Chapter One

INTRODUCTION

1.1 An Integration Approach, What and Why ?

Today's science and technology have reached such a diversity that a young researcher can easily get lost in the face of countless disciplines. Therefore some philosophical guideline might be helpful for motivating the road chosen for the research and development, pursued,on which this thesis reports.

Since the celebrated work of Newton 300 years ago, Western society has experienced scientific and industrial revolutions which constitute an important component of today's Western civilization. Due to its success "Newtonianism", or the mechanistic world view, has been dominating Western science and technology, especially natural science. This world view perceives the universe as a machine, governed by exact mathematical laws. By this philosophy, in principle, any system can be modelled like a clock; it consists of different elements like the parts of the clock. If all individual elements of the system and their interactions can be analyzed clearly, one will get perfect understanding of the total system behavior. Under such a philosophy, the methodology of the present Western science, especially natural sciences, can be characterized as analytical, rational, reductional and experimental. This method has been extremely successful for studying mechanical systems. Recent developments, however, are showing that this method can not give satisfactory solutions to problems when studying modern physics, sociology, economy, biology, and so on. Now some researchers are convinced that modern science should be guided by a philosophy that has an organic systematic and dynamic world view; cf. Capra, (1984); in fact this was the world view of ancient Eastern philosophy and wisdom (Chinese and Indian). Perhaps it was also the world view in the West before Newton.

Coming from China, let me try to tell some Chinese stories. In the old time, the Chinese believed that there is an ultimate reality which underlies and unifies the multiple things and events. This reality was called the *dao* (*tao* 道), inadequately translated as 'the Way'. A principal characteristic of the *Tao* is the cyclical nature of its ceaseless motion. This world view was symbolized by the *Tai-ji-tu* (*Tai-Ji-Tu* 太极图), or 'Diagram of the Supreme Ultimate', see Fig. 1.1. This diagram is a symmetric arrangement of the polar opposites: the dark *yin* (阴) and bright *yang* (阳). From this pattern, one feels strongly a continuous cyclic movement: "The *yang* returns cyclically to its beginning; the *yin* attains its maximum and gives place to the *yang*" (Kuei Ku Tzu, 鬼谷子 , fourth century B.C.; translated by J. Needham, 1956).

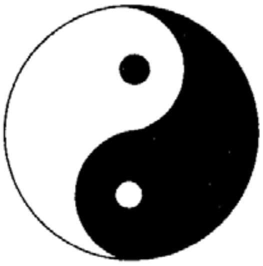


Fig. 1.1 *Tai-Ji-Tu*

The two dots in the *Tai-Ji-Tu* suggest the idea that the two forces contain in themselves the seeds of their opposites. *Yang* is associated with strong, male and creative power; *yin* is associated with receptive, female and maternal element. Further associations are:

yin	*yang*
earth	heaven
moon	sun
night	day
winter	summer
water	fire
coolness	warmth
interior	surface
⋮	⋮

The relation between *yin* and *yang* is complementary. It is important to recognize that these opposites do not belong to different categories but are extreme poles of a single whole. *Yin* does not exist without *yang* and vice versa. Nothing is only *yin* or only *yang*. All natural phenomena and social events are manifestations of a continuous oscillation between *yin* and *yang*. Just as it does not make sense to ask which is more important for life, the is good is not *yin* or *yang* but the dynamic balance or harmony between the two; what is bad or harmful is imbalance.

There were two most influential schools in old China: Confucianism, founded by Kong Fu-Zi (Confucius, 孔夫子, 551 — 479 B.C.), and Taoism, founded by Lao Zi (Lao Tzu, 老子, who was said to be 20 years older than Confucius). Confucius studied social system; and he believed that in order to keep the balance of the society there must be a strict convention of social etiquette. One of the rules Confucius made for the people was that every one in society should behave according his social position — an emperor should act as an emperor, minister as minister, father as father and son as son (君君臣臣父父子子). He also advised people not to be extreme and radical (中庸之道, moderation). Taoists studied more on the relation between the human being and nature. The harmony of this system is achieved if people can discover the *tao*, or the law of nature, acting spontaneously. *Wu wei* (无为) is the action Taoists took; it means follow the nature and do not act against nature.

