TTK4135 Optimization and Control
Lab Report

750001, 750002, 750003, and 750004 (Tor Aksel Heirung)
Group 4?

April 20, 2016

Department of Engineering Cybernetics
Norwegian University of Science and Technology

Abstract

This document outlines a few important aspects of the lab report. It contains some advice on both content and layout. The Latex source for this document is also published, and you can use it as a template of sorts for your own report.

When you write your own report, this section (the abstract) should contain a *very* short summary of what the lab is about and what you have done.

Contents

1   Introduction

Your introduction should contain an overview of the work you were assigned, as well as a few sentences putting the work into a larger perspective. You should also give a quick description of how the report is organized (as is done below).

You should of course put most of the work into doing good work in the lab and then presenting it in the report. When presenting your work in the report, both content and presentation/layout matters. Since your only way of communicating your good effort in the lab is through writing about it here, the way you write about it is essential. This means that even if you have the very best controller but describe it poorly, you will probably not be rewarded for the good results. A plot showing perfect control is worth very little if it is not accompanied by a clear description of what it represents.

Layout is naturally less important than content, but it still matters. You can think of report writing like selling an apartment; when you present your apartment for potential buyers you will of course clean the apartment and make it good looking. How clean the apartment is does of course not determine its value, but it is still important since it influences the subjective value your buyers will put on the apartment.

1.1   Software

You are of course free to use whatever software you want for report writing. You can also submit a handwritten report, although this is probably not a great idea if your handwriting can be hard to read.

You can also use Word or a similar word processor. However, it is next to impossible to achieve decent layout with Word. The support for vector graphics (discussed later) is extremely poor, and text tends to look pretty bad (bad support for kerning and ligatures). Furthermore, math is both time consuming and difficult to input, and tends to look very ugly. In general, a report written in Word looks like a draft.

It is strongly recommended to use Latex. Unless you tweak the layout too much, your report will almost certainly look very good. Although it can take a bit of effort to get started, it is also much quicker to use than Word and similar programs. The support for math and vector graphics is also great.

If you are new to Latex, you can have a look at the source for this document to get started. You can also look at the presentation by Berland (2010) (in Norwegian) or consult Oetiker et al. (2011). Another good reason to learn Latex is that you probably don't want to write your master's thesis in something like Word, doing so would likely be very frustrating. Being reasonably fluent in Latex before you get that far will make your thesis work much smoother.

Some of you are probably fluent in Latex and might plan to write the report using it. Please resist the temptation (if any) to change the fonts, make super fancy headers (they are not necessary for a report like this), change the margins, change the paragraph indentation and/or spacing, and similar things.

A great tool for collaborating on Latex documents is ShareLaTeX at `https://www.sharelatex.com/`; if you use this you won't have to install anything on your computer. Texmaker at `http://www.xm1math.net/texmaker/` is a good cross-platform editor. Some people like Lyx, which is a Latex editor that behaves a little bit like Word.

1.2   Other Comments

If you have problems with Latex, the solution is usually just a few Google searches away.

You can write the report in Norwegian or English. Writing in English is encouraged and is great practice, but entirely optional. *Do not interpret any of the advice or suggestions here as requirements.*

This report is organized as follows: Section 2 contains a few remarks on report writing and some random Latex advice. An example of a table can be foundin Section 3, along with two remarks on report writing. Section 4 contains some advice on using plots from MATLAB. A few suggestions for making illustrations are given in Section 5; a matrix equation can also be found here. Section **??** has a few comments on references and floats in Latex. The closing discussion and concluding remarks are in Sections 6 and 7, respectively. Appendix A contains a MATLAB file while Appendix B shows an example Simulink diagram. The Bibliography can be found at the end, on page 27.

2 Problem Description

In this section you should describe the lab setup and discuss the model. If you want, you can copy the source code for the model equations:

$$\ddot{e} + K_3 K_{ed}\dot{e} + K_3 K_{ep}e = K_3 K_{ep}e_c \tag{1}$$

$$\ddot{p} + K_1 K_{pd}\dot{p} + K_1 K_{pp}p = K_1 K_{pp}p_c \tag{2}$$

$$\dot{\lambda} = r \tag{3}$$

$$\dot{r} = -K_2 p \tag{4}$$

Since these equations belong together, it's a good idea to number them like this:

$$\ddot{e} + K_3 K_{ed}\dot{e} + K_3 K_{ep}e = K_3 K_{ep}e_c \tag{5a}$$

$$\ddot{p} + K_1 K_{pd}\dot{p} + K_1 K_{pp}p = K_1 K_{pp}p_c \tag{5b}$$

$$\dot{\lambda} = r \tag{5c}$$

$$\dot{r} = -K_2 p \tag{5d}$$

You can then both reference individual equations ("the elevation equation (5a)") or reference the entire model ("the linear model (5)"). Regardless of your choice of software, never hard-code a reference, always use dynamic references.

You could also align the equations like this:

$$\ddot{e} + K_3 K_{ed}\dot{e} + K_3 K_{ep}e = K_3 K_{ep}e_c \tag{6a}$$

$$\ddot{p} + K_1 K_{pd}\dot{p} + K_1 K_{pp}p = K_1 K_{pp}p_c \tag{6b}$$

$$\dot{\lambda} = r \tag{6c}$$

$$\dot{r} = -K_2 p \tag{6d}$$

You can consult Downes (2002) for more about writing math.

If you decide to include a figure, that's great. You can in general copy figures from the textbook, the assignement text, or other places. However: ALWAYS CITE THE SOURCE.

Table 1: Parameters and values.

Symbol	Parameter	Value	Unit
l_a	Distance from elevation axis to helicopter body	0.63	m
l_h	Distance from pitch axis to motor	0.18	m
K_f	Force constant motor	0.25	$\mathrm{N\,V^{-1}}$
J_e	Moment of inertia for elevation	0.83	$\mathrm{kg\,m^2}$
J_t	Moment of inertia for travel	0.83	$\mathrm{kg\,m^2}$
J_p	Moment of inertia for pitch	0.034	$\mathrm{kg\,m^2}$
m_h	Mass of helicopter	1.05	kg
m_w	Balance weight	1.87	kg
m_g	Effective mass of the helicopter	0.05	kg
K_p	Force to lift the helicopter from the ground	0.49	N

3 Repetition/Introduction to Simulink/QuaRC

This section should not be very long.

If you want, you can use the source for Table 1 to see how a (floating) table is made.

Variables and symbols are always in italics, while units are not.

4 Optimal Control of Pitch/Travel without Feedback

Answer all the parts of the first exercise in an organized and clear manner. You should of course try to get good results in all the exercises, but if you have made a good effort without achieving great performance, a good discussion of possible reasons is just as good. Present your thinking and efforts and discuss possible reasons for good or bad results.

Include plots of all relevant results, but make sure you don't overwhelm the reader with too many plots. Also keep in mind that the plots should be as "readable" as possible; that is, they should not be too hard to interpret.

There are some important things to consider when exporting figures from MATLAB, most importantly which format you use. Never ever use JPEG for anything that is not a photography or similar. Any figure, like a plot or block diagram, must never be stored as a JPEG. If you zoom in on Figure 1 you can see a lot of noise close to any of the dark curves and lines, this is due to the compression in JPEG. Figure 1 will look horrible both on a screen and on paper.

The PNG format is slightly better for plots, but since it is a raster format (a grid of pixels), it looks ugly if you zoom in. It also looks ugly if you scale it, both on a screen and on paper. Try to avoid PNG if you can. Figures 2 and 3 are both PNG figures; the latter being a larger figure scaled more than the former. Note both how choppy and ugly the blue curve is, and how the different sizes create inconsistent font sizes.

The simplest way to get a reasonably good looking plot is to save it as EPS in MATLAB. Do this by clicking "File" in the figure window, and the "Save As...": choose "EPS file (*.eps)" in the "Save as type:" menu.[1] Figure 4 shows a plot in EPS format. Since EPS is a vector format, the Figure can be scaled and still look good (but mind the font size!). If you zoom in you can see that the curve and the letters/numbers are smooth. A figure in vector format will usually look good both on a screen and on paper.

Note that the size of the actual figure window in MATLAB determines how large the exported figure is. Hence, if you enlarge the figure window before exporting, you will need to scale the figure by a larger factor in the report. This will lead to a tiny font in the figure. There are many better ways of exporting graphics from MATLAB, but they quickly become fairly involved. The above method of exporting to EPS will in most cases give nice figures.

You can write Latex in your MATLAB figures. The script used to create Figures 1–4 is included in Section A.1. Do not use a screen shot of a scope of figure in MATLAB in your report.

---

[1]pdfLatex does not support EPS directly, but since we have loaded the *epstodf* package, this is not a problem.
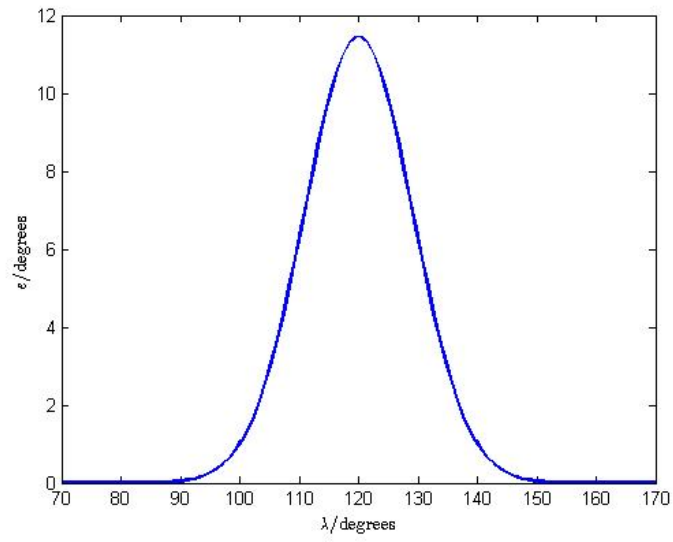
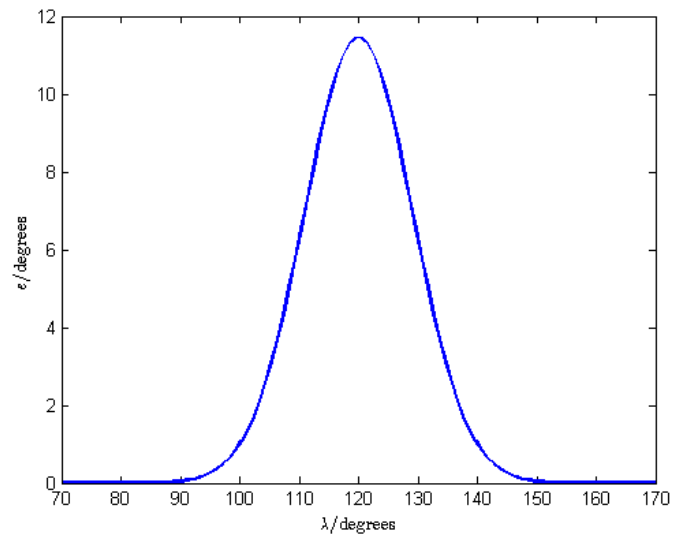Figure 1: A plot in JPEG format — a very bad idea.

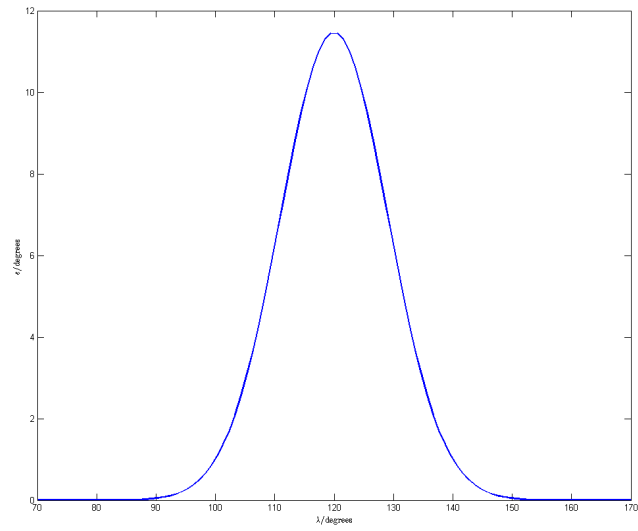Figure 2: A plot in PNG format — a bad idea.

