Fuzzy Systems Exam Coursework 2001-2002
Deadline April 22th 2002 at 10.00 am *

Download the research paper *Fuzzy logic based attitude control of the spacecraft X-38 along a nominal re-entry trajectory*, S.-F. Wu *et al.*, Control Engineering Practice, Vol. 9, 2001, p. 699–707 via the library's electronic journal portal http://www.lib.ic.ac.uk/ejournals/ejnls_titl.htm

This paper describes the fuzzy control of a space-shuttle-like vehicle when it re-enters the atmosphere and starts flying using the pressure exerted by the air.

Read the introductory section 1. Skip anything you do not understand. The rotation of a three-dimensional solid can be described by the variation in three angles. The angles chosen in this paper are α, the angle of attack, β, the side-slip angle, and σ, the bank angle. It is not necessary that you understand the physical meaning of these angles, only know that they completely characterize the rotation. The control action is represented by three other angles, the deflection of elevator, rudder, and aileron, δ_e, δ_r, δ_a respectively. These are movable surfaces of a plane or space-shuttle. You may need to look up the meaning of inertia in one of your physics textbooks. In such a textbook, inertia is usually explained for rotation of a solid around a single axis. If the rotation is simultaneously around two axis, the scalar inertia becomes a 2 by 2 matrix, called an inertia tensor. For rotation around three axis, the inertia tensor is a 3 by 3 matrix. Ignore sentences with the word "quaternion" whenever they occur in the text. The roll , pitch and yaw p, q, r are rotation rates around axis of the shuttle (imagine one axis lengthwise, one from one wing-tip to another, and the third perpendicular). The emphasis of this exam will be on fuzzy control, not aircraft properties. You should aim at using mathematical variables in your report, rather than the aeronautics terms.

Read section 2 on fuzzy flight control, without looking up any of the references. How does a fuzzy logic controller allow representation of uncertainties of the plant, and the treatment of nonlinearity (1/20)?

*Hand it in at the General Office, Level 6

In section 3, figure 1 explains how the attitude angles α, β, σ are controlled by the deflection control signals $\Delta\delta_{e_c}, \Delta\delta_{a_c}, \Delta\delta_{r_c}$. However, the dynamics of the shuttle is difficult to describe in terms of these angles. Instead equation (1) is used (you should ignore equation (2)). The symbol I^{-1} denotes the inverse of the 3 by 3 inertia tensor I, the symbol $\times$ denotes vector cross or external product, and $\cdot$ denotes matrix-vector product. Refresh you knowledge of the vector cross product for two-dimensional vectors. The notation $\dot{p}$ stands for $\frac{dp}{dt}$, the derivative of p with respect to time t.

Write down a one-dimensional equivalent of equation (1) (1/20). Does it correspond to the physical law $\tau = I\dot{\omega}$, for the torque τ, inertia I, and rotation speed ω of a rigid body rotating around a fixed axis? The law $\tau = I\dot{\omega}$ is the rotational equivalent of Newton's second law $f = m\dot{v}$, for a force f, mass m, and speed v. This equivalence is very important. Discretize your one-dimensional equivalent of (1) for time-steps of one second (1/20).

Section 4 on fuzzy controllers is the last section you have to study. Table 1 represents a fuzzy associative memory. The first row contains values for e, the last column contains values for $\dot{e}$, the other entries are values for the output u. This output can be $\Delta\delta_{e_c}, \Delta\delta_{a_c}, \Delta\delta_{r_c}$, dependent on whether $e_\alpha, e_\sigma, e_\beta$ is selected for e in table 1. Read until equation (6).

This is the main part of your exam coursework. Find a fuzzy controller for a system that evolves in time with dynamics equal to the one-dimensional equivalent of equation (1). Find membership functions for input and output (4/20). Find the fuzzy associative memory for the controller (4/20). Show via simulations that your controller works (4/20). Choose triangular membership functions, less numerous than those in the paper.

Choose the inertia to be equal to the CID number on your college security card, multiplied by a power of 10 of your own choice. If your security card bears no number, use your date of birth.

The Challenge. If you want to get top marks, you have to do this challenge. However, you will get better marks for a good report without the challenge than for a mediocre report with the challenge solved.

Describe a fuzzy controller for the system (1), but with two degrees of freedom (5/20). The controller does not need to be implemented, but you need to give detailed expressions for membership functions and FAM. Because of the six page limit, you will not have space to plot the membership functions for this challenge. You need to use mathematical notation. You will need to look up the inertia tensor in a book. Just as in the main part of this coursework, there is no need to introduce quaternions (equation (2)).

You could organize your work as follows.

day 1 Read the paper, looking up anything you don't understand in your lecture notes. Plan what you are going to program.

day 2 Do the programming, and debug your program.

day 3 Run the simulations, and collect the results in a form that you can present in your report. Simulations can be in any programming language, on any machine. You can use Matlab or other software packages, but make sure that you have control over the parameters that you want to vary. If you are desperate, you could use a calculator, or even pen and paper, but this will make this coursework difficult.

day 4 Write the report. It should be maximum six pages (single sided) a4, in a font not smaller than 10 point. You will not get marks for anything exceeding six pages, even if it is appendices. Font size in tables and figures should be at least 10 point, or the tables and figure will not be marked. Describe the problem, and how you have solved it. Describe your simulations, but do not give programme listings. Do not give references to the literature. Make sure you do and answer everything that is asked for in the coursework. If you have problems with formulas in text processing, do them by hand. Do not bind the report, but staple the pages together. Mention your name, and indicate for what degree (e.g. MEng Elec. Eng., MEng ISE, etc.) you are studying.

day 5 Check the consistency and quality of your work. Make last minute changes if necessary. If you feel confident and have the time, tackle the challenge. Resist the temptation to spend more than five 8-hour days of intensive effort on your coursework. You will not be compensated for it in marks. Just as an exam paper requires a concentrated effort over a few hours, this coursework requires a concentrated effort over a few days.

Do not forget to attend on the "exam" day. Bring a copy of your report with you, and your college security card. I will ask you one or two questions based on what you have written in your report, to make sure that you have written it yourself. No preparation is necessary.

Good luck.

Dr. P. De Wilde