscillations in the horizontal direction.

The improvements of the model can be seen in the figure below.



Data from the simulation and the forklift using the same input signals.

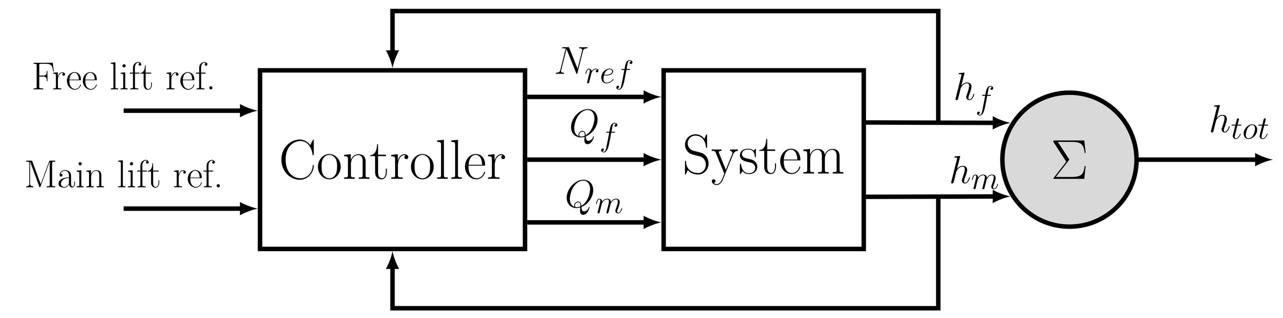
Trajectory Optimization

The reference trajectory for the controller is created by minimizing the cost function J, where P_{in} is the input power and T is the total lift time. This is done in subject to the forklift's constraints and with a constraint that all oscillations should be zero at $t = T$. The optimization is solved numerically using a direct collocation method. Different solutions are found depending on the weight w_1.

$$J = T + w_1 \int_0^T P_{in}(t)dt$$

Controller

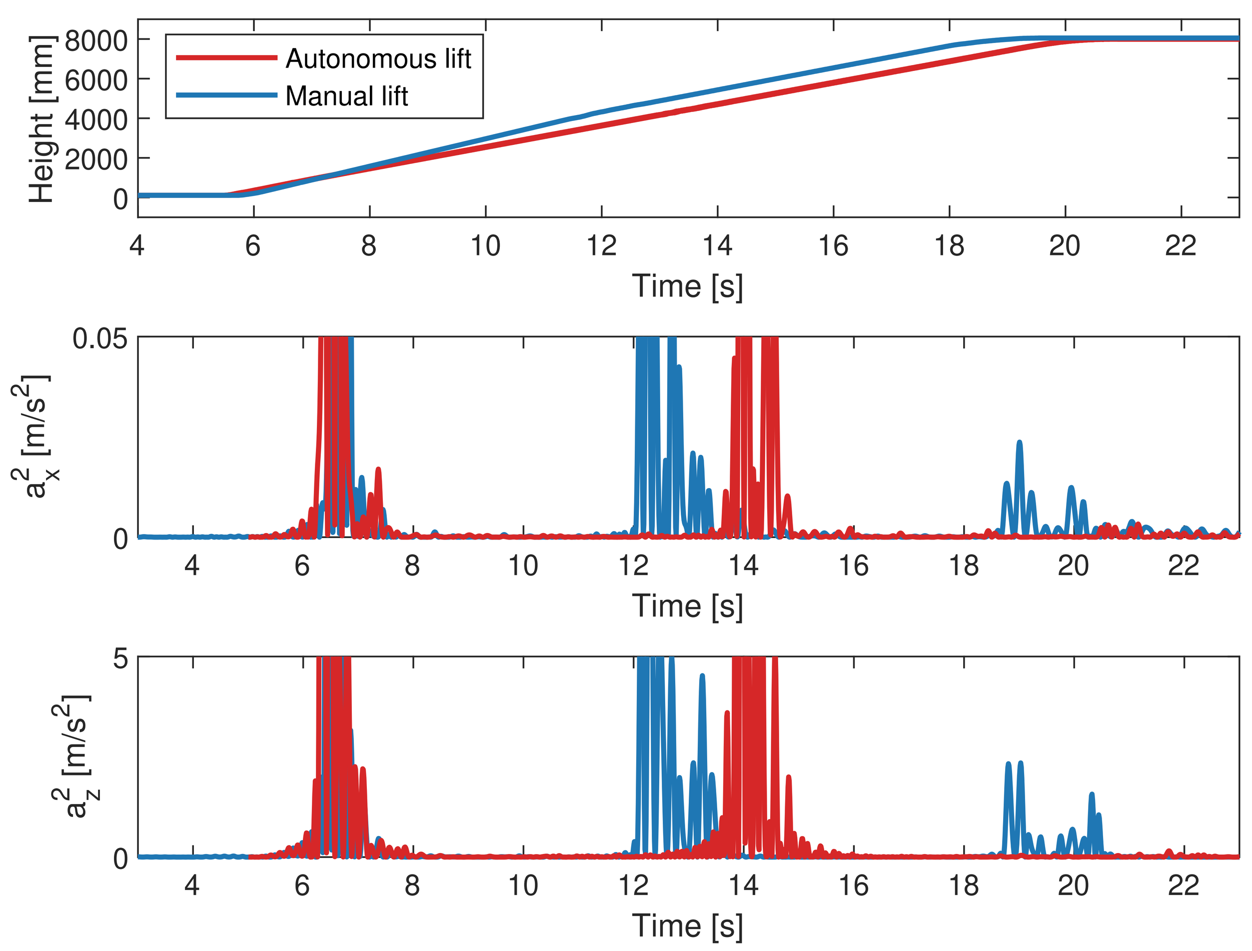
To follow the trajectories the controller is utilizing the three input signals pump speed, free lift valve current and main lift valve current. It uses two feedback loops with feed forward terms.



The structure of the controller.

Results

The goal of the controller and trajectory is to reduce the oscillations at the end of the lift, at around 20 s in the figure below. The oscillations are evaluated by the square of the accelerations. With this measure the implementation reduced the oscillations with over 80 % in the horizontal direction and over 90 % in the vertical direction compared to the manual lift.



Comparison of IMU-data between a manual and an autonomous lift.

Achievements

- The model behaviour has closer resemblance to the real forklift.
- The oscillations are decreased with over 80 %.

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