Figure 3: A plot in PNG format — a bad idea. This figure is originally larger than the other PNG figure, but both are scaled to the same size.
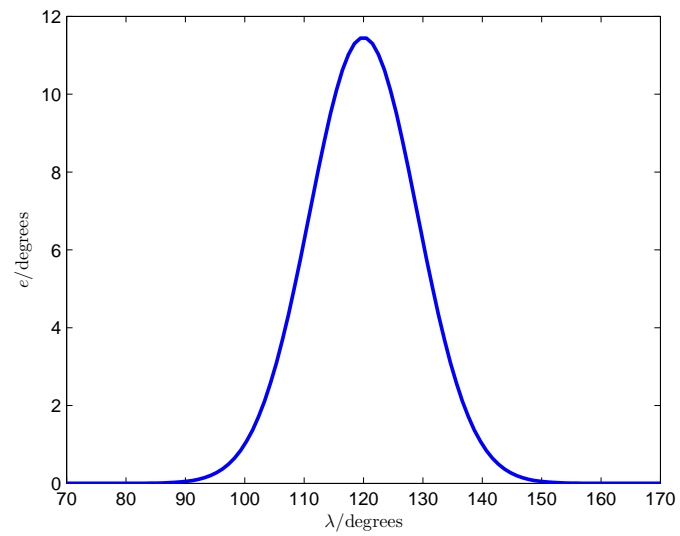

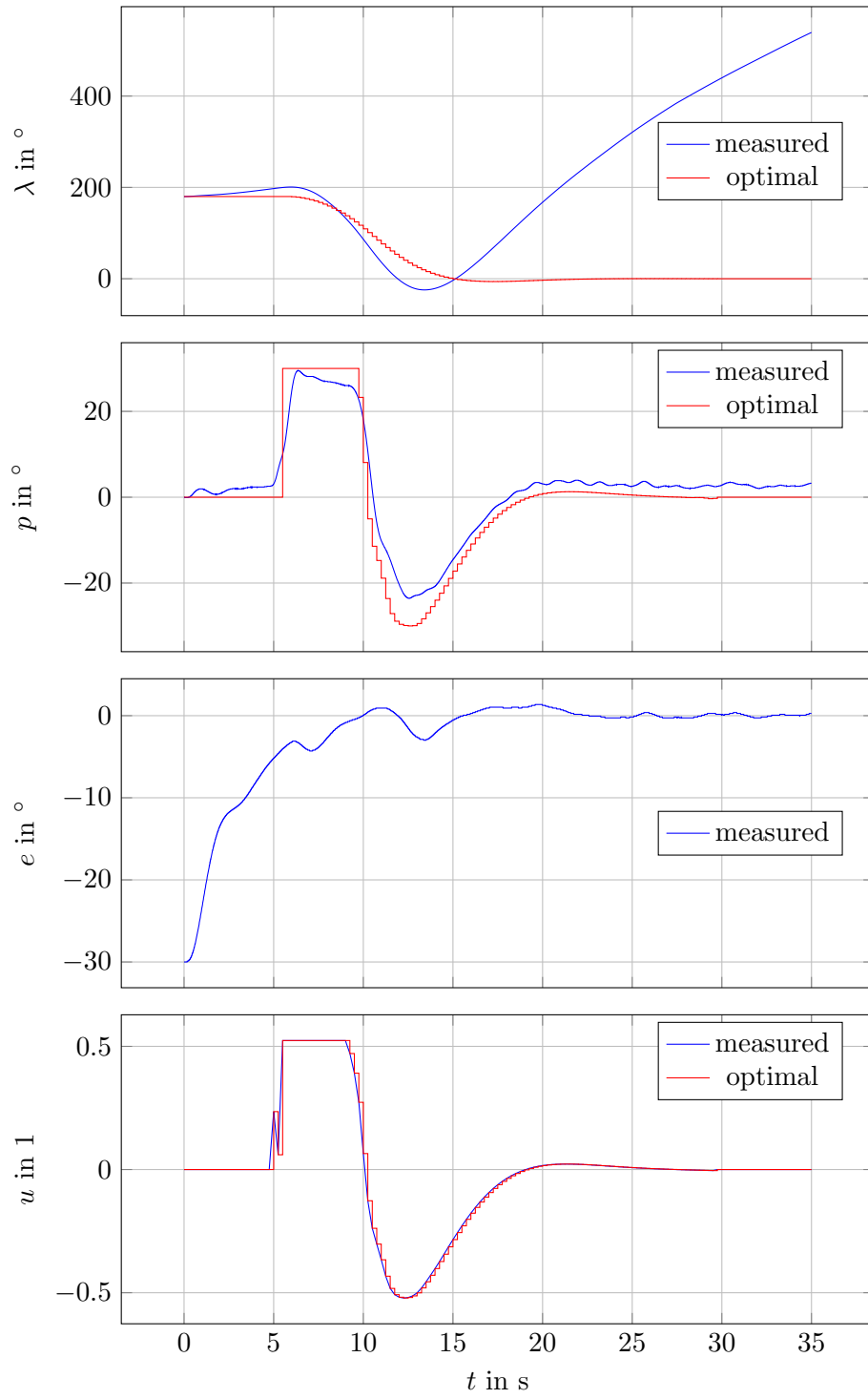Figure 4: A plot in EPS format — a much better idea.
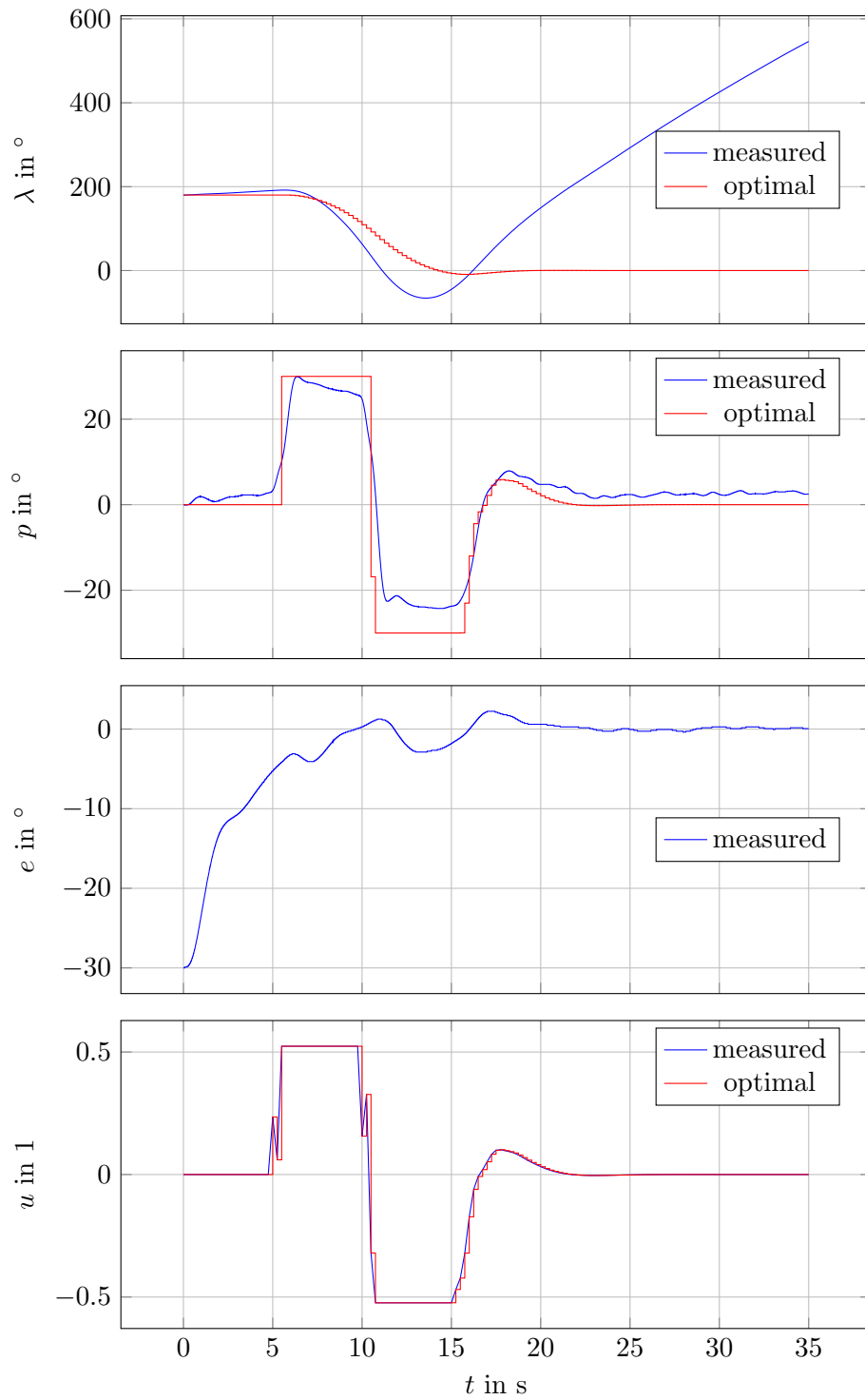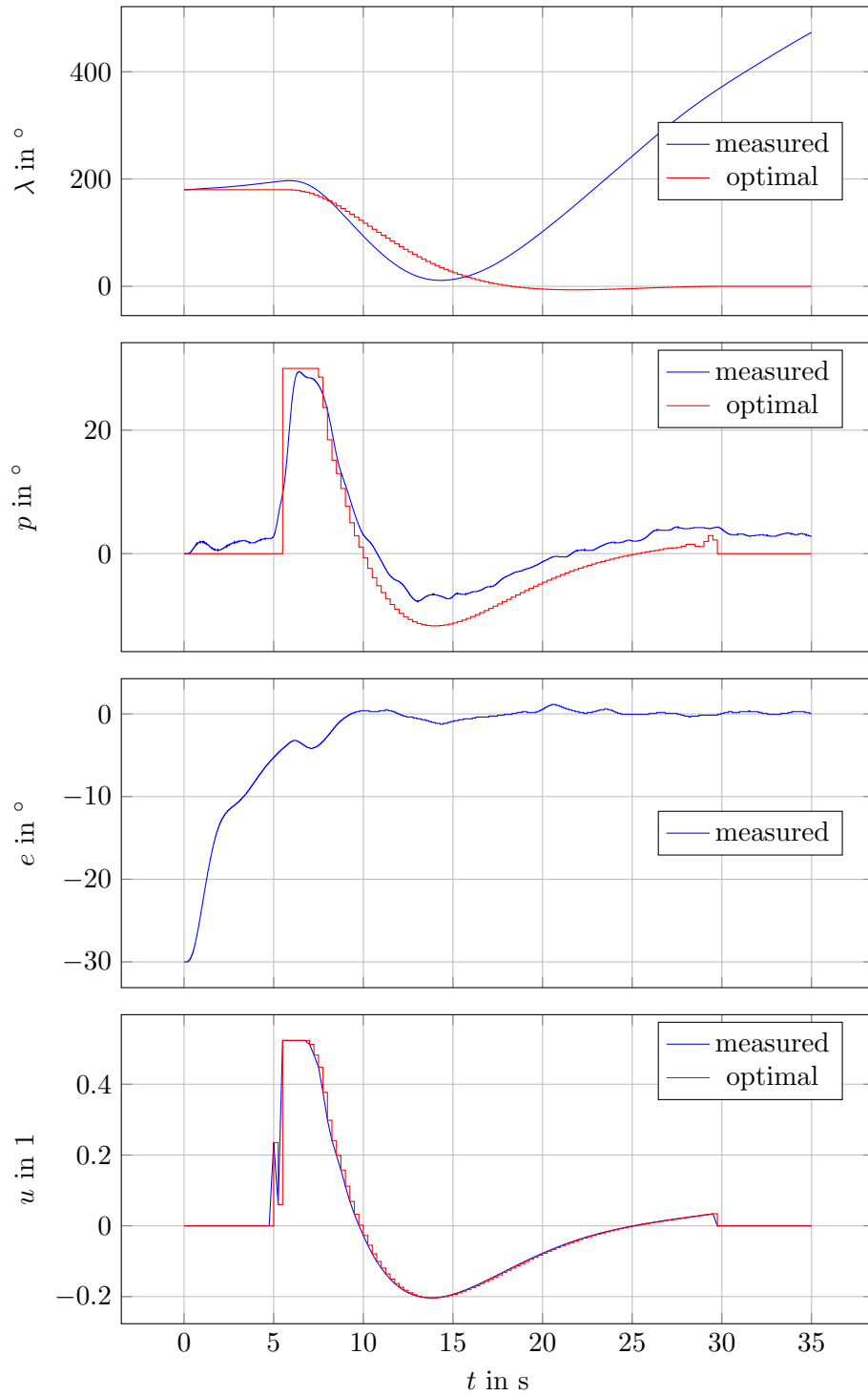
10

Figure 5: problem2plots_q_1.0

11

Figure 6: problem2plots_q_0.1

Figure 7: problem2plots_q_10
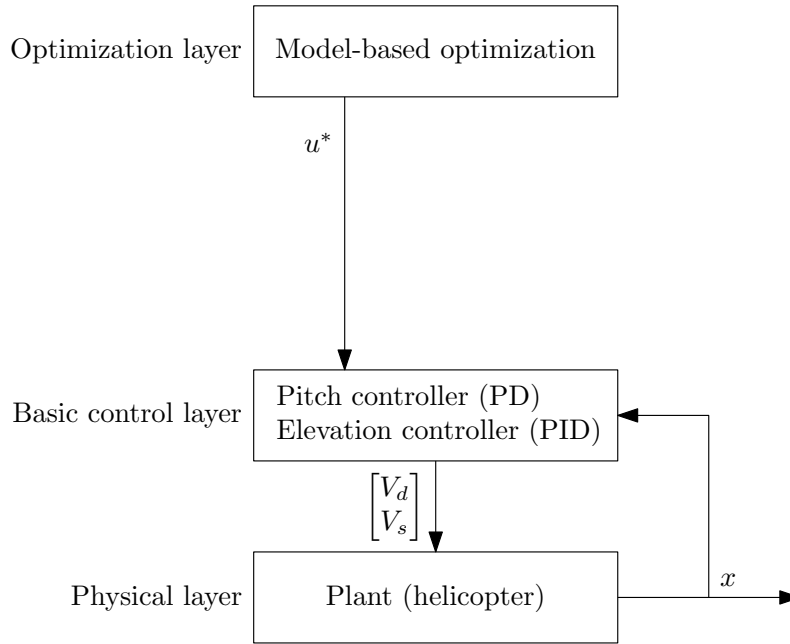
Figure 8: A figure created with Ipe.

5 Optimal Control of Pitch/Travel with Feedback (LQ)

You are as mentioned welcome to use the figures from the assignment text if you want to (cite the source!). You can also draw your own (cite the source if it is heavily based on someone else's.). Figure 8 was created quickly with Ipe. Inkscape is a good alternative for more advanced illustrations. Some people prefer the Latex package TikZ (http://texample.net/tikz/examples/), but this takes a little effort to learn.

