
CONTROL SYSTEM DESIGN

Graham C. Goodwin

Stefan F. Graebe

Mario E. Salgado

Chapter 1

The Excitement of Control Engineering

Motivation for Control Engineering

Feedback control has a long history which began with the early desire of humans to harness the materials and forces of nature to their advantage. Early examples of control devices include clock regulating systems and mechanisms for keeping wind-mills pointed into the wind.

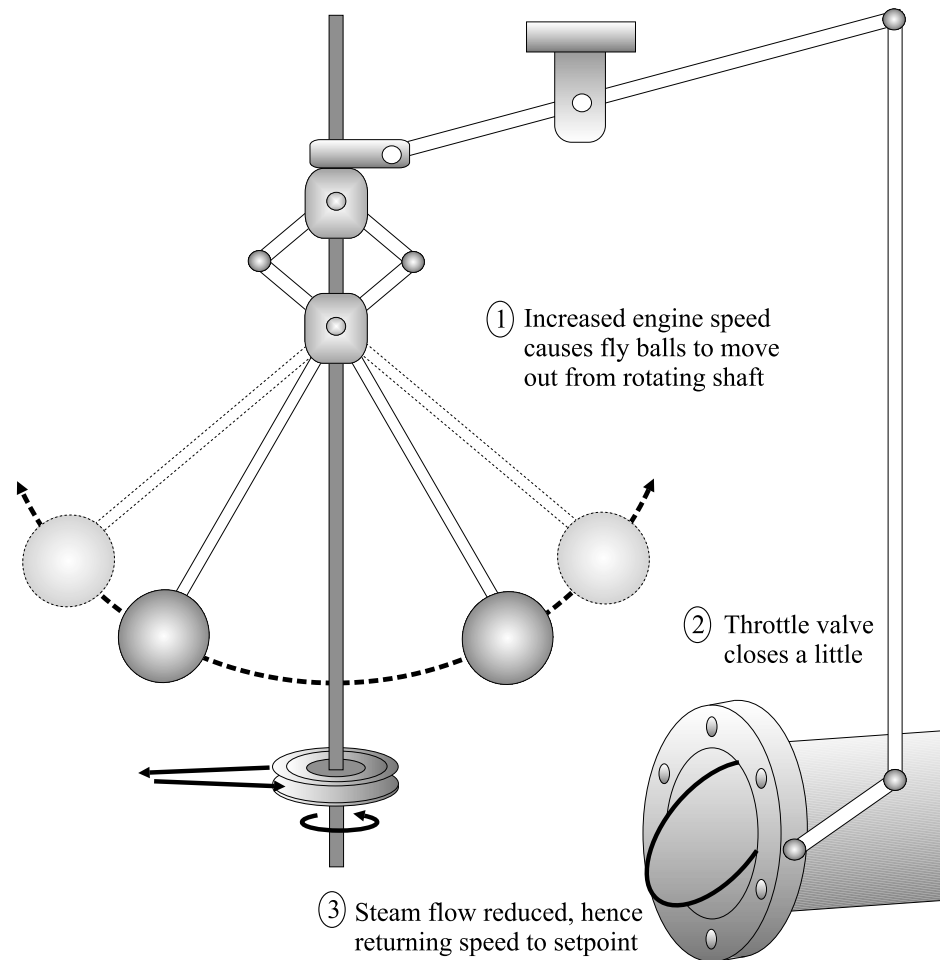
Modern industrial plants have sophisticated control systems which are crucial to their successful operation.