In our time, when talking about social life and scientific research, the following associations of *yin* and *yang* might be acceptable:

yin	*yang*
feminine	masculine
contractive	expansive
conservative	demanding
responsive	aggressive
cooperative	competitive
intuitive	rational
synthesizing	analytic
integral	reductional
⋮	⋮

Examining this list of opposites, we see that at least since 300 years ago, Western society and science have consistently favored *yang* over *yin* (when compared with Eastern culture): competition over cooperation, exploitation of nature over conservation, rational knowledge over intuitive wisdom, reduction over integration, analysis over synthesis, and so on.

After having recognized this imbalance, it is not difficult to understand why Western scientists are so fond of formal mathematics; why they are so good in differentiating problems into their smallest possible components; and why they often forget to put the pieces back together again. This imbalance also shows that there is a need to emphasize more strongly *yin* in Western research, i.e., to emphasize intuition, synthesis and integration.

Under such a guideline, in this work, we will try to integrate identification and control for industrial manufacturing systems; we will show how this philosophy can be useful for choosing a research topic and even for generating new ideas.

In the last few centuries in the history, however, Chinese preferred *yin* to *yang* (when compared with Western culture) — they would give response to the nature rather than exploit it, they tried to follow the rules in order to avoid conflicts, they preferred talking about general philosophy to the completion of a concrete project, they preferred intuitive wisdom and common sense to analytical reasoning. This is perhaps one of the reasons why modern science has not been born in China.

One might ask what modern China can learn from Western culture. The author believes that there is a need to emphasize *yang*. For example, make competition fair play and bring it into the public eye from underground; give individuals more freedom and opportunities for self-fulfilment; use more scientific reasoning and analytical approach to study social, political and economical problems; test theories by facts instead of by doctrines; and so on. The science and technology in modern China, however, suffer the same illness as in the West, that is, there is in general a lack of intuition and integration approach. One of the reasons is that most researchers in China are in the learning period, we do not have enough experience and confidence yet to go further to combine the Western and the Chinese approaches. Time and an open policy are needed to achieve a good combination of the Western and the Eastern approaches and, more broadly, their cultures. But if this happens, there will be a renaissance of Eastern culture, which will be enjoyed , this time, by both Eastern and Western people due to modern communications. More discussions on this topic is beyond the scope of the thesis.

1.2 The Philosophy of Identification

There are basically two ways of building models of systems — the mathematical modelling approach and the identification approach.