Here is a matrix equation you can use as a template:

$$
\begin{bmatrix}
1 & 0 & 0 & 0 & -b & 0 & 0 & 0 \\
-a & 1 & 0 & 0 & 0 & -b & 0 & 0 \\
0 & -a & 1 & 0 & 0 & 0 & -b & 0 \\
0 & 0 & -a & 1 & 0 & 0 & 0 & -b
\end{bmatrix}
\begin{bmatrix}
x_1 \\ x_2 \\ x_3 \\ x_4 \\ u_0 \\ u_1 \\ u_2 \\ u_3
\end{bmatrix}
=
\begin{bmatrix}
ax_0 \\ 0 \\ 0 \\ 0
\end{bmatrix}
\tag{7}
$$
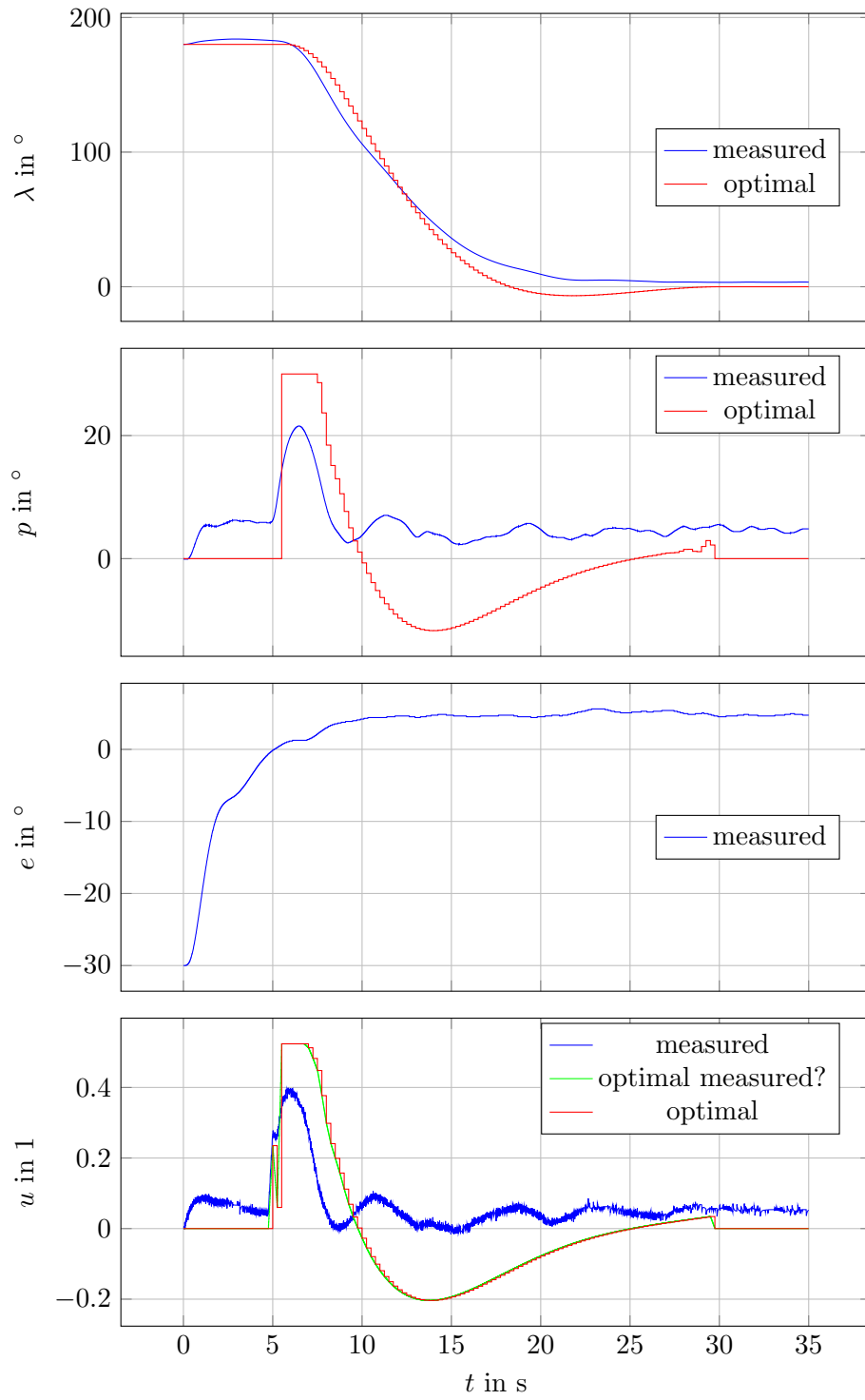
Figure 9: problem3plot_1010_1
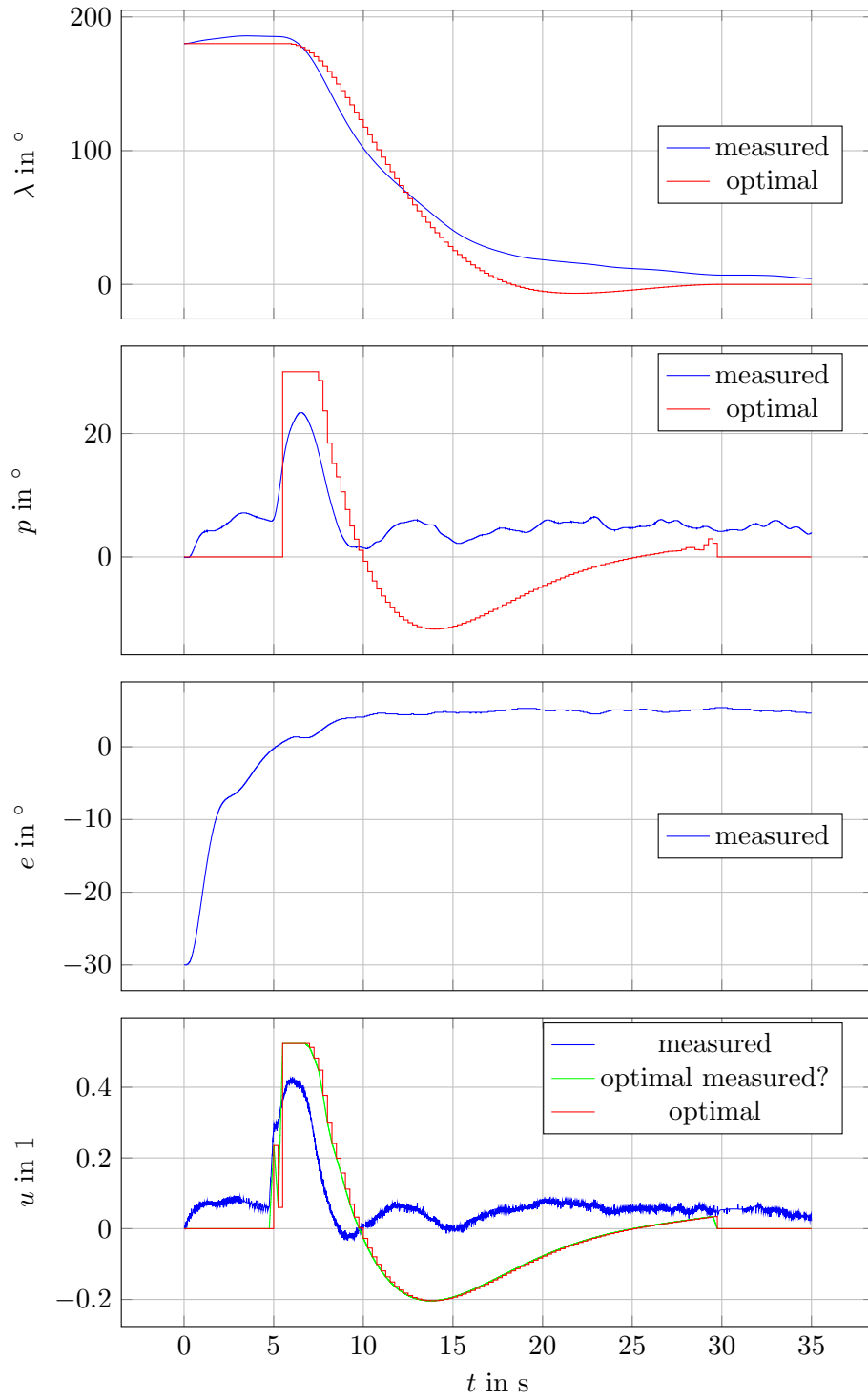
