Computer Science 773

Robotics and Real-time Control

WHAT IS CONTROL ?

BEFORE ELECTRICITY.

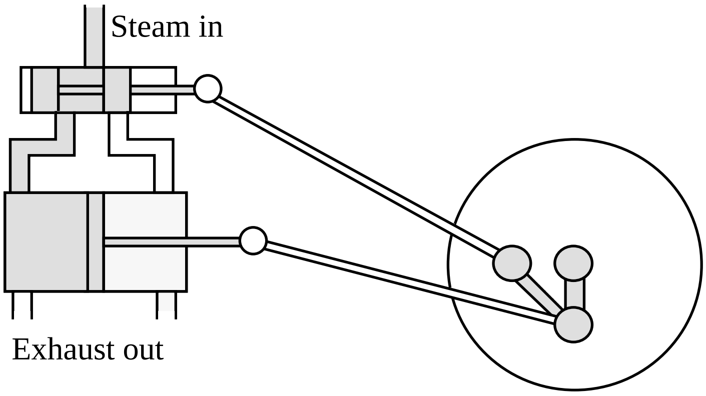
Control machinery of one sort or another has been around for a long time. Leaving aside low-technology examples like horses' reins, effective clocks have been built for many centuries, windmills have automatically pointed themselves into the wind, musical boxes and barrel organs have done their respective things, and so on. But the first widespread applications of control systems came with the development of steam power. Of course, the devices used were not dignified with the name *control systems* until much later – they were thought of, along with pistons and cranks and other bits of hardware, as merely parts of the engine. They were mechanical devices, by modern standards cumbersome and slow; but they worked, and the functions they perform are still very much a part of control engineering today. Some examples :

Steam engine governor : automatically adjusts the steam supply to an engine to maintain constant speed. This is a continuous closed-loop feedback system.

<<<<<<<<<<<<<<<<< SCAN PICTURE

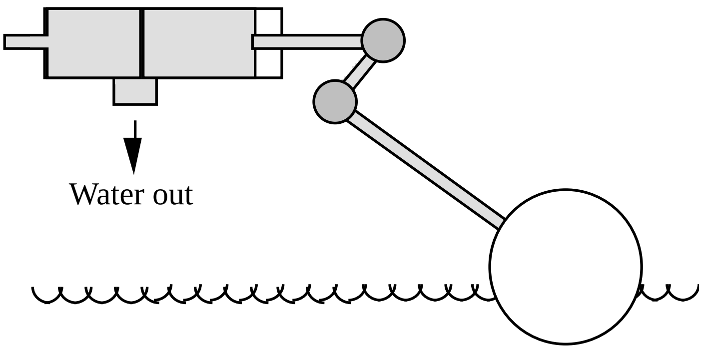
The picture shows a slightly advanced version of the steam engine regulator first used by James Watt, though he developed it from rather similar devices used for controlling the spacing between millstones in windmills. In the early models, the steam valve would be directly controlled by the output from the governor ("speed sensitive element"); the hydraulic amplifier is a later development, which is in principle much like the ball valve.

Steam engine valve gear : makes sure that the inlet and outlet ports of a steam engine's cylinder open and close at the correct times. This is an example of sequencing control.



James Watt didn't use a steam turbine either. He had reciprocating steam engines, in which a cycle of operations is controlled by the admission of steam to a cylinder followed by the removal of steam from the cylinder. The earliest engines were used to drive pumps, when continuous motion wasn't important and manual control of the valves was acceptable. Once the engines were used for providing continuous rotary motion, manual control was not sufficient, so automatic means were provided. This simple valve gear is an example; as the wheel rotates, the link to the valve redirects the steam as required for the next part of the cycle. I've left out the similar gear which opens and closes the exhaust stream. Notice that the link controlling the steam valve is out of phase with the connecting rod from the drive cylinder.

Ball valve : opens a tap to fill a reservoir when the liquid level falls too low. This illustrates the idea of on-off control.



It's true that in practice the flow rate decreases gradually until it stops, but that's an accident; the logic of the system is that when the level is too low, you turn on the tap, and when it's high enough you turn off the tap.

That's just a bit more than a trivially obvious statement. It illustrates that you can think of this continuous system either as a continuously varying device with – in effect – an infinite number of states (which you would probably call a monostable system), or as a binary device with (obviously) two states. Both views are true, and both are useful; we shall meet them again later.

Later on, hydraulic and pneumatic systems were also used. Simple control systems were developed which were very effective and reliable, but all these methods which rely on a physical working substance (levers, liquids, gases) are comparatively cumbersome, rather slow, and use quite a lot of power. It is therefore difficult to develop very large control systems based on these techniques, particularly as precise power amplifiers have been hard to construct until comparatively recently.

ELECTRICITY.

More flexible, much faster – needs much less power, as some sort of amplification is reasonably easy.