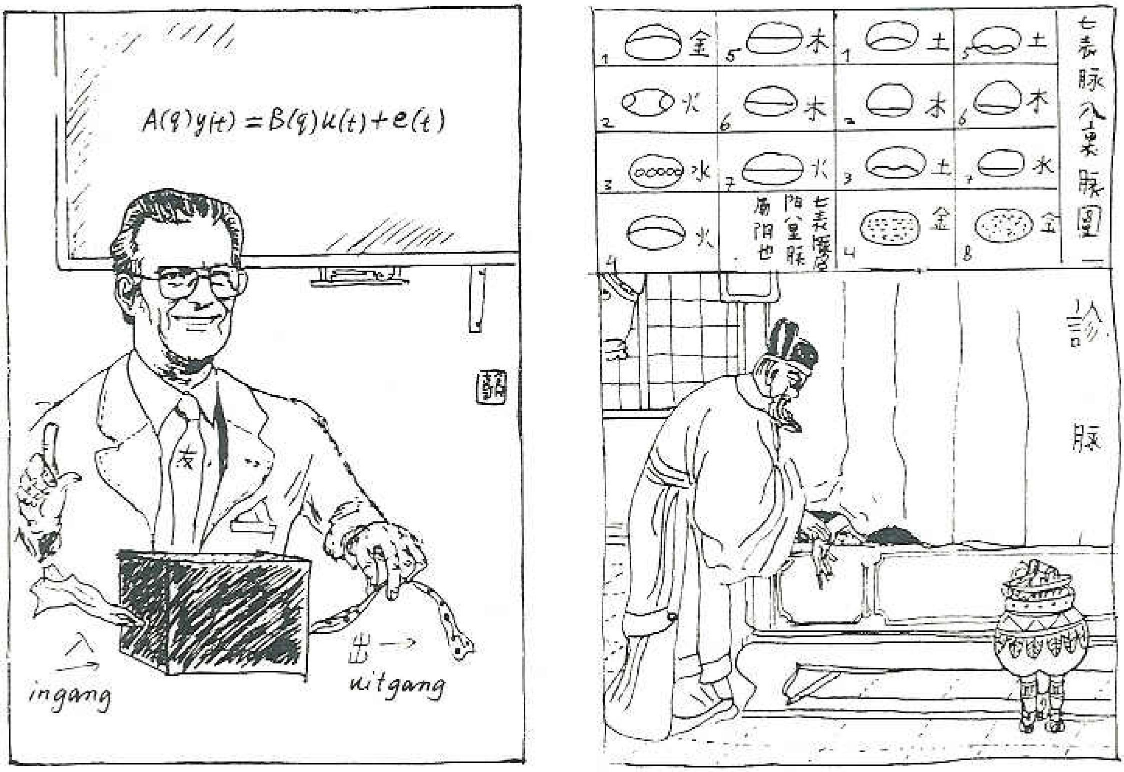
Mathematical modelling is the most common and conventional method in Western science and technology. By this approach one starts with decomposing the system into its subsystems, and subsystems into their elements; then one writes down the equations for each element based on first principles, e.g., physical laws; and finally one forms the system model by putting the equations together according to the interrelations between the elements and the subsystems. Some people also call this approach physical modelling. From the methodological point of view, this is typically a reductional, rational and analytical approach; a *yang* approach.

System identification can be defined as deriving system models from observations and measurements. In this approach, the system is viewed as a whole; there is perhaps no need or intention to analyze each element of the system; the systems behavior is observed by measuring some relevant variables; and such a model is chosen of which the behavior fits best the measurements. By this approach one does not attempt to go deep into the system, the precise physical knowledge of the system elements and their interrelations is not necessary; therefore identification is also called black-box modelling; see Fig. 1.2.a. Identification is a new branch in the field of dynamic systems and control; and is formally founded about 25 years ago (the first IFAC symposium on identification was held in Prague, 1967).

In contrast with the mathematical modelling approach, the philosophy of identification is the wholeness; its methodology is integral and synthetical. This is, however, not very much a typical modern Western methodology. It has a strong *yin* force. Here we see another parallel between ancient Eastern philosophy and modern Western science and technology (physicists have pointed out many parallels between Eastern philosophy and modern physics; see e.g., Capra, 1984). It is interesting to observe that modern identification has been born on the bed of systems and control. From a philosophical point of view, it is not difficult to see why this happened. Needless to say, the philosophy behind dynamic system theory is the systems view or the wholeness. The mathematical modelling approach follows Newton's philosophy; its use is limited whenever the fundamental laws of some system elements and/or some interrelations are not known yet or too complex. With the aid of identification, which has also a systems view, one might go beyond this limit. A remark should be given here that we are not trying to say that identification is better than mathematical modelling or vice versa. To obtain the best model of a system in practice, one should combine the two approaches (that is, to reach a balance between *yin* and *yang*)

There is more to tell about identification. Chinese medicine is a good example to show how the ancient Chinese philosophy and wisdom influenced the practice of Chinese people. The human body was modelled as the universe;

viewed as an organic whole and there are *yin* and *yang* parts. For example, the back is *yang*, the front is *yin*; the skin or surface is *yang*, the interior is *yin*. Inside the body, there are *yin* and *yang* organs. Of the five viscera the heart and liver are *yang* organs and the spleen, lungs and kidneys are *yin* organs. The balance between *yin* and *yang* is maintained by a continuous flow of *qi* (chi 气), or vital energy, cyclically between *yin* and *yang* organs. Whenever the flow between *yin* and *yang* is obstructed (hindered), an imbalance will occur and the body falls ill. To detect the illness, pulse feeling was the most important method of diagnosis of Chinese medicine. The examination is made upon both the right and left wrists, the physician using three fingers (index, middle and ring fingers) to feel the pulse of his patient. It is recorded that Bian Qiao (Pien Chiao, 扁鹊) who lived about 255 B.C. was