Figure 10: problem3plot_1050_1
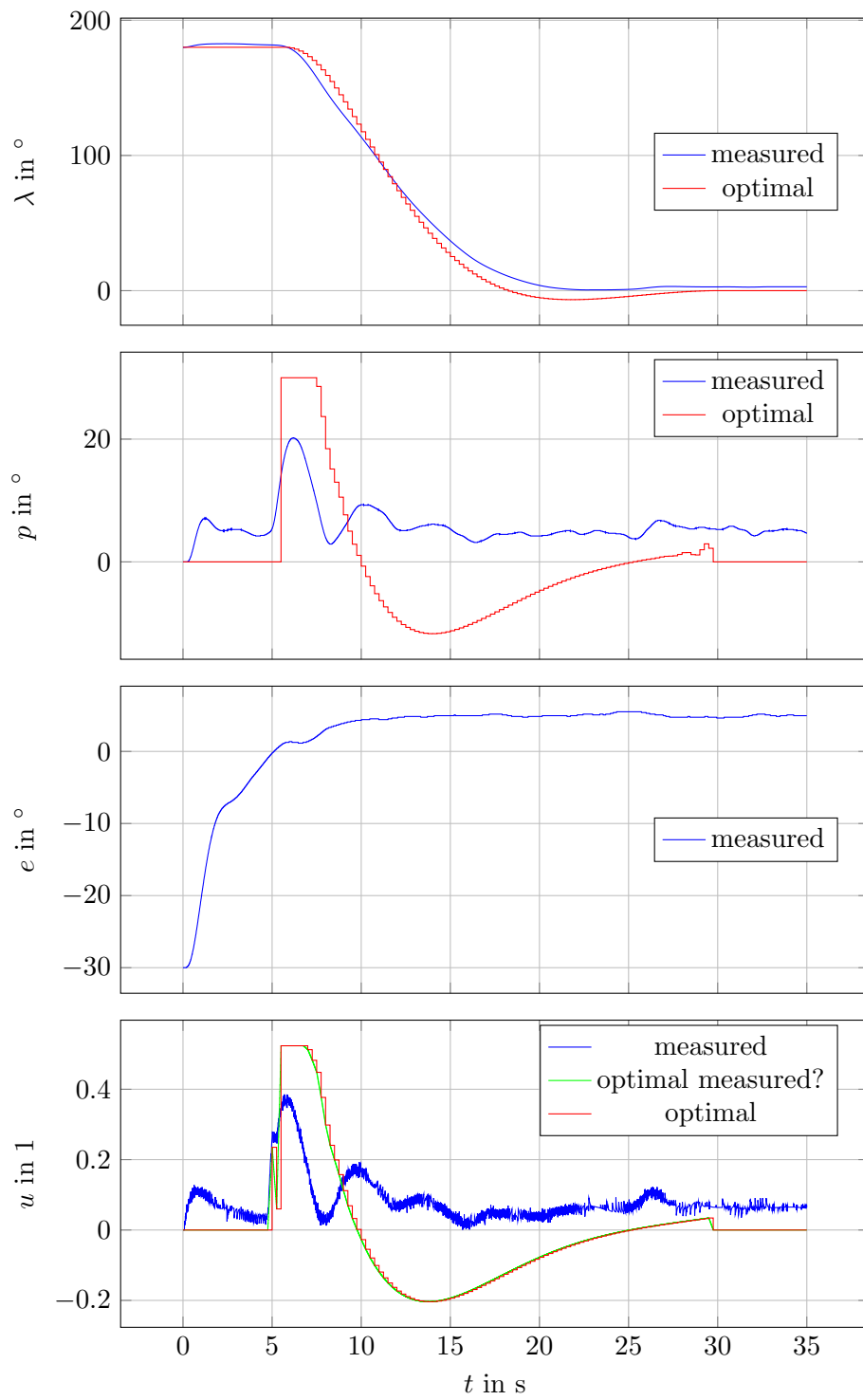
Figure 11: problem3plot_5010_1
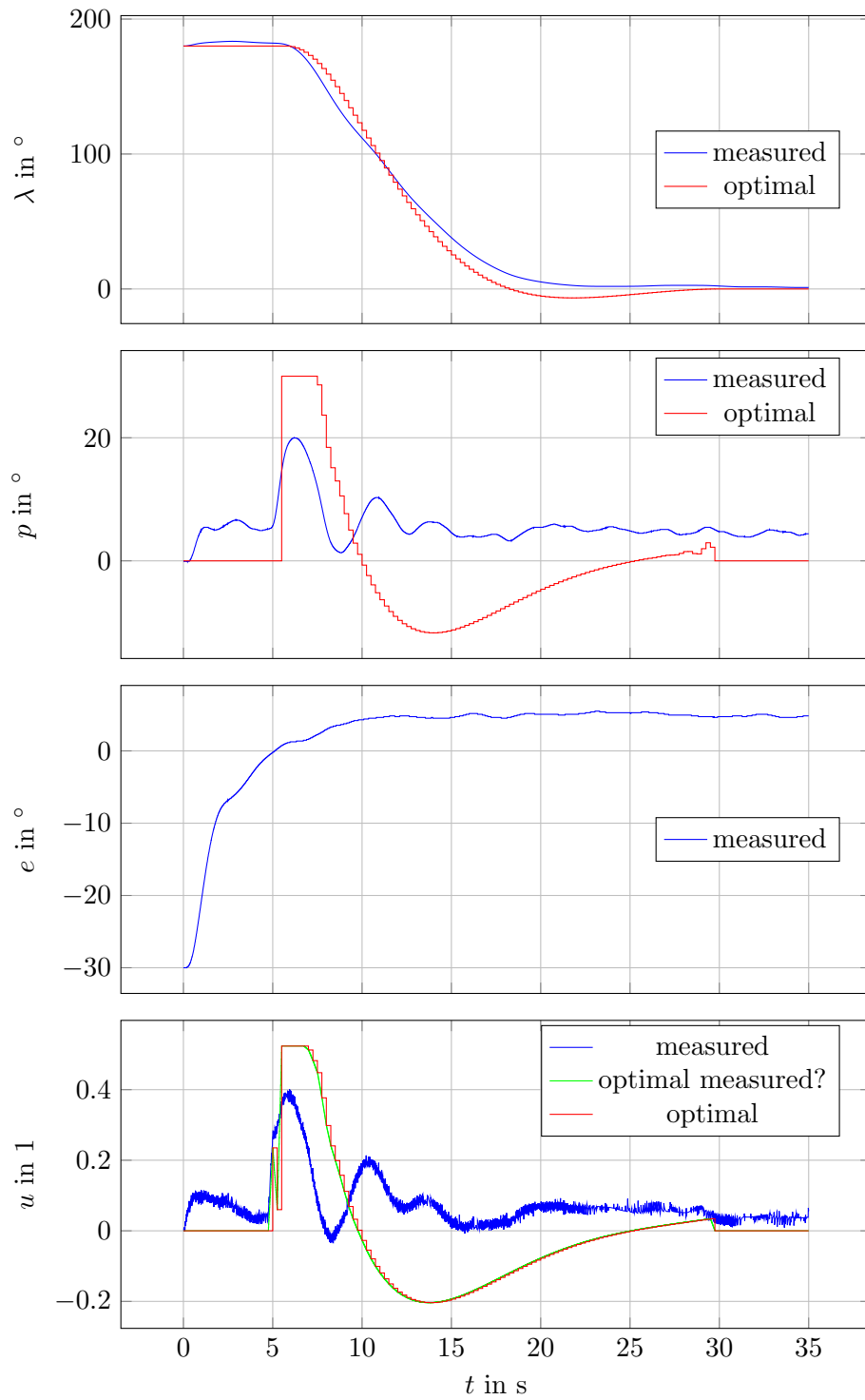
Figure 12: problem3plot_10150_0.5
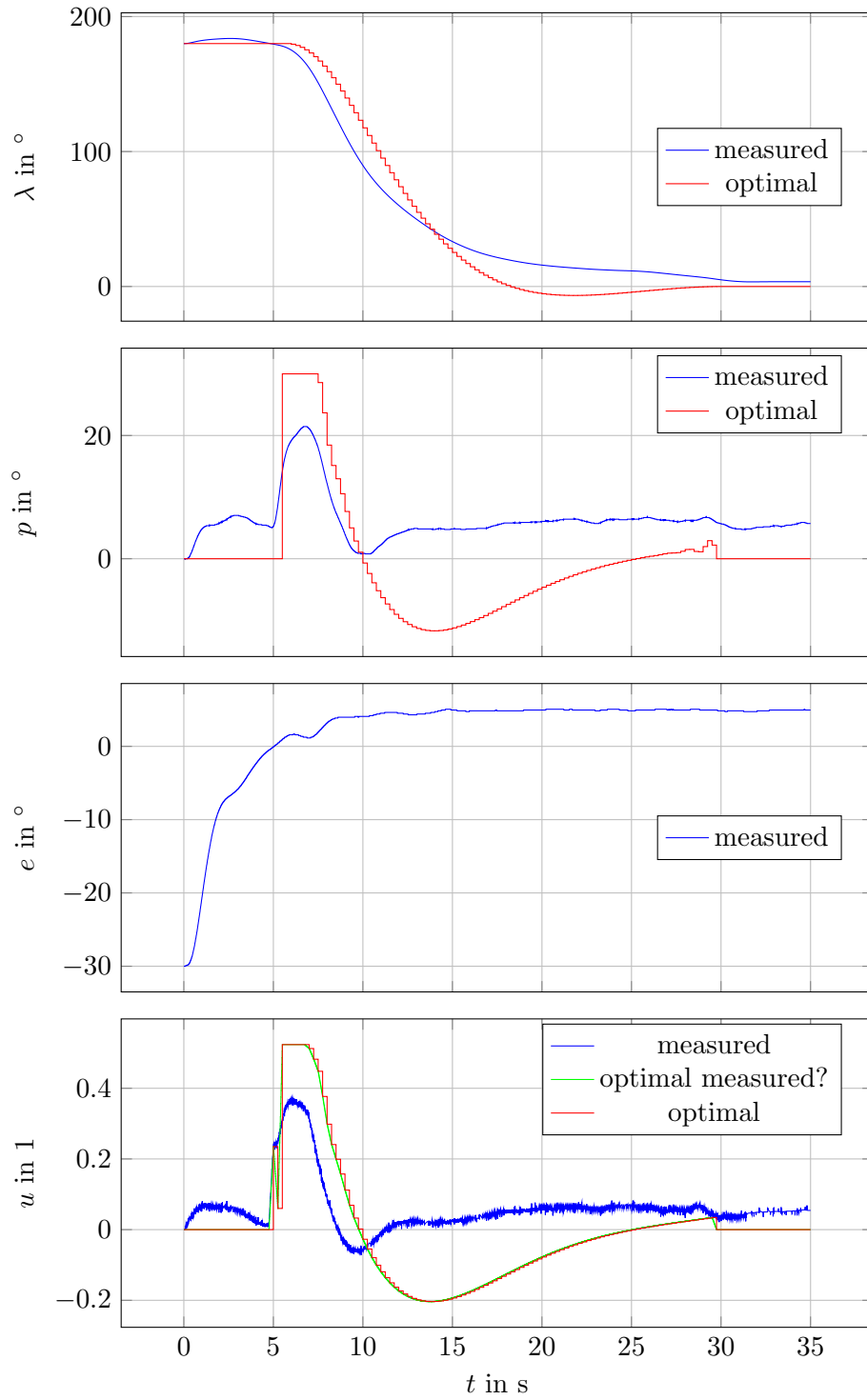
Figure 13: problem3_LQR[1,0,10,0], R = 0.5
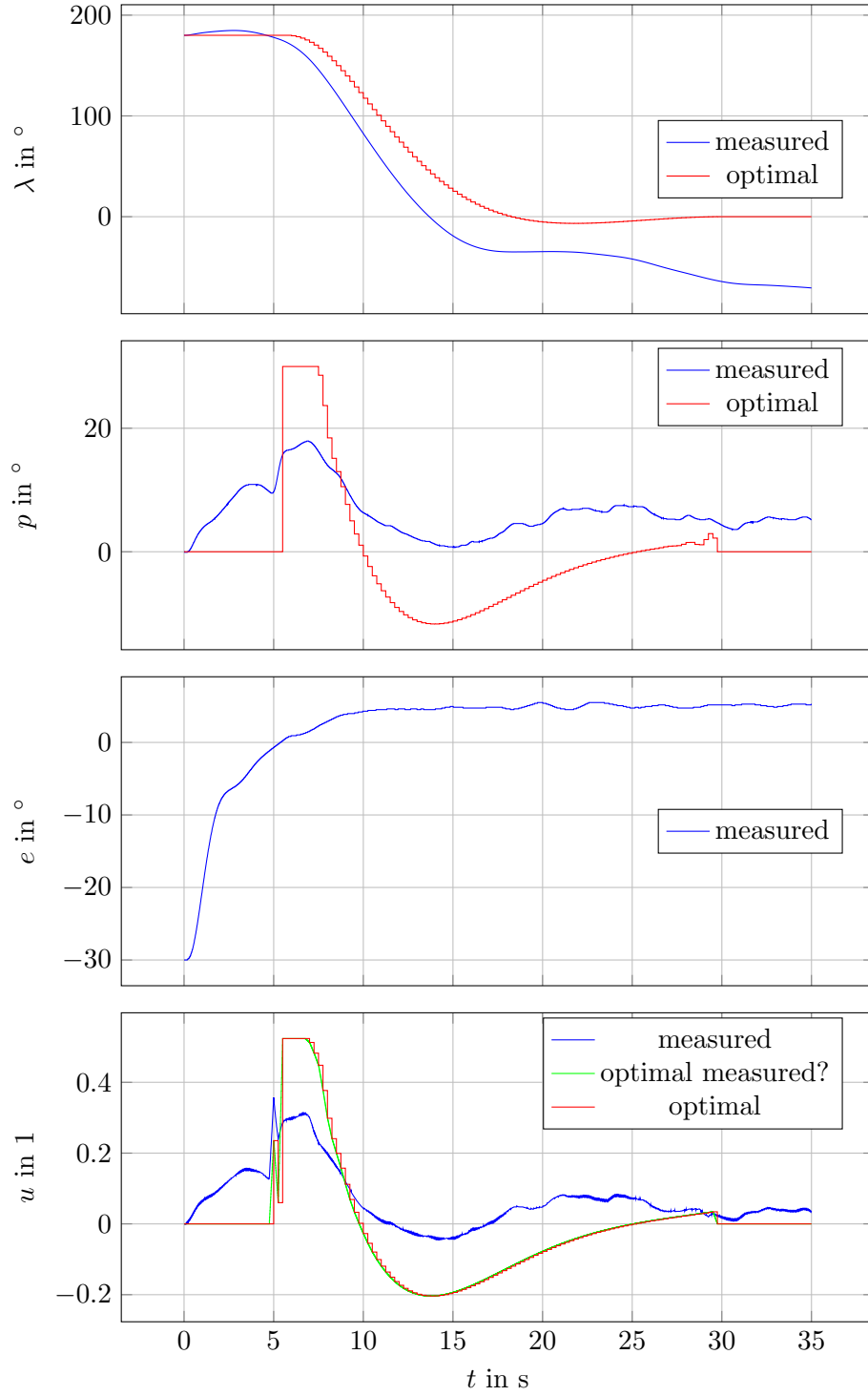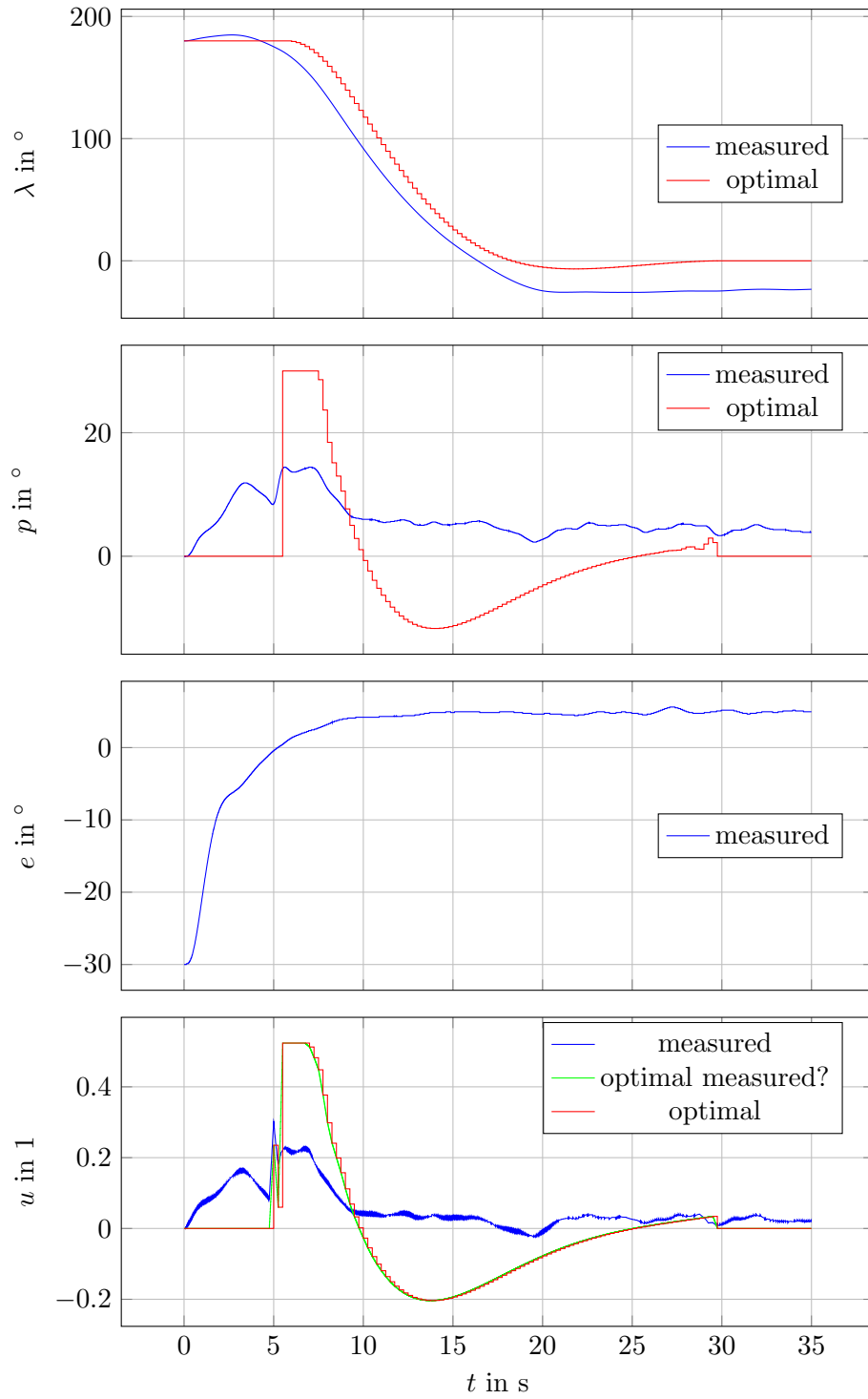
Figure 14: problem3_LQR[1,0,10,10], R = 0.5
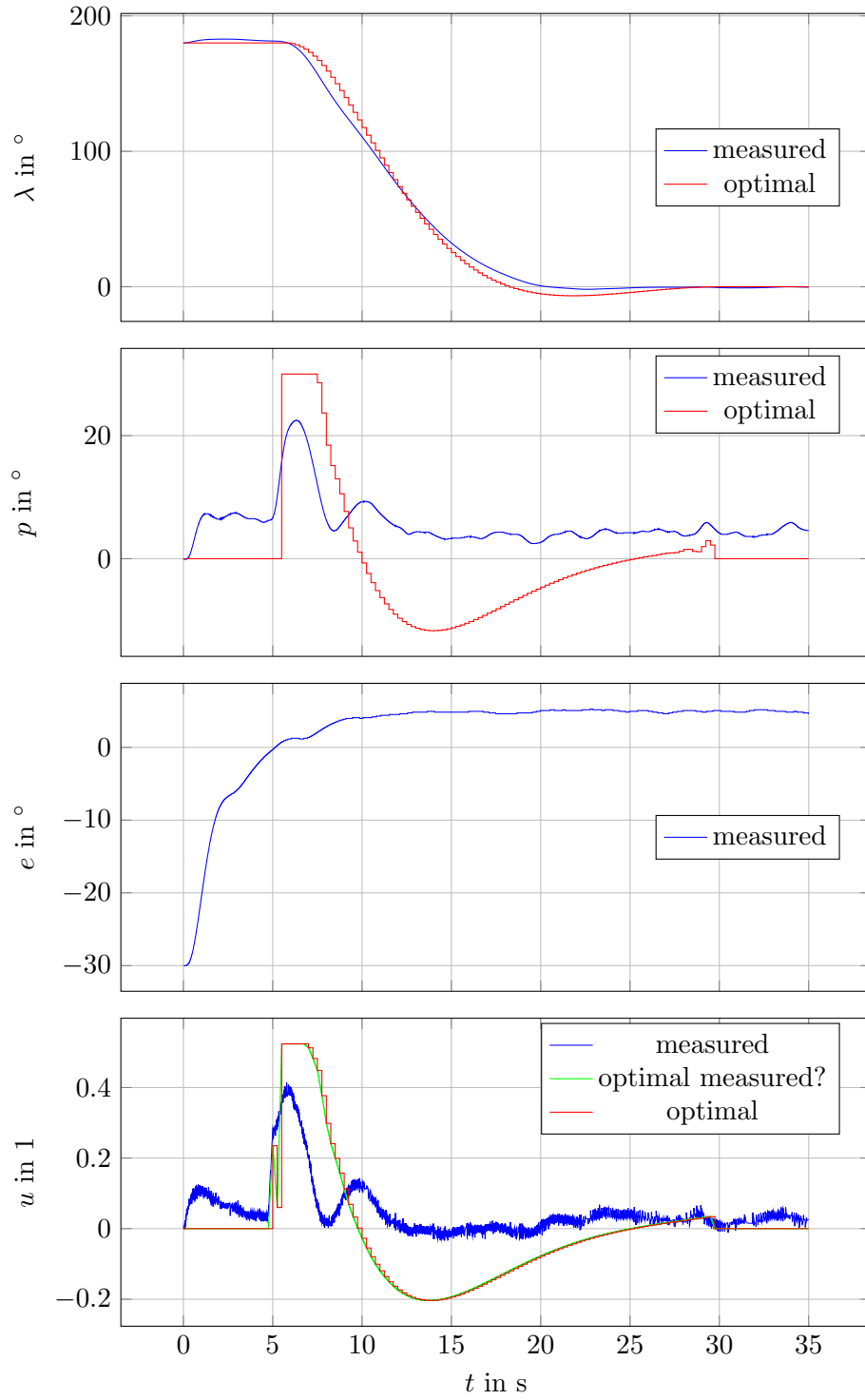
Figure 15: problem3_LQR[5,0,0,5], R = 0.5