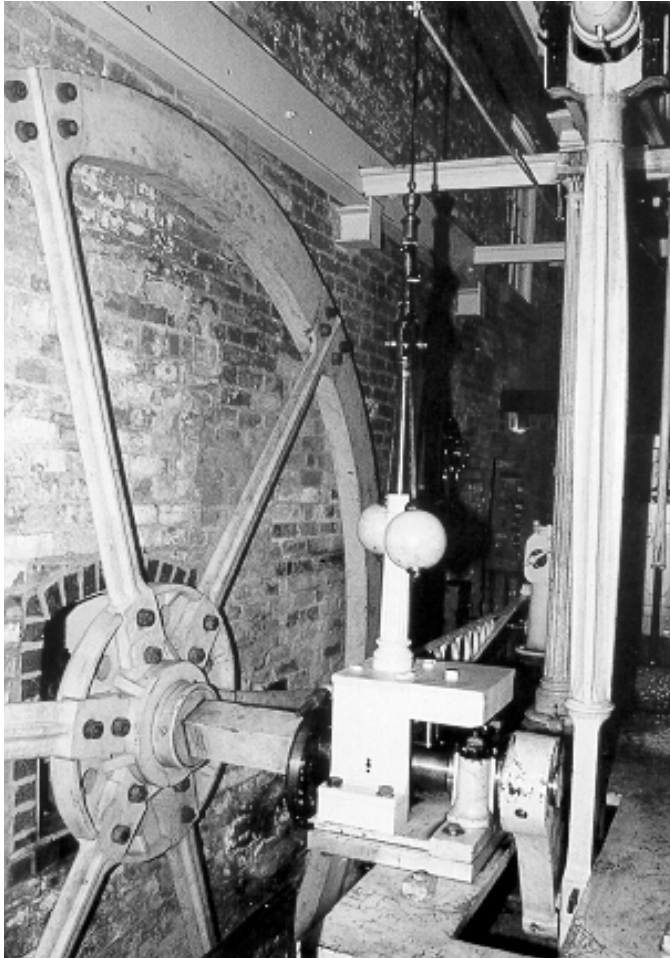
A modern industrial plant: A section of the OMV Oil Refinery in Austria



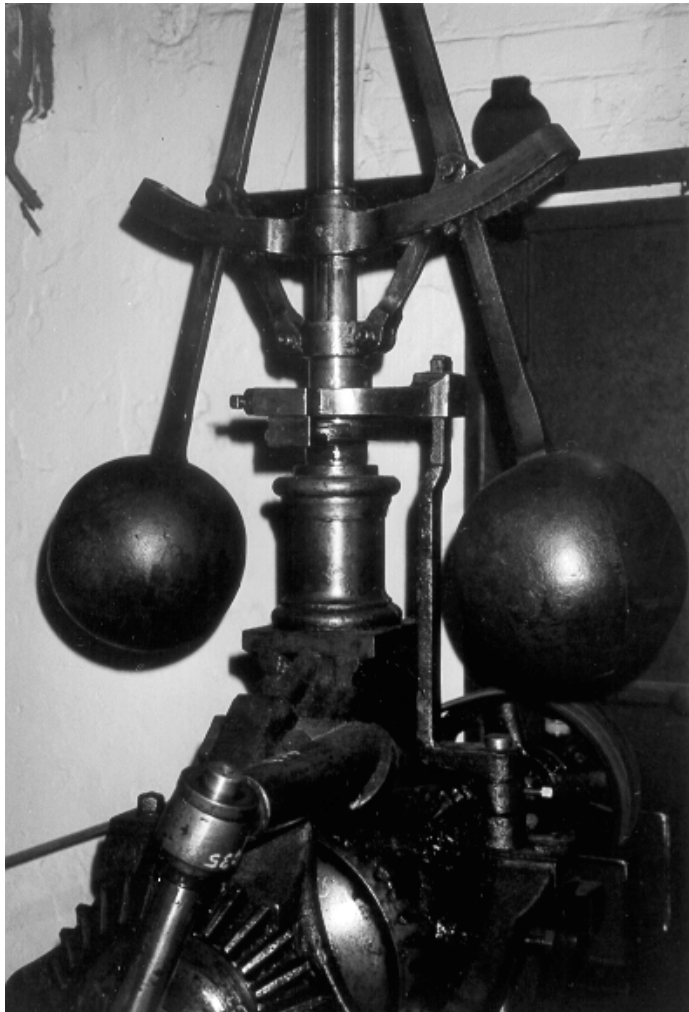
Control Engineering has had a major impact on society. For example, Watt's Fly Ball Governor had a major impact on the industrial revolution. Indeed, most modern systems (aircraft, high speed trains, CD players, ...) could not operate without the aid of sophisticated control systems.

Figure 1.1: *Watt's fly ball governor*





This photograph shows a flyball governor used on a steam engine in a cotton factory near Manchester in the United Kingdom. Of course, Manchester was at the centre of the industrial revolution. Actually, this cotton factory is still running today.



