**Spreadsheets**

# Simulation of Linear and Non-linear Dynamic Systems using Spreadsheets

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## Abstract

*EXCEL has been used to provide simulation facilities in support of teaching control to engineers. This dictates a sampled data approach which fits in naturally with digital implementation of control. The technique also allows students to explore the affects of non-linearities in systems such as control signal saturation. It provides a 'hands-on' dimension which students find valuable. The approach is capable of use with other dynamic systems and is not restricted to teaching control.*

**Level of Material: Third Year**

## The Execution

Control is a subject most students find difficult. Whilst the mathematics is not particularly onerous, the understanding required is demanding.

Years ago, when I was a student, we had analogue computers and these were a great help in understanding dynamic systems. One could see them at work and change parameters. Similar things are provided digitally today with packages such as MATLAB. However, such packages are not available on every machine, and particularly on students' own machines. Also, when a 'clever package' does something for you, you aren't quite sure how it did it. With a spreadsheet such as EXCEL, everyone has a copy and the students has to set up everything – there's nothing clever being done for him/her.

## Pre-requisite Knowledge

Whilst students have met differential equations, few have understood what they are modelling. The approach described here is designed to develop that necessary understanding.

Some understanding of digital signal processing is developed at the same time, in particular the need to sample frequently enough.

## How Are Students With Different Mathematical Backgrounds Supported?

The more able students get through tutorial problems quickly and/or elect to work in their own time asking for help as required. The less able students are therefore more fully supported in the tutorial time made available in the form of computer labs.

## What Support Was Needed?

Staff availability, with a PC, in the form of 'face to face' contact is the only real way of resolving problems though small difficulties may be resolved at a distance using phone or email.

## The Barriers

Some students devote more time to avoiding the difficulties than would be needed to resolve them! The idea that they need to 'get their heads round a problem' is considered strange, abhorrent and beyond their abilities – till you oblige them!

## The Enablers

The lecturer – who used the technique to cover more ground more quickly, more thoroughly and with a greater level of understanding on the part of the students.

## Evidence of Success

Better understanding – especially evident when students come to their final year projects. Whilst that's not an objective test, it tells me what I want to know.

## Quality Assurance

Module descriptors and exams subject to the normal review procedures. Ultimately, though, it's a matter of letting a competent teacher get on with the job.

## Other Recommendations

This technique is not limited to the teaching of control. Indeed, it could be used quite widely. For example, in chemistry and chemical engineering it is a good way of examining reaction dynamics.

Ultimately, why not use the technique from the beginning with differential equations. It avoids the situation where students learn how to solve differential equations without knowing what the solution means! (Yes! I have to admit that I was just such a student!)

# Simulation of Closed Loop Systems
## Now let's try some feedback

All we have to do to apply some feedback is to add another formula to the spreadsheet so that the input (control signal) depends on the error, the difference between the output, y, and the setpoint.
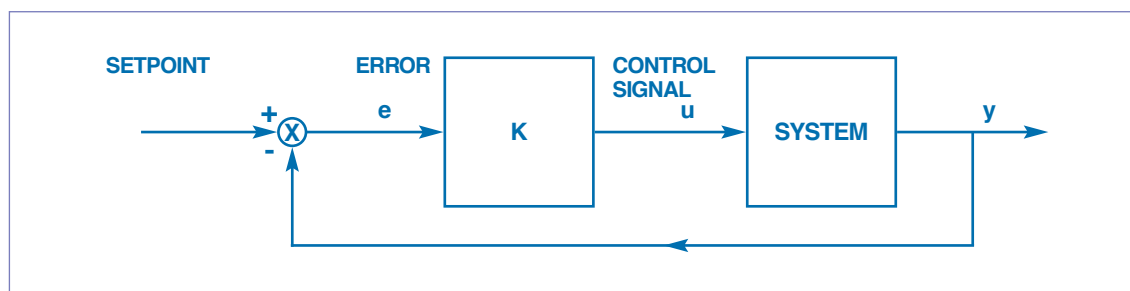


**Figure 1:** Block diagram for proportional control

The simplest formula would be:- $u_n = K(\text{setpoint} - y_n)$

So now we have:- for setpoint = 1, K = 2

| Time, t | Input, u | Output, y | | |
|---------|----------|-----------|---|---|
| 0 | 2 | 0 | | |
| T | 1.6 | 0.2 | y = 0.1 x 2 + 0.9 x 0 | u = 2(1-0.2) |
| 2T | 1.32 | 0.34 | y = 0.1 x 1.6 + 0.9 x 0.2 | u = 2(1-0.34) |
| 3T | 1.124 | 0.438 | …….. | |

Obviously the response is going to be very different from the open loop response. As with continuous control, it will be the same sort of shape, but on a shorter time-scale and with the response not settling at the setpoint.

By varying K we can observe      (i) the varying steady state error
                                         (ii) the varying speed of response
                                         (iii) the changing control signal
and, because it's a discrete system,   (iv) overshoot and eventual instability.

It is good practice to use separate plots for the control signal and the response. The former changes step-wise and should be represented by vertical bars.The latter is continuous and should be represented by a line:
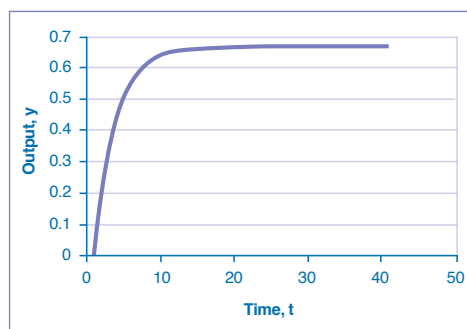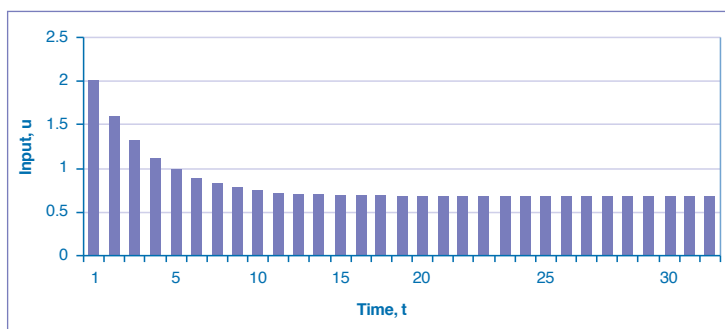


We have done all this by programming two cells on the spreadsheet and calling up some displays. We have explored a number of things, hands on, in our own time.

## A careful look at what we are doing

In the above simulation, the controlled input, u, only changes at a sampling interval. In between u is constant. That is why it plotted as a series of vertical bars. We could describe u as being 'piece-wise constant' or we could say it changes 'step-wise'. It is not a continuous function of time. However, the output, y, shown above, is a continuous signal and so it is plotted as a line.

What we are simulating is a sampled data control system where T is the sampling interval. This corresponds to what happens when we use a computer to control a process.