21

Figure 16: problem3_LQR[10,1,5,0], R = 0.5

6 Optimal Control of Pitch/Travel and Elevation with and without Feedback

If you claim something you read in the textbook (Nocedal and Wright, 2006), you should cite it. Also, remember to reference all figures in the text. Figures have a number and should be referenced by that number (again, always use dynamic references). They also tend to float around, meaning they generally don't appear where you ask them to in the text. This is fine, do not try to force a figure (or a table) to appear in a particular place. As long a you refer to it, it's easy to find. No figure should be included without being referenced in the text.

If you look at the source code for including figures, you can see that I've used the optional option `[htb]`. This tells Latex where you wish the figure to appear, in prioritized order. h means "Here", t means "Top of this page", b means "Bottom of this page", and p (not used here) means "on a Page with only floats (such as figures and tables)". Note that your wish might not be granted, and this is because Latex actually optimizes the placement of figures. If you start forcing figures to be in specific places, it often leads to really strange layout somewhere else in the document.

Generally, let Latex handle the documentation layout.

6.1 Results and Discussion

Each of the four problems should have their own discussion of results.

Remember: all plots and results need a description, explanation, and discussion.
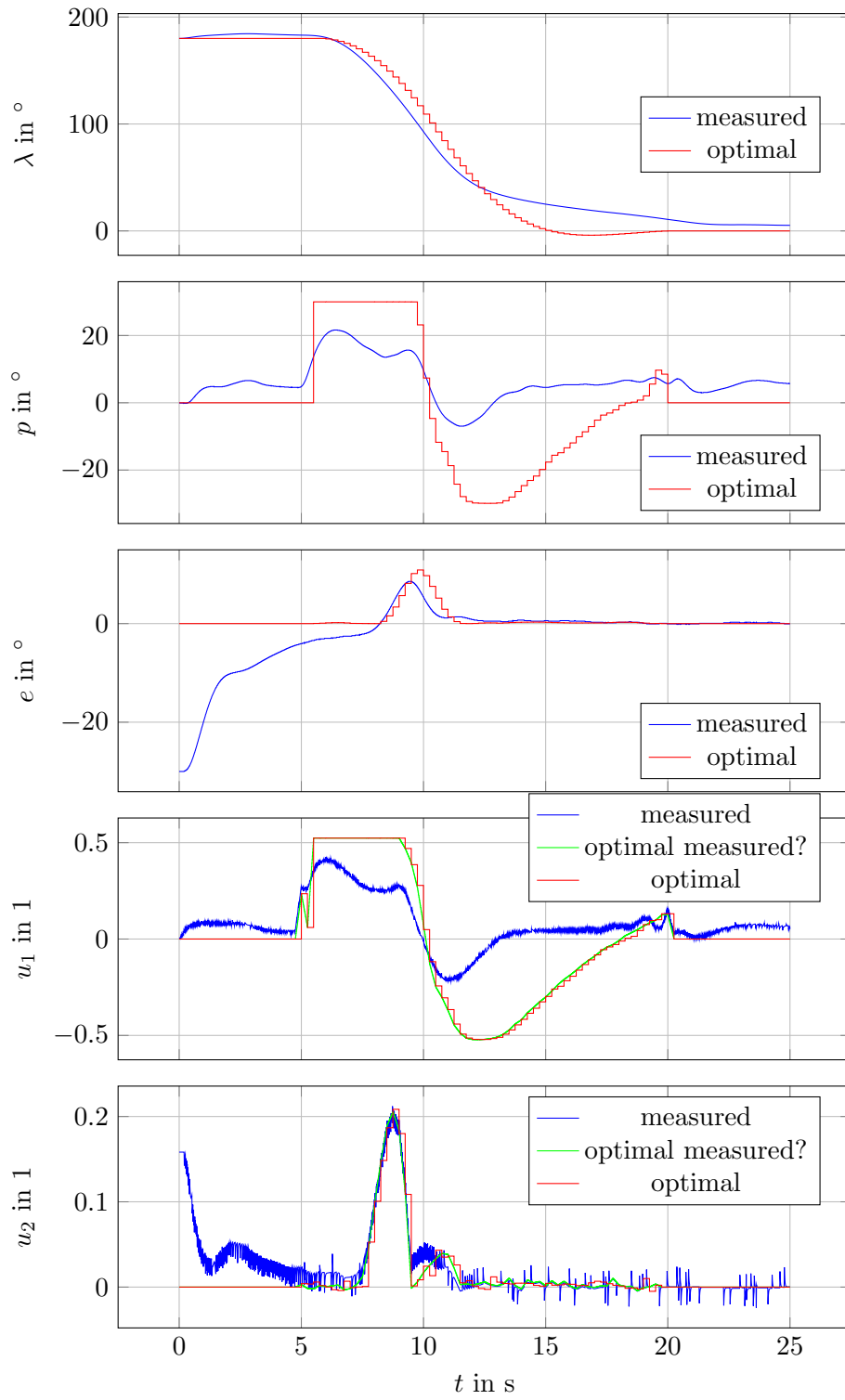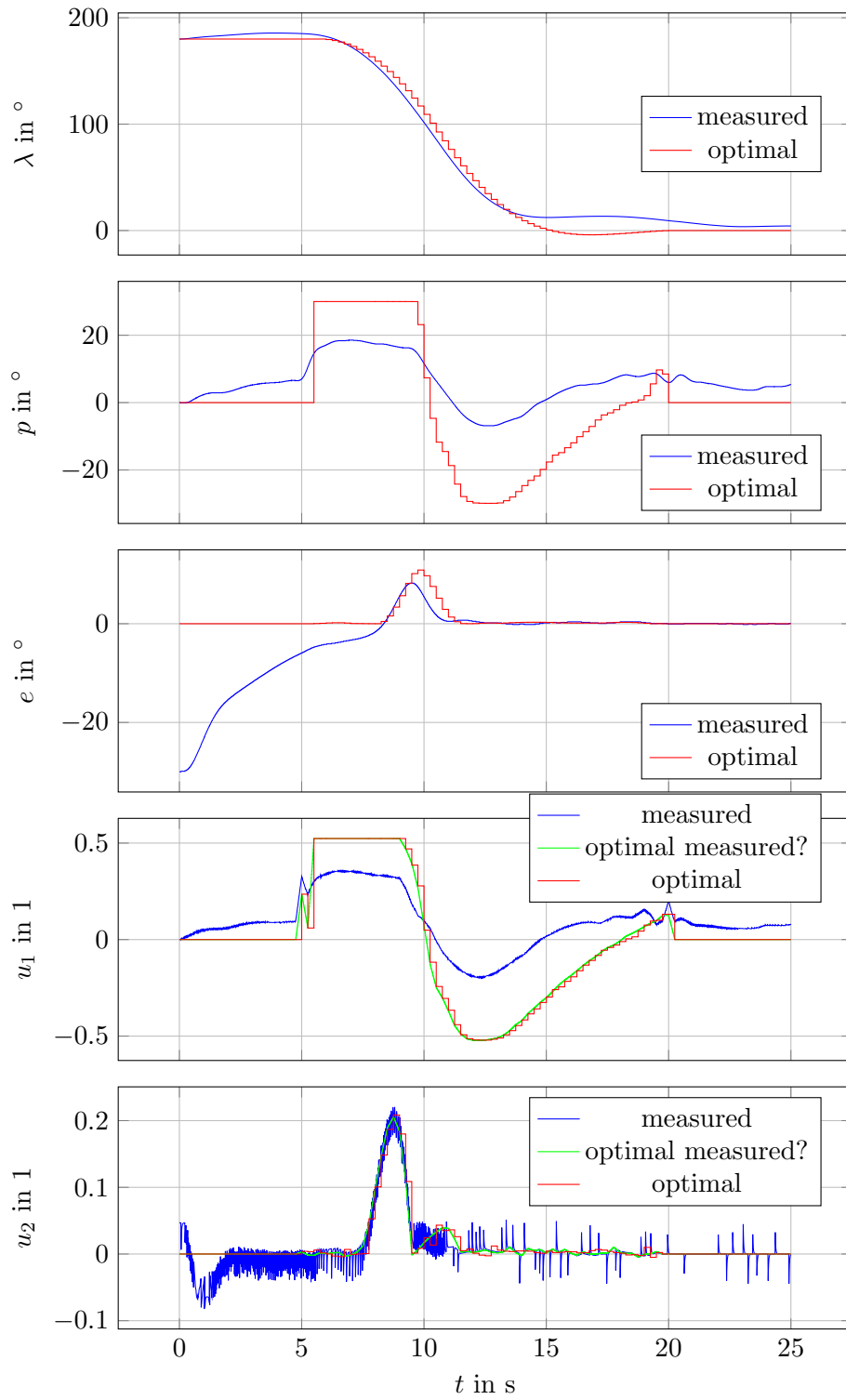
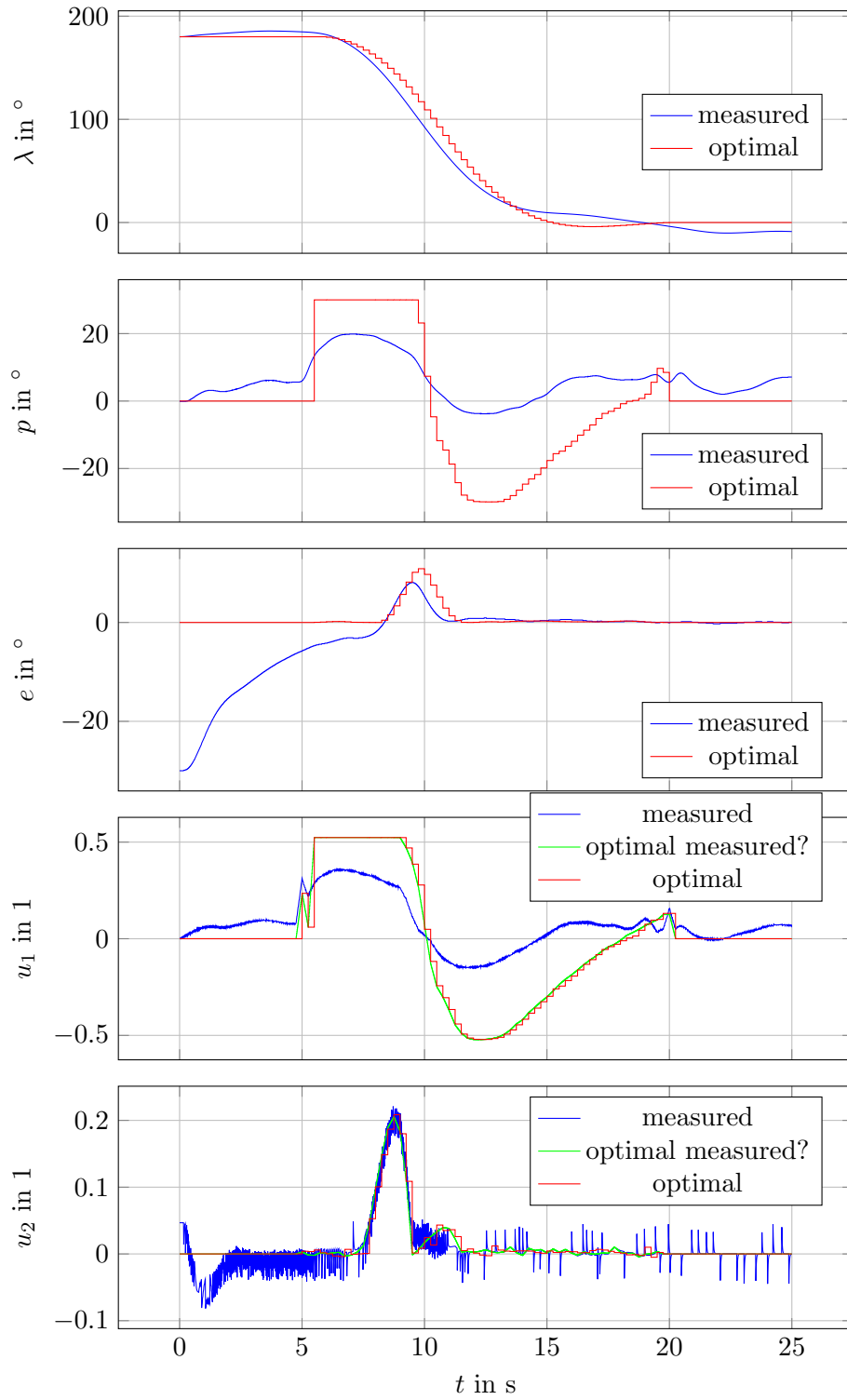Figure 17: problem4plot_101010_11