a. Identification is black-box modelling

b. Performing a diagnosis for his female patient

Fig. 1.2 The philosophy of identification the inventor of this idea; cf. Wong and Wu, (1936). Before him the pulses from many places of the body should be measured. But Bian Qiao realized that one could gather enough information only from the two wrists of the patient, which was much more convenient.

One of the rules made by Confucianism was that men and women should not be close with each other (男女授受不亲), except within the family; and an unmarried girl should not be seen by male outsiders. But this rule was not really a restriction for a Chinese doctor to perform diagnosis for his female patient. In such a case, he could simply feels the pulses of the lady behind the curtain; see Fig. 1.2.b. This procedure, however, fits very well to the definition of identification; and we note that the doctor was identifying a three output system! This story of pulse feeling suggests that the history of system identification is at least 2000 years longer than we usually think.

So much about philosophy. Let us now turn to more practical and technical issues.

1.3 Defining and Analyzing the Problems

In the 1980's, due to the world-wide competition, shortage of natural resources and pollution of the environment, an industrial manufacturer has to face following challenges:

- decreasing delivery times;
- increasing demand on product quality;
- large variety but smaller series of products;
- more constraints on material consumption, energy consumption, and pollution;
- ...

Research on and development of advanced process control systems is one way to meet such challenges. To this end, many disciplines, such as modelling, identification, systems and control, microelectronics, informatics, measurement and sensors, physics and chemistry, need to be used jointly. It is obvious that we are forced to combine things when solving practical problems. This is also feasible because most of the fields mentioned above have experienced a fast development in recent years and much work has been done on the fundamentals. The main problem is how to put these pieces together. Due to my academic background and personal interests, the interalation of two pieces —— identification and control —— will be studied in this work.

A wide class of industrial manufacturing plants can be characterized as follows:

- They are multi–input, multi–output (MIMO) processes.
- Modelling by physical laws is only partly feasible or, in other words, physical modelling alone can not supply a model that is suitable for control; so identification, that is, deriving a process model from experimental data, is necessary for obtaining a model to be used in the controller design.
- The process dynamics is highly complex, e.g., nonlinearity and time variation might occur, and there are process disturbances. These cause model uncertainties (modelling errors). But still linear and time invariant models will give good approximations of the process dynamics at each working point
- Time delay(s) exist(s) in the process under study; the plant is often a nonminimum–phase process.
- *Disturbance attenuation* and *stability robustness* are the main desired features of the controlled system.

Example 1.1 A glass tube production process (Backx, 1987).
The process outline is shown in Fig.1.3. By indirect electric heating the glass is melted and flows down through a ringshaped hole along the accurately positioned mandril. The glass tube is pulled down due to gravity and supported by a drawing machine.

Shaping of the tube takes place at, and just below the end of the mandril. The longitudinal shape of the tube is characterized by two important parameters, the averaged wall thickness and averaged diameter, which will be taken as the process outputs to be controlled. Both of these dimensional variables are influenced by many process variables:

- the mandril gas pressure,
- the drawing speed,
- the power applied to melt the glass,
- the pressure in the melting vessel,
- the composition of raw materials,
- the room temperature,
- and others.

Among these variables, the mandril pressure and the drawing speed can affect the wall–thickness and the diameter most directly and easily, with the shortest delay times and over the widest frequency range. Hence the process is modelled as a two input (mandril pressure and drawing speed) and two output (wall–thickness and diameter) process with the other variables being treated as disturbances. Large time delays exist because the measurement of the tube dimensions (process outputs) is only possible after the tube has cooled down to sufficiently low temperatures.