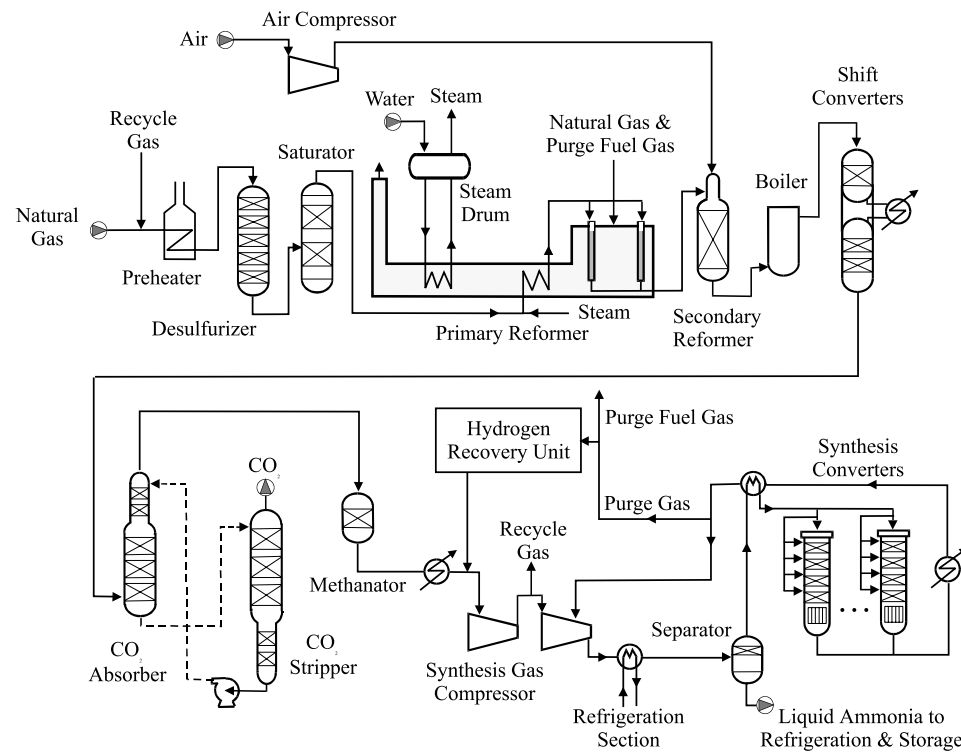
This flyball governor is in the same cotton factory in Manchester. However, this particular governor was used to regulate the speed of a water wheel driven by the flow of the river. The governor is quite large as can be gauged by the outline of the door frame behind the governor.

Improved control is a key enabling technology underpinning:

- ❖ enhanced product quality
- ❖ waste minimization
- ❖ environmental protection
- ❖ greater throughput for a given installed capacity
- ❖ greater yield
- ❖ deferring costly plant upgrades, and
- ❖ higher safety margins

Figure 1.2: *Process schematic of a Kellogg ammonia plant*

All of the above issues are relevant to the control of an integrated plant such as that shown below.



Types of Control System Design

Control system design also takes several different forms and each requires a slightly different approach.

The control engineer is further affected by where the control system is in its lifecycle, e.g.:

- ❖ Initial "grass roots" design
- ❖ Commissioning and Tuning
- ❖ Refinement and Upgrades
- ❖ Forensic studies

System Integration

Success in control engineering depends on taking a holistic viewpoint. Some of the issues are:

- ❖ plant, i.e. the process to be controlled
- ❖ objectives
- ❖ sensors
- ❖ actuators
- ❖ communications
- ❖ computing
- ❖ architectures and interfacing
- ❖ algorithms
- ❖ accounting for disturbances and uncertainty

Plant

The physical layout of a plant is an intrinsic part of control problems. Thus a control engineer needs to be familiar with the "physics" of the process under study. This includes a rudimentary knowledge of the basic energy balance, mass balance and material flows in the system.

Objectives

Before designing sensors, actuators or control architectures, it is important to know the goal, that is, to formulate the control objectives. This includes

- ❖ what does one want to achieve (energy reduction, yield increase,...)
- ❖ what variables need to be controlled to achieve these objectives
- ❖ what level of performance is necessary (accuracy, speed,...)