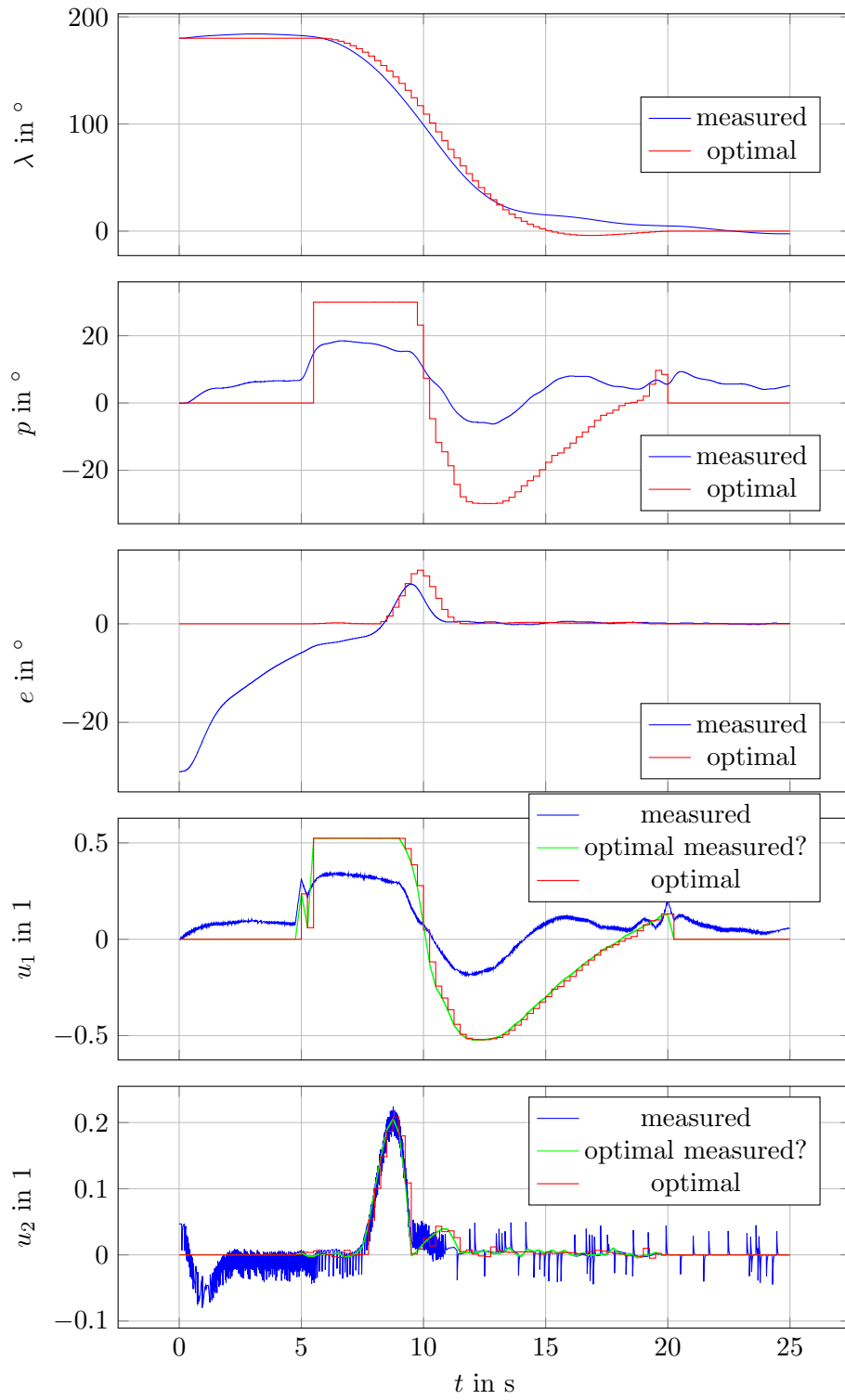Figure 18: problem4plot_111111_11

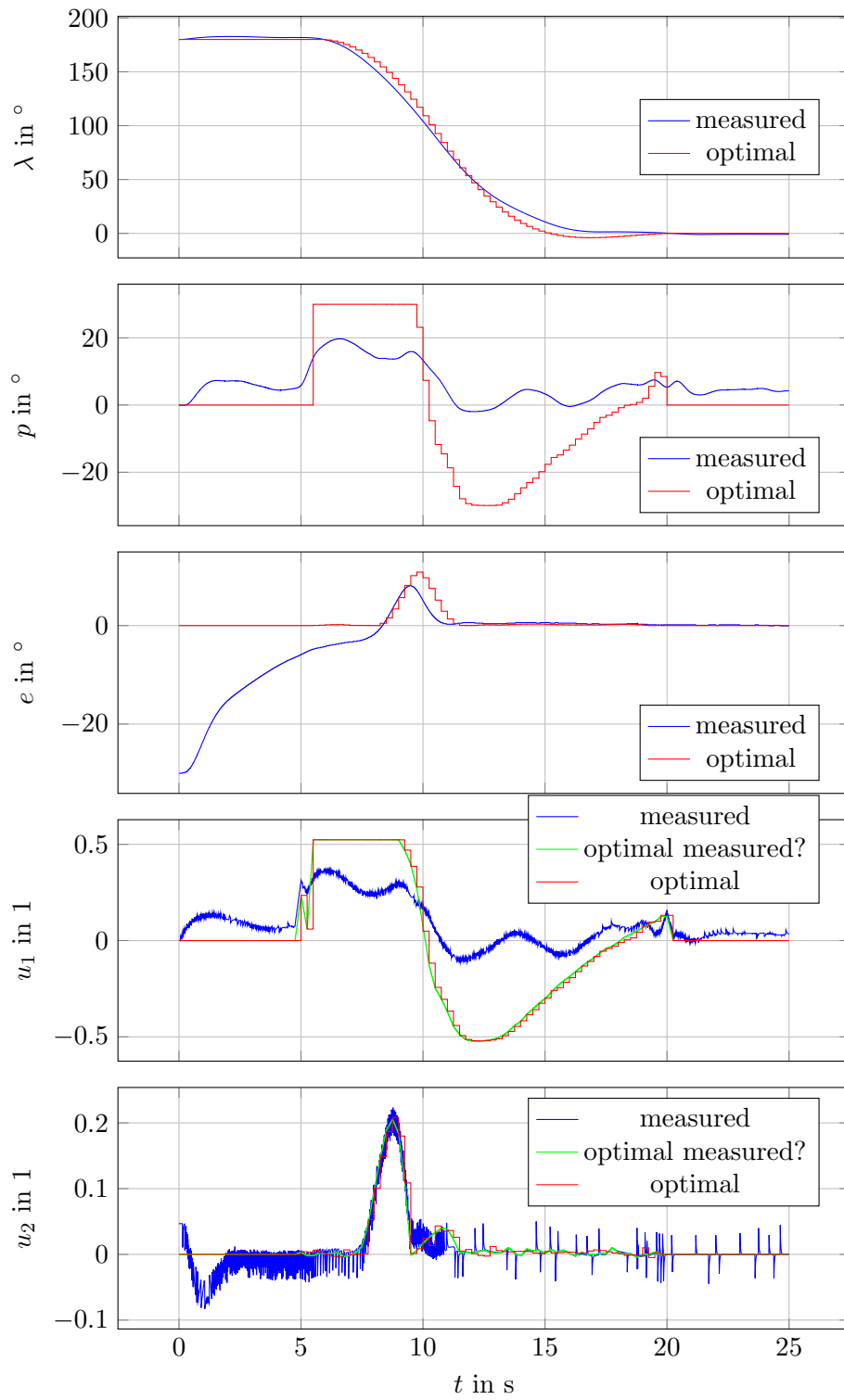Figure 19: problem4plot_211111_11

Figure 20: problem4plot_511111_11

