Lab 2: Proportional Control

Overview

The Mayan calendar may have been wrong about the world ending for the rest of us back in 2012, but tragically, for a cat in the Netherlands named Orville, the apocalypse did arrive that year in the form of an oncoming car. Orville was survived by his brother, Wilbur, and human roommate, Bart Jansen, who decided to honour Orville's memory by turning him into a pioneer of flight, like the Wright brother who gave him his name. With the help of an engineer, Arjen Beltman, and a taxidermist, Orville became the Orvillecopter, and was finally able to take to the skies among the birds that so fascinated him in life.

Now, you get to have a (virtual) kitticopter to call your own! In this lab, you will design a proportional controller to help your flying feline track a position input according to a set of specifications.

This assignment will take place over **two** sessions in the lab: first you will perform tests to determine a model of your cat, then you will test your controller on the system. **Both sessions have required prep work that you MUST do beforehand. If you haven't done your prep work, you cannot attend the lab.**

Session 1: Getting to Know Your Cat

All cats are beautiful[1], but some cats are more aerodynamic than others. Your first objective is to determine a suitable model for your kitticopter that you can use to design your controller. The parameters of your cat are unique to you. As in the first lab, you will not be able to confirm the transfer function of your cat, so you are advised to validate your model through simulations. You will also be using the same system in the next lab, so ensure that you model it as accurately as you can to save yourself two labs worth of trouble.

Preparation

Consider the following information about your kitticopter:

- The kitticopter is acted upon by three forces: rotor thrust $f_t(t)$ – the input to the system , aerodynamic drag and gravity.
- You may assume that all parameters are normalized to the mass of the kitticopter (i.e. unit mass).
- You may model aerodynamic drag as being directly proportional to the velocity of the kitticopter, but in the opposite direction. You can use b to stand in for the proportionality constant.
- You may model gravity as a constant disturbance at the **input** to the system. Let $g = 9.81\ \mathrm{m/s^2}$. Hint: Since this is a known disturbance, you may wish to counteract it through a constant offset to the input force.
- The kitticopter is equipped with a sensor that perfectly measures its **velocity** $\boldsymbol{\dot{y}(t)}$**,** however you are trying to control its **position** $\boldsymbol{y(t)}$**.** The output of the kitticopter must therefore be integrated to give the output variable you are interested in.
- To allow for electronic control, the kitticopter's position must be converted from a value in meters to a voltage by the feedback sensor. The relationship between the position and the voltage is a simple scalar that needs to be determined experimentally. The scalar is unique to each student.
- The command input from the controller to the kitticopter will also be in the form of a voltage. You may assume that the voltage is directly proportional to the rotor thrust it instigates.

Based on this information, please complete the following tasks **before** attending session 1 of your lab.

a) Draw a block diagram of the kitticopter system, representing all of the given information.
b) Derive a differential equation describing the acceleration of the kitticopter.

[1] Spray ACAB on a wall if you agree.

c) Derive the open-loop transfer function $G(s)$ relating the **velocity and rotor thrust** of the kitticopter, and the closed-loop transfer function $G_{cl}(s)$ relating the **position** to the **given setpoint $\boldsymbol{x(t)}$** for the overall system.
d) Derive closed-loop transfer functions describing (i) the position error in relation to the setpoint, and (ii) the effect of gravity on the position output. Determine the **type number** of the system and describe the tracking performance you expect to be able to achieve using proportional control with respect to position setpoints (i.e. will the error and effect of the disturbance be infinite, finite or zero?)
e) OPTIONAL: create a Simulink model of the kitticopter system and bring it with you to the lab. This is not essential, but it will allow you to simulate your proposed model during the session rather than afterwards.

Briefly write up these tasks and present them to Mr. de Maar or a tutor at the start of the lab session. It would be a good idea to check your work with a tutor well before your session, so you can be sure that you are modelling the system correctly. Each session is limited to **an hour,** so you don't want to waste valuable lab time re-doing your prep work if you did not do it correctly.

Ensure that you bring your **breadboard** with you, as you will be using it to construct the input circuit for this experiment.

Instructions

The simulated kitticopter system operates in a similar way to the spring-mass-damper system you used in the previous lab, but this time, you will be giving it inputs that you create using a physical voltage rather than ideal simulated inputs. These will be fed into the computer through an analogue-to-digital converter (ADC). The simulated kitticopter responds to values between 0 and 5 V.

You will build a simple potentiometer circuit using your breadboard to control the voltage given to the ADC. Instructions for how to do this are provided in the attached lab manual.

The goal of this session is to complete the transfer function model $G(s)$ by determining the unknown aerodynamic constant b of your kitticopter by performing a step test.

Hints:

- It may be easier to work at the velocity level for these open-loop tests, as the relationship between the velocity output and rotor thrust input should be first-order. You can get back to the velocity output by taking the derivative of the position response you obtain.

- You want to start your step from initial rest, but because of gravity, this does not necessarily mean zero input voltage. Zero input voltage will, in fact, result in your poor cat plummeting to earth (luckily they always land on their feet so no harm done 😊). You need to find the input voltage where gravity is perfectly counteracted by the rotor thrust, so the cat hovers at a steady height. It is important to note this value, as it is effectively the "zero" point for your controller, and you will have to offset the controller output by this value to achieve the expected results.

- Because of the hand-made input step and imprecise process of taking the derivative of the position digitally, you are advised to repeat the step test several times. The average of the resulting system parameters will probably be closer to the truth than the results of any individual test.

Clearly document the tests you perform as part of your lab report.

Session 2: Proportional Controller

Now that you have a good model of your system, you are ready to do some actual control!

Specifications

Your proportional controller is required to achieve the following performance specifications:

1) Tracking of position inputs with >90% accuracy (i.e. the tracking error and effects of disturbances must be <10%).
2) Settling time improvement of at least 20% compared to the open-loop system.
3) Overshoot of less than 5%.
4) Robustness to uncertainty of up to 10% in the aerodynamic constant of the system. (Since you are determining this parameter experimentally, you should make sure your design works even if you don't get it precisely "correct".)
5) Robustness to a tolerance of 10% in the components used to assemble the controller.
6) BONUS [up to an extra 20%]: Tracking of velocity inputs with >80% accuracy.

You may improve on these specifications if you are able to. Note that the inputs your controller can deliver are limited to 10V by the power supply.

Preparation

Completion of the following activities is essential before you may attend session 2:

1) **Session 1:** present your write-up of the first session, showing that you have obtained a complete model of the system.

2) **Proportional controller design:** you can use any methods learned in class to design your controller. Clearly explain your reasoning and show any graphics or calculations needed to support your decisions. You may also wish to perform preliminary simulated tests of your controller's performance using MATLAB or other software. Present your design at the start of the session.

3) **Controller build:** construct your controller **on Veroboard** and present it at the start of the session. You may bring a controller on breadboard, but your mark for the controller demonstration portion of the lab will then be **capped at 50%.**

   Hint: The appendix of this document includes instructions for how to build a proportional controller using an op-amp, and a helpful recap of how op-amps work.

Instructions

The aim of this session is to demonstrate that your controller meets all the given specifications. You may perform any suitable tests to do so. You will find instructions for how to connect your controller to the simulated system in the appendix of this document.

Report

Use the provided template to write a brief report on your findings.

EEE3094S Lab 2 Report

(Pending – will add ASAP)