SERVOMECHANISMS are analogue devices good for continuous control, usually involving feedback. They needn't be electrical, but often are. The electrical variety use circuitry based on properties of operational amplifiers; this makes it easy to work with functions involving addition, scaling by a constant factor, integration, and differentiation, which are just about what you want to construct quite elaborate control systems. (Nonlinear operations – multiplication, comparison, etc. – can be done too, but are harder and might be approximate.)

RELAYS for switching – good for sequencing systems. The most visible example is probably traffic lights, and early automatic telephone exchanges used the same sort of electromechanical technology, but many large industrial relay-based control systems were built. (We'll come across one sort later in the course.)

The 1939-1945 war stimulated much development in control systems based on these technologies, but also hurried along the birth of digital electronic technology, which since about 1955 has largely replaced the older approaches in a wide range of control systems.

DIGITAL ELECTRONICS.

By 1950, electromechanical systems and servomechanisms were well developed, well understood, and very reliable; that was the competition for the early digital systems. Because of the state of digital technology at the time, the only feasible digital control system in the very early days was a "large" (bear in mind that "large" is a comparative term – by modern standards, they were tiny in everything but size) mainframe (because that's all you could buy), which was used to control all the machines in a largish factory (because you had to spread the cost thinly over many machines to make it economic). This is called direct digital control (DDC), and came into use during the 1960s.

Remark : This is exactly the wrong place to start. The easy way would be to begin with one processor controlling a single simple machine, and work up from there. Unfortunately, computers were far too expensive to waste in such a way, so computer control started with the hard problems, and it's got easier ever since. Or it would have done, if people hadn't insisted on trying to do harder things all the time.

ADVANTAGES OF A DIGITAL SYSTEM :

Cheaper : although the processor is expensive, it replaces a large number of separate units, so the benefit increases with the size of the system.

More flexible : if you want to change the details of the control system, you don't have to stop the plant for a week to rewire it. You just write a new programme.

More stable : an analogue system is always subject to drift, so its characteristics can change slowly with time. Stable analogue systems can be built, but they're more expensive. In a digital system, drift is of little consequence. (Relay systems are essentially digital too, so this is only an advantage with continuous control systems.)

More reliable : a corollary of the previous remarks.

Can implement more sophisticated control : while the early systems usually simply mimicked the analogue or relay systems they replaced, it was clear that more elaborate forms of control could in principle be used. The elaboration can take the form of cleverer control algorithms, or systems which look beyond the immediate environment for useful information, or systems which make use of historical material – analogue storage is difficult to manage over any length of time. Notice that using a large computer for the whole plant implies that all the information about the plant is available for use by any part of the control system.

DISADVANTAGES OF A DIGITAL SYSTEM :

Fragility : if one processor fails, the whole system stops. Clearly, you should get a standby processor – or maybe leave the old electromechanical system in for emergencies. The older systems relied on many control units to keep things going, so if one failed the damage was localised.

Catastrophe : when something does go wrong in a digital system, it can go very wrong; a mistake in a single bit can be very dangerous. In many cases, analogue systems degrade slowly, so that the behaviour of the controlled machine would begin to deviate from that required slowly enough for someone to notice it and take action before an damage occurred.

Difficulty : it turned out to be far harder to write the required programmes than anyone had expected – and they ran much slower. Recall that at the time no one had any real ideas about structure in conventional programming, let alone real-time systems.

Since then, things have changed, and the disadvantages have, in some degree, disappeared. Much cheaper hardware (starting with minicomputers around the late 1960s) has made it possible to use more computers, or to use computer control economically for smaller systems. Developments in instrumentation and communications led on from there to distributed control systems, with many processors each doing much less work. These came into use in the mid-1970s. It is also much easier to add extra hardware at critical points to increase reliability. The distributed nature of the system is a move back to the older pattern of many separate controllers, so if one fails consequences are restricted to the immediate environment.

Advances have also been made in programming techniques, but these are less spectacular. Ideas from structured programming and software engineering techniques as applied to conventional computing are useful, but only up to a point. Conventional methods are designed to take account of complexities which arise from the logical interactions between different parts of a system; but they do not not address the additional interactions imposed by the timing constraints characteristic of real-time systems.

Analogue techniques, electrical and other, have improved a lot too; even so, there's no sign of any trend back to analogue systems. Instead, more and more machinery is moving towards digital methods.

DIGITAL WINS – BUT WHY ?

We're rather accustomed to digital systems replacing analogue systems in the long term, but it's interesting to consider the reasons for their perceived superiority. The table below is grossly oversimplified, but it suggests that the major advantages of digital systems in control computing were not those which led to its preeminence in conventional data processing.

Area	Competition	Winning points
CONVENTIONAL (data processing, science, engineering)	Digital calculators, mechanical and electromechanical; punched card systems	Speed Memory
CONTINUOUS CONTROL	Analogue systems	Precision Flexibility Reliability
SEQUENCING CONTROL	Relays, hard-wired logic	Flexibility Reliability Size

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Alan Creak,
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