Figure 21: problem4plot_10011111_11

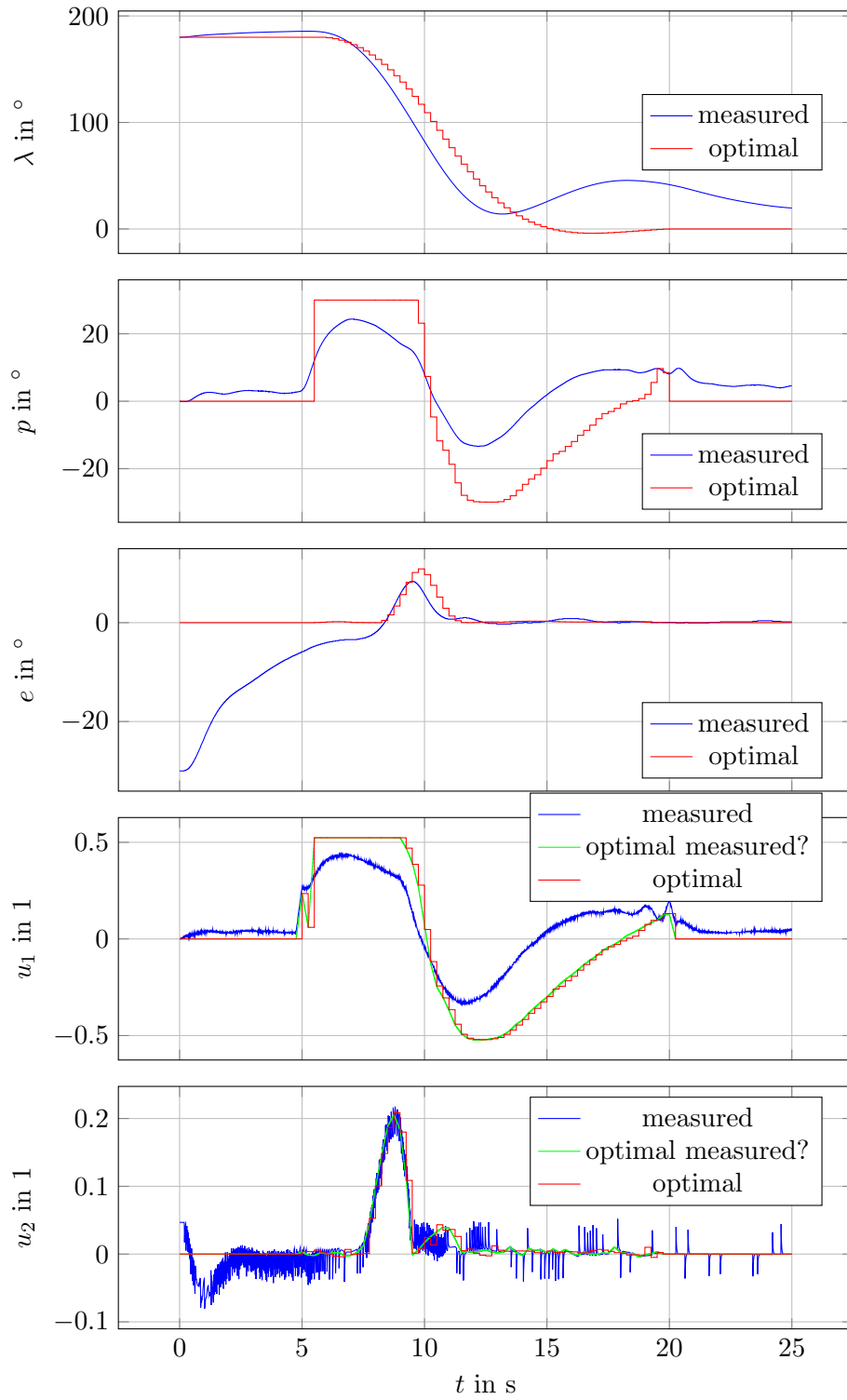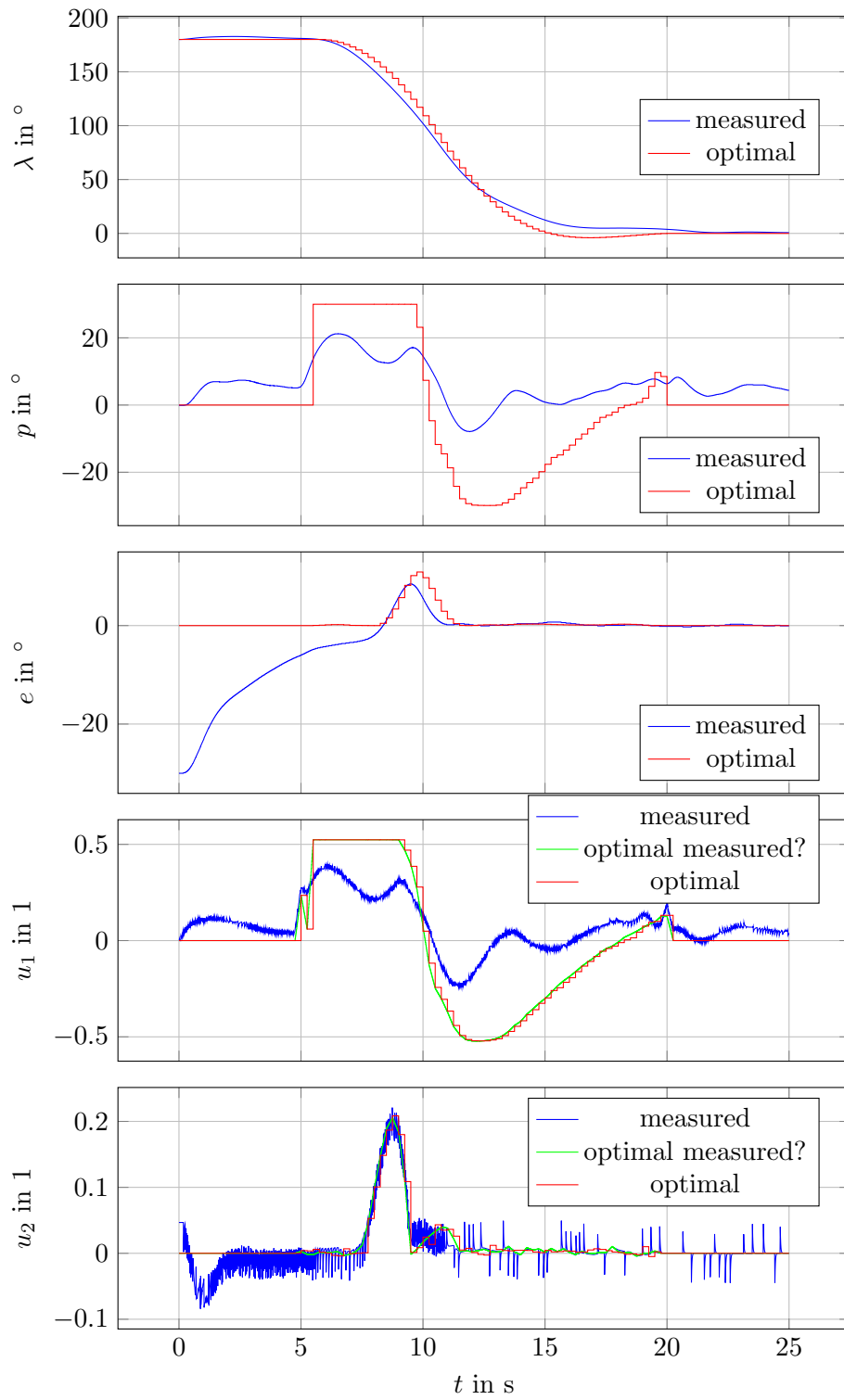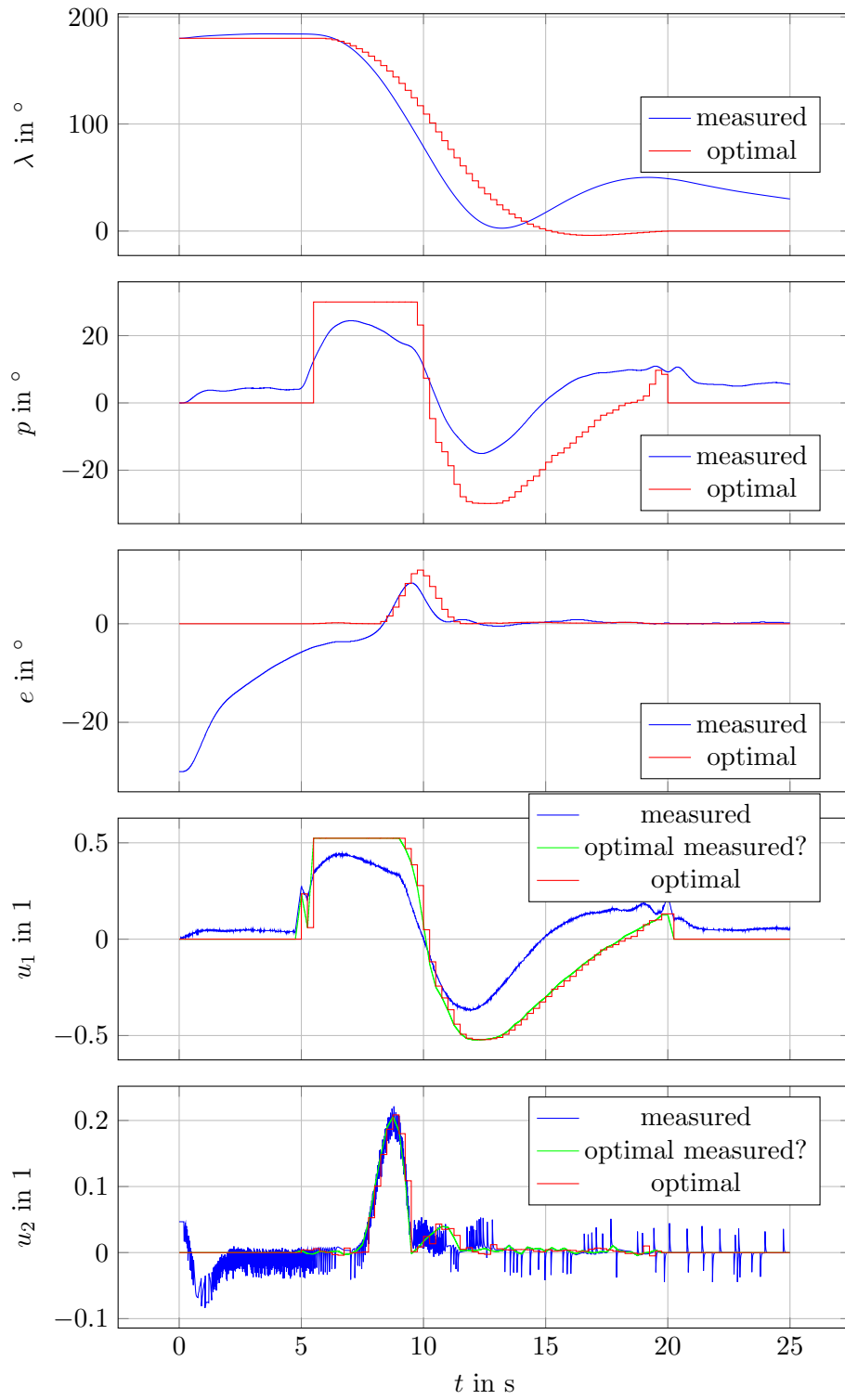Figure 22: problem4plot_21100111_11