Sensors

Sensors are the *eyes* of control enabling one to *see* what is going on. Indeed, one statement that is sometimes made about control is:

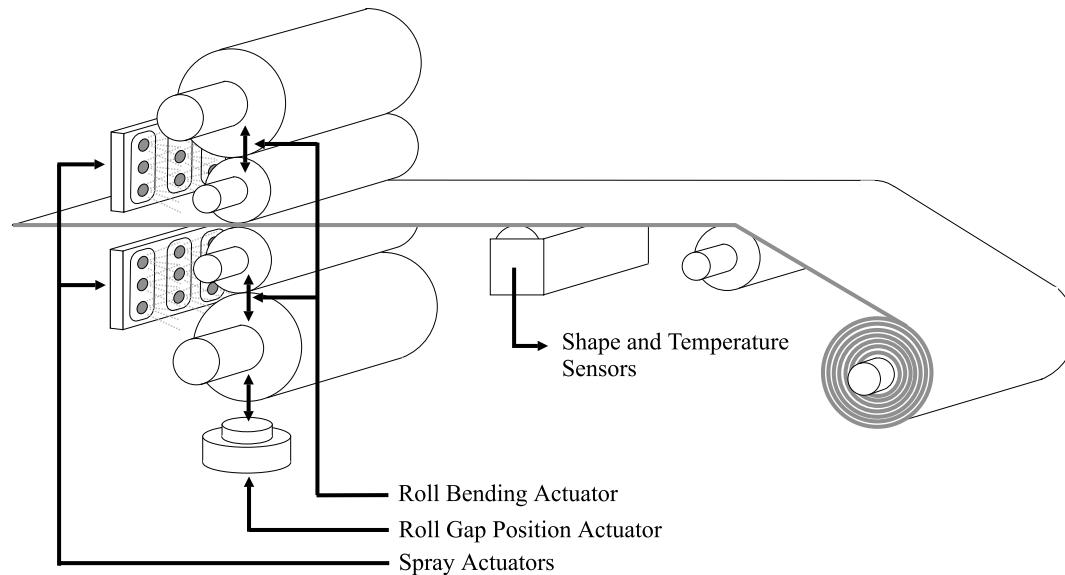
If you can measure it, you can control it.

Actuators

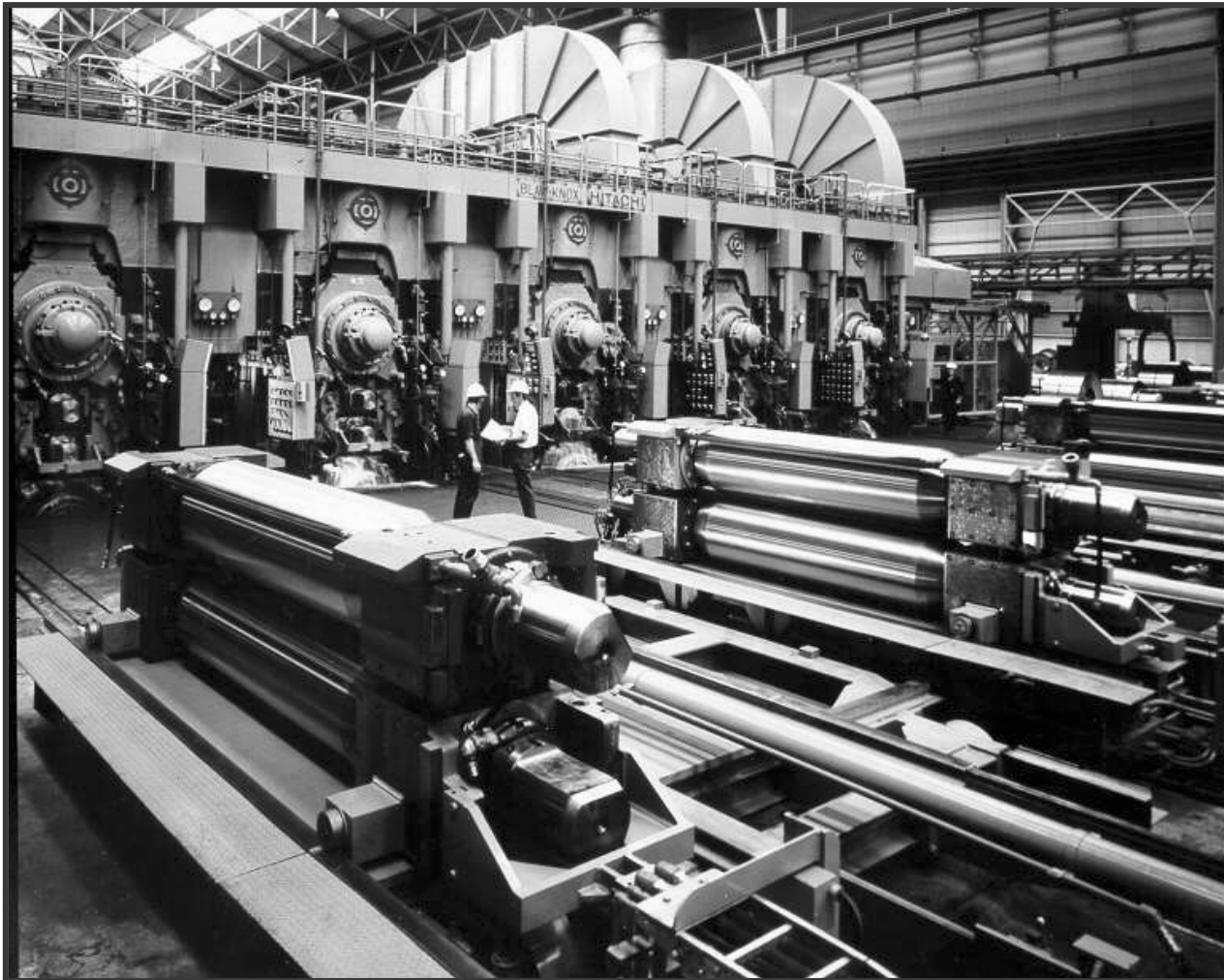
Once sensors are in place to report on the *state* of a process, then the next issue is the ability to affect, or actuate, the system in order to move the process from the current state to a desired state