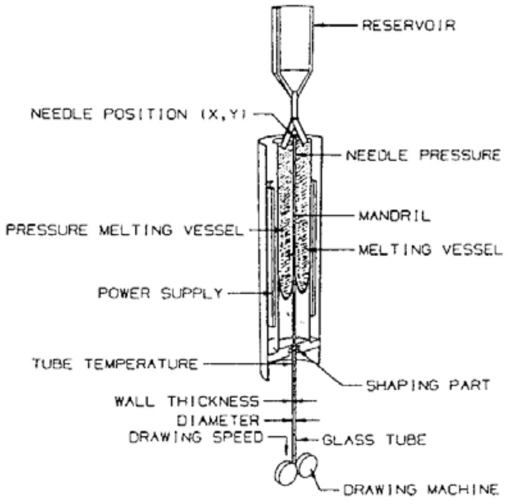


Fig.1.3 Outline of the glass tube production process

The purpose of the study was to develop a computer control/supervision system in order

(1) to reduce the variations of the dimensions at a working point (increase product quality), and
(2) to automate the change–over between different working points and decrease the change–over time (make production more flexible).

The mathematical modelling of the process would result in two partial differential equations with some important parameters being unknown. Experience has shown that it is more appropriate to use identification techniques to derive approximate linear, lumped parameter models of the process at various working points from the experimental data, and to design or adjust the control system based on estimated models. In this approach mathematical modelling can supply *a priori* knowledge about the process for the identification and parameter estimation. ■

More details about the glass tube production process and discussions on the characteristics of industrial processes can be found in Backx (1987); abd we will come back to this process in Chapter 6.

1.4 Scope of This Thesis

For such class of industrial processes, control theory and design techniques that can cope with model uncertainties will be more suitable than the conventional approach. This topic, usually called *robust control*, has been studied extensively since 1980. For the analysis and design of a robust control system, one needs not only a nominal model of the process but also a suitable description of the model uncertainty, typically, an upper bound of the modelling errors in the frequency domain.

Thus, it is clear that an estimation of the uncertainty of identified models in the frequency domain will be the key to linking identification and robust control. This topic, however, has not received enough attention; most of recent research on identification has been focused on time domain parametrical estimation methods and convergence analysis. Based on these observations, we decide *to develop an identification method which delivers a nominal model together with an upper bound of its errors in the frequency domain*; this should be applicable for industrial processes. This forms the first part of the work (Chapter 2, 3, and 4).

Here, the idea of integration has motivated naturally such a research topic. Choosing a research topic might be one of the most difficult parts of research. Many researchers chose topics based on reductionism: split a problem into its smaller pieces and analyze deeply one such piece. Here we can say that the opposite is also possible (even commendable), that is, to put pieces back together again.

Often identification experiments have to be performed in closed loop, that is, under feedback control, due to safety and/or economical reasons. It is well known that, compared to an open loop experiment, there is a degradation of process model quality when using closed loop data. In this structure, there is a conflict between identification and control; and the estimation algorithm may even be unsuccessful (not converge) when the open loop process is unstable or nearly unstable, which is often the reason for a closed loop experiment. But,

- when viewing identification and control as two aspects of the same problem rather than two separate problems,
- when viewing the closed loop system as a whole,

a question arises: *for control system design or adjustment, is it really necessary to identify the original process dynamics when it already belongs to a closed loop system*? By answering this somewhat philosophical question, we arrive at a new and natural solution to the problem: first identify the closed loop system dynamics, then design a second loop controller based on this system model. *The model of the original process is not needed for the design of the second loop controller.* This approach is studied in Chapter 5, which is the second part of the work. In the new scheme, identification and control are mutually supporting; there is no need to develop new identification and control techniques for the scheme.

There is another question to be asked: why such a simple solution for combining identification and control has not been proposed for so many years? Perhaps it is not because that it is too simple to mention. The reason might be that most researchers follow Newton's reductionism: they tend to start with studying the smaller pieces of the original problem, even when it is not necessary. Taoists said, the more you know about *tao,* the more you can achieve with less effort.

If one wants to know how the ideas work, please read the following chapters.