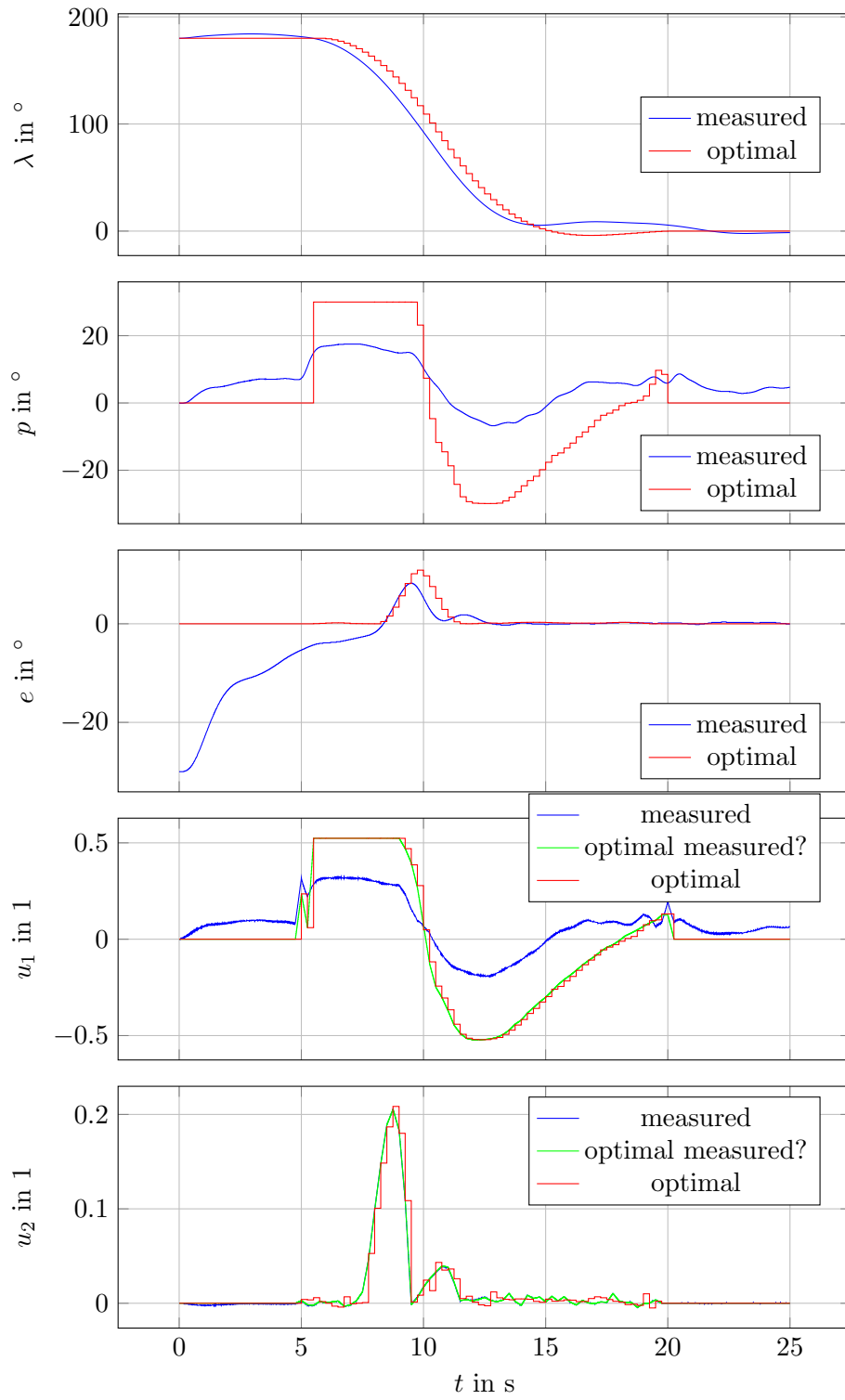Figure 23: problem4plot_100110111_11

Figure 24: problem4plot_111111_1001

Figure 25: problem4plot_111111_1100
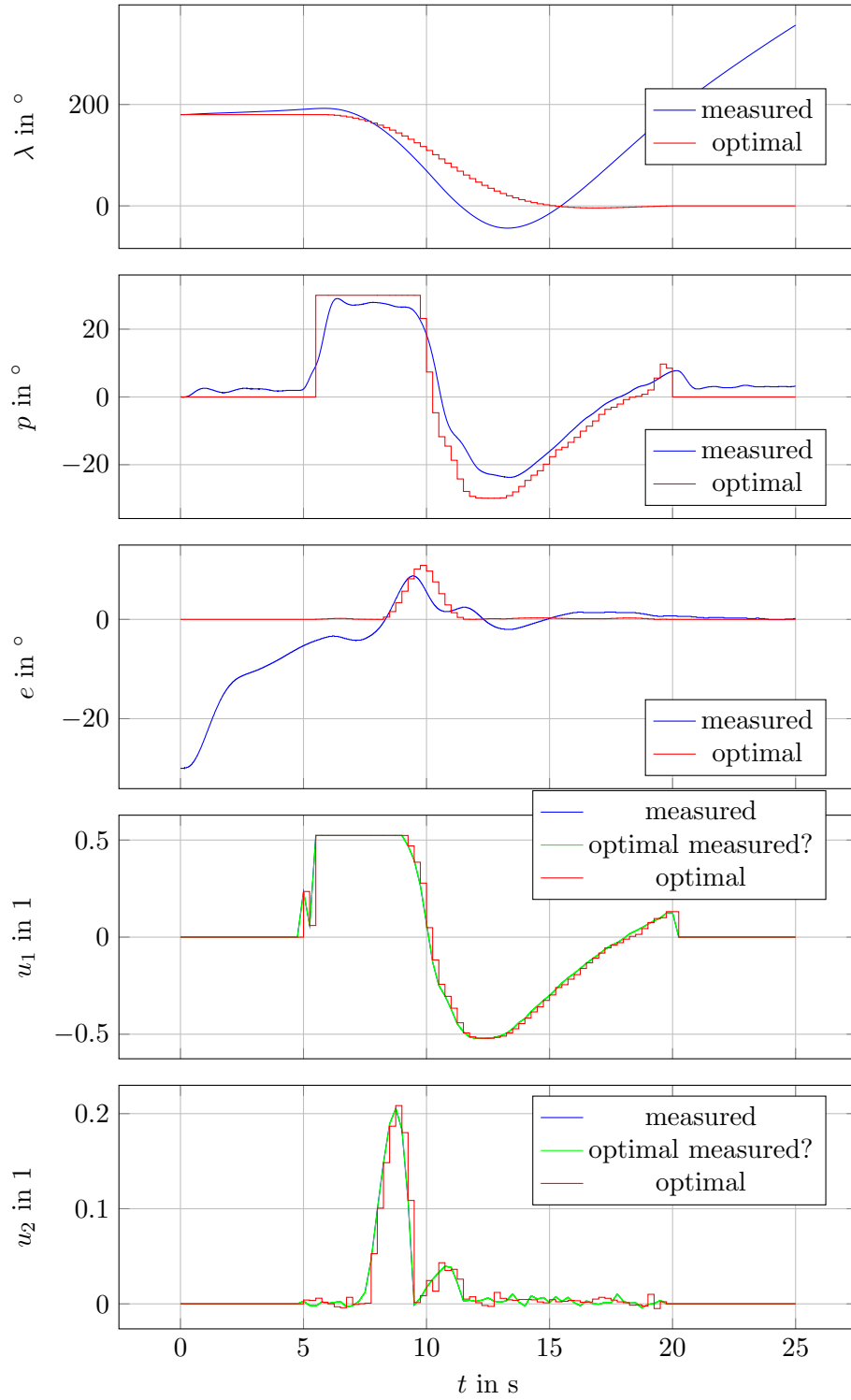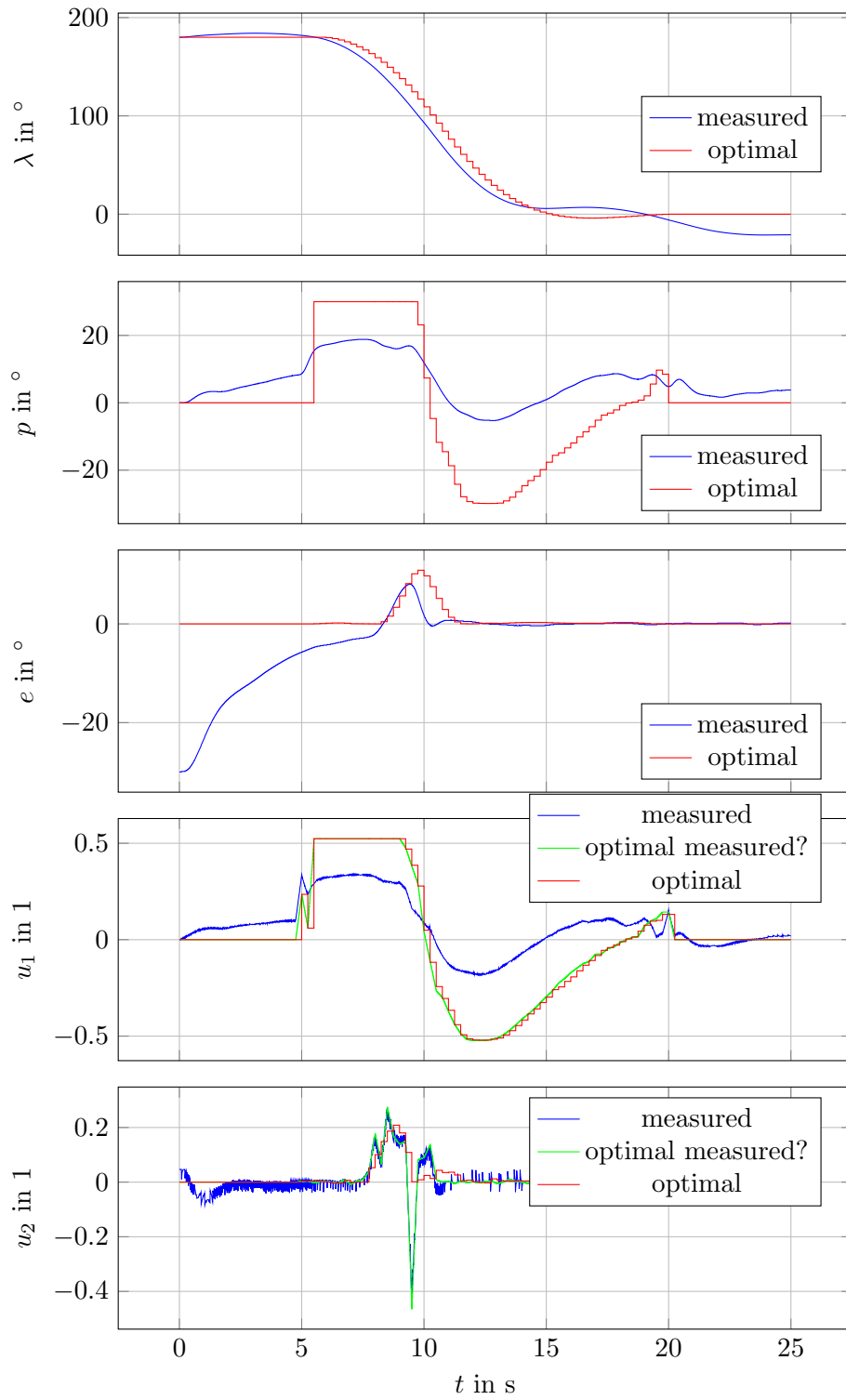
Figure 26: problem4plots_without_feedback
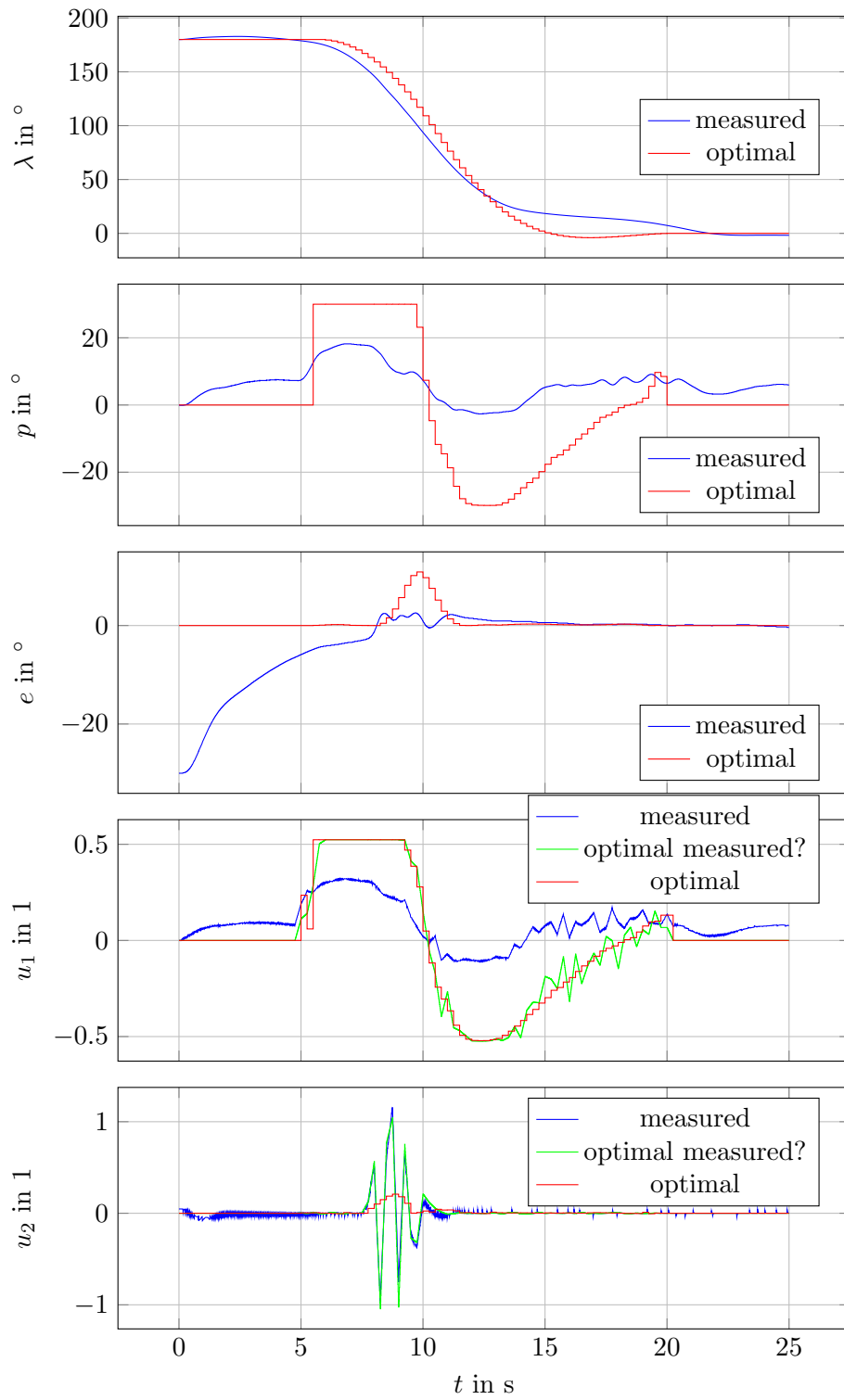
Figure 27: problem4plot_111111_11_opt_ed_1_lambdad_1

Figure 28: problem4plot_111111_11_opt_ed_1_pd_1

7 Discussion

A section like this does not have to be long, but write a few short paragraphs that show you understand what you have been doing and how the different results relate to each other.

8 Conclusion

Again, this does not have to be long, but try to write a few reasonable closing remarks.

A MATLAB Code

This section should contain your MATLAB code. DO NOT attach files posted online (that you didn't write). Note that the method used to input code below does not look as pretty when the lines are too long.

A.1 plot_constraint.m

```matlab
% Plot a figure with some Latex in the labels
l = linspace(70,170)*pi/180;
a = 0.2;
b = 20;
l_b = 2*pi/3;

e = a*exp(-b*(l-l_b).^2);

l_deg = l*180/pi;
e_deg = e*180/pi;

figure(1)
plot(l_deg,e_deg, 'LineWidth', 2)

handles(1) = xlabel('$\lambda$/degrees');
handles(2) = ylabel('$e$/degrees');
set(handles, 'Interpreter', 'Latex');
```

B Simulink Diagrams

This section should contain your Simulink diagrams. Just like the plots, these should be in vector format, like in Figure 17. Make them tidy enough to understand.

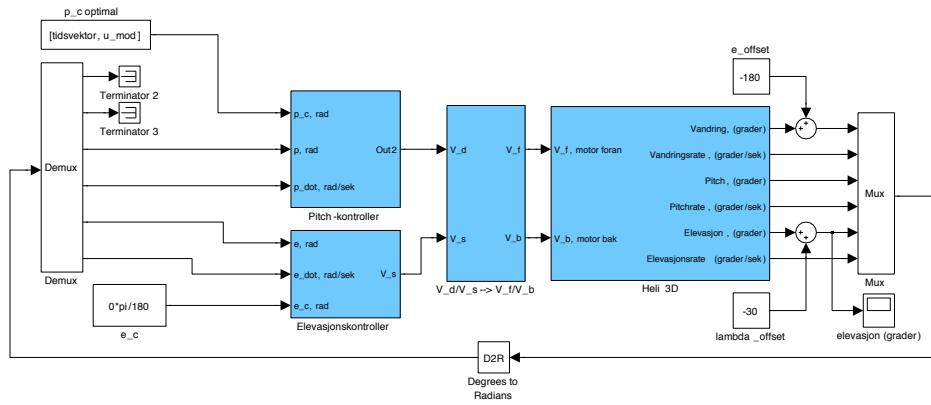## B.1 A Simulink Diagram

Figure 17 shows a Simulink diagram.

Figure 29: A Simulink diagram.

Bibliography

Berland, H. (2010). *En introduksjon til Latex.* `http://www.pvv.ntnu.no/~berland/latex/latexintro4up.pdf`.

Downes, M. (2002). *Short Math Guide for LATEX.* `ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf`.

Nocedal, J. and Wright, S. J. (2006). *Numerical Optimization.* Springer, second edition.

Oetiker, T., Partl, H., Hyna, I., and Schlegl, E. (2011). *The Not So Short Introduction to LATEX 2e.* `http://tobi.oetiker.ch/lshort/lshort.pdf`.