Figure 1.3: *Typical flatness control set-up for rolling mill*

A typical industrial control problem will usually involve many different actuators - see below:



A modern rolling mill




Communications

Interconnecting sensors to actuators, involves the use of communication systems. A typical plant can have many thousands of separate signals to be sent over long distances. Thus the design of communication systems and their associated protocols is an increasingly important aspect of modern control engineering.

Computing

In modern control systems, the connection between sensors and actuators is invariably made via a computer of some sort. Thus, computer issues are necessarily part of the overall design. Current control systems use a variety of computational devices including DCS's (Distributed Control Systems), PLC's (Programmable Logic Controllers), PC's (Personal Computers), etc.

A modern computer based rapid prototyping system



UNAC-PC

Product Sheet

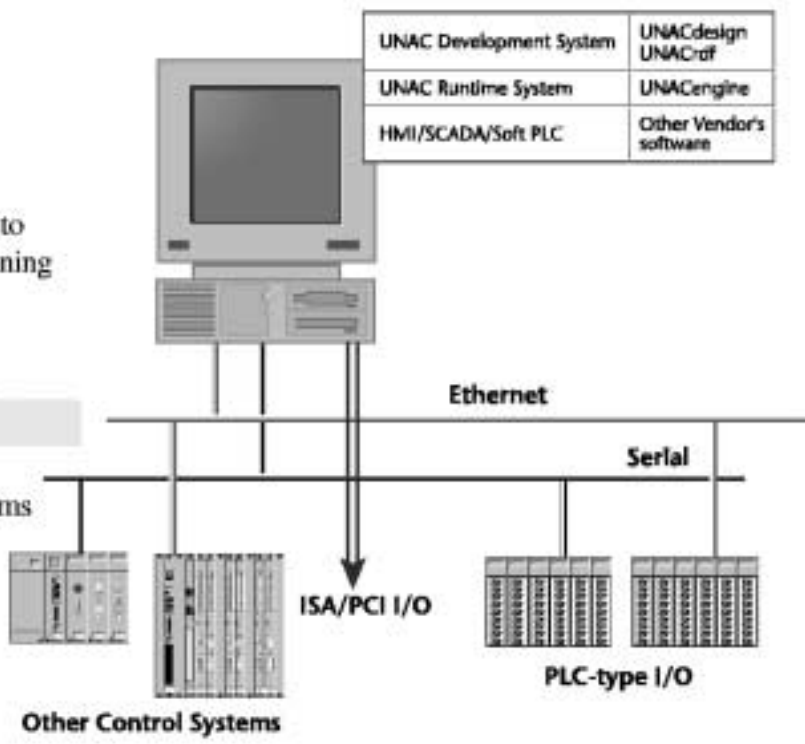
Turn a Laptop, Desktop or Industrial PC into a powerful complete modern process control system

Typical Uses

- Stand-alone control system
- Rapid-prototyping platform for enhanced and advanced control
- Hardware-in-the-loop simulation system
- Condition monitoring and soft-sensing
- Data logging, dynamic modelling and simulation
- Interfacing to existing DCS/PLC installations to provide user-friendly data logging and loop tuning

Features

- Real-time control performance on PC platforms
- Available interface software includes:
 - Elsag Bailey INFI90 and Net90
 - Allen Bradley DF1
 - Modbus Master/Slave
 - TCP/IP
- Interfaces to HMI software (eg. C/Tect)



