Opposition Report

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1 Introduction

This report present the opposition for the Master's Thesis *Model Predicitive Control of a Tricopter* by Karl-Johan Barsk, written during the spring semester of 2012 at Linköping University.

1.1 Thesis Outline

The thesis presents the identification and control of a tricopter UAV. Three different models are proposed, identified and evaluated in the thesis, and used for state estimation and MPC control.
Two variants of MPC are evaluated: explicit MPC and Fast Gradient MPC. Each of the variants are tested on a microcontroller using code generated from MATLAB.
The proposed MPC controllers focus on stabilizing the angular rates of the tricopter, following the reference of a pilot.

1.2 General Comments

The thesis covers an interesting subject in a very demanding type of application - not least because of the computational limitations of the system. The report is very well structured, and the workflow is easily followed through the report.
The citation style used in the thesis - text without brackets - sometime makes it quite difficult to know when a citation is referenced, and sometimes even makes for very strange sentences[1].
In some later parts of the report, the text is somewhat too implementation-specific, explicitly defining the MATLAB commands that were used. While detail is not nescessarily wrong, it receives too much focus, especially in the *Controller*-chapter.
The report is well supported by good figures and relevant choices of plots.

2 Structure

To the thesis, a table of notation is prepended. Although the table may be somewhat inexhaustive, this is a very good idea and helps the uninitialized reader to understand the terminology.

[1] Example from p. 21: "*... and then inverting Gustafsson ...*"

In the introduction, a good description of the thesis outline is provided as well as a description of the problem that was studied in the thesis. The section of related work could be expanded, however.
The thesis is logically divided into the following parts:

- Description of the tricopter,
- Motion model structure,
- Motion model identification,
- State estimation,
- Model Predictive Control.

The chapter outline is well chosen and logical, and there is an apparent thread throughout the thesis that is consitently followed on the path to obtaining the controller which was to be studied in the project.
The discussion of each chapter is placed at the end of each chapter, although the only chapter where this is apparent is the *System Modeling* chapter, which is the only chapter with a section called *Discussion*. In the other chapters, it is somewhat unclear where the theory ends and the discussion begins. The discussion might have been favorably collectively deferred to a separate chapter following the presentation of the results.

3 Modeling

Three different models are described and evaluated in the thesis:

- The Physical model,
- The Simple model,
- The Virtual model.

The naming of the model is somewhat confusing - why, for example, can't the virtual model be a simple model? A common font style for the models could increase the readability.
It is nonetheless an interesting addition to the thesis to study different variants of models. It would be interesting to for instance continue the efforts to improve the performance of the physical model for comparison with the *simple* and *virtual* models, which were the ones that received the most focus in the thesis.
One discrepancy in the thesis is the use of rotational velocity of the propellers in the modeling, whereas the controller later sees this variable as a measure of PWM pulse width. The variable may be used somewhat interchangably in the case of a linear relation between the two, although the connection is very unclear in the thesis.
There also seems to be a slight misconception as to the interpretation of the roll (ϕ), pitch (θ) and yaw (ϕ) angles, as these are presented as the rotation around the Earth-fixed base vectors, which is not generally true - see for instance Tait-Bryan angles common in avionics.
The inclusion of the virtual model, and its comparison to the simple model, is an interesting addition to the thesis.
The model identification performed in the thesis is well described and the verification experiments are relevant.

4 Control

The controller part of the thesis uses the models from the previous chapters to evaluate two methods for Model Predictive Control, both of which are well justified, relevant choices for the purpose of implementation on a microcontroller. Even though the MPC problem is well defined in the thesis, it would be beneficial to describe and discuss its relation to the Linear Quadratic controller, and to use this as a simple case to describe the weighting of error versus control signal amplitude.
The optimization problem that the MPC solves is well described in the thesis, although without prior knowledge of the nature of PWM signals, the reader may be severely confused as to why the rotational velocity of the propeller is limited to $[1000, 2000]$ microseconds (wait, what?), and the angle of the servo to $[-300, 300]$ microseconds - the latter including negative time.

5 Discussion

The following questions are relevant for discussion of the report, following the formal presentation.

5.1 Modeling

- The grey-box physical model that was identified in the thesis could not properly describe the motions of the vehicle, do you have any ideas as to why?
- When the simple model was used, the amplitude of the control signals are unbalanced between the motors. Is this behaviour “optimal” in the MPC optimization, or are there e.g. model errors that introduce this behaviour?
- The matrix of inertia is assumed to be diagonal. Are there symmetry reasons for this, or is it just a simplification?

5.2 Filtering

- In the thesis, a Low-Pass filter is described as a way for state estimation. What was it used for, and to what benefits?
- For the estimation and validation data set, MATLAB was used to concatenate different datasets. How was the data merged and fitted in the joints?

5.3 Control

- In the thesis, it is mentioned that an MPC without active constraints is equivalent to an LQ controller if the weight of the end state is chosen as the solution to the Riccati equation. Can you, briefly, explain why this is so, and how this can be a general result for all prediction horizons?
- In the explicit MPC, the prediction horizon is only two steps - that is, 0.04 seconds. How does this affect the performance of the system?

- In the explicit MPC, a tree search is used to find the active polyhedra. Could the performance of the algorithm be improved by using other methods of indexing? Is the tree search a relevant time-factor?
- The control variable in the MPC is the PWM pulse width, whereas in the model identification, the rotational velocity of the propellers is used. How are these two related?