UNAC Development System	UNACdesign UNACrpf
UNAC Runtime System	UNACengine
HMI/SCADA/Soft PLC	Other Vendor's software

Ethernet

Serial

ISA/PCI I/O

PLC-type I/O

Other Control Systems

Architectures and interfacing

The issue of what to connect to what is a non-trivial one in control system design. One may feel that the best solution would always be to bring all signals to a central point so that each control action would be based on complete information (leading to so called, centralized control). However, this is rarely (if ever) the best solution in practice. Indeed, there are very good reasons why one may not wish to bring all signals to a common point. Obvious objections to this include complexity, cost, time constraints in computation, maintainability, reliability, etc.

Table 1.1: Typical control hierarchy

<i>Level</i>	<i>Description</i>	<i>Goal</i>	<i>Time frame</i>	<i>Typical design tool</i>
4	Plant wide optimization	Meeting customer orders and scheduling supply of materials	Everyday (say)	Static optimization
3	Steady state optimization at unit operational level	Efficient operation of a single unit (e.g. distillation column)	Every hour (say)	Static optimization
2	Dynamic control at unit operation level	Achieving set-points specified at level 3 and achieving rapid recovery from disturbances	Every minute (say)	Multivariable control, e.g. Model Predictive Control
1	Dynamic control at single actuator level	Achieving liquid flow rates etc as specified at level 2 by manipulation of available actuators (e.g. valves)	Every second (say)	Single variable control, e.g. PID

Algorithms

Finally, we come to the real *heart* of control engineering i.e. the algorithms that connect the sensors to the actuators. It is all too easy to underestimate this final aspect of the problem.

As a simple example from our everyday experience, consider the problem of playing tennis at top international level. One can readily accept that one needs good eye sight (sensors) and strong muscles (actuators) to play tennis at this level, but these attributes are not sufficient. Indeed eye-hand coordination (i.e. control) is also crucial to success.

In summary:

*Sensors provide the eyes and actuators the muscle
but control science provides the finesse.*

❖ Better Sensors

Provide better *Vision*



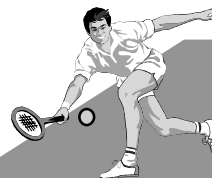
❖ Better Actuators

Provide more *Muscle*



❖ Better Control

Provides more finesse by combining *sensors* and *actuators* in more intelligent ways



Disturbances and Uncertainty

One of the things that makes control science interesting is that all real life systems are acted on by noise and external disturbances. These factors can have a significant impact on the performance of the system. As a simple example, aircraft are subject to disturbances in the form of wind-gusts, and cruise controllers in cars have to cope with different road gradients and different car loadings.

Homogeneity

A final point is that all interconnected systems, including control systems, are only as good as their weakest element. The implications of this in control system design are that one should aim to have all components (plant, sensors, actuators, communications, computing, interfaces, algorithms, etc) of roughly comparable accuracy and performance.

In order to make progress in control engineering (as in any field) it is important to be able to justify the associated expenditure. This usually takes the form of a cost benefit analysis.

Cost benefit analysis

Typical steps include:

- ❖ Assessment of a range of control opportunities;
- ❖ Developing a short list for closer examination;
- ❖ Deciding on a project with high economic or environmental impact;
- ❖ Consulting appropriate personnel (management, operators, production staff, maintenance staff etc.);
- ❖ Identifying the key action points;
- ❖ Collecting base case data for later comparison;
- ❖ Deciding on revised performance specifications;
- ❖ Updating actuators, sensors etc.;

Cost benefit analysis (*Contd.*)

- ❖ Development of algorithms;
- ❖ Testing the algorithms via simulation;
- ❖ Testing the algorithms on the plant using a rapid prototyping system;
- ❖ Collecting preliminary performance data for comparison with the base case;
- ❖ Final implementation;
- ❖ Collection of final performance data;
- ❖ Final reporting on project.

Signals and systems terminology

	<i>Tangible examples</i>	<i>Examples of mathematical approximation</i>	<i>Examples of properties</i>
Signals	set point, control input, disturbances, measurements, ...	continuous function, sample-sequence, random process,...	analytic, stochastic, sinusoidal, standard deviations
Systems	process, controller, sensors, actuators, ...	differential equations, difference equations, transfer functions, state space models, ...	continuous time, sampled, linear, nonlinear, ...