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Soft Sensors in Industrial Applications

1.1 Introduction

Soft sensors are a valuable tool in many different industrial fields of application, including refineries, chemical plants, cement kilns, power plants, pulp and paper industry, food processing, nuclear plants, urban and industrial pollution monitoring, just to give a few examples. They are used to solve a number of different problems such as measuring system back-up, what-if analysis, real-time prediction for plant control, sensor validation and fault diagnosis strategies.

This book deals with some key points of the soft sensors design procedure, starting from the necessary critical analysis of rough process data, to their performance analysis, and to topics related to on-line implementation.

All the aspects of soft sensor design are dealt with both from a theoretical point of view, introducing a number of possible approaches, and with numerical examples taken from real industrial applications, which are used to illustrate the behavior of each approach.

Industries are day by day faced with the choice of suitable production policies that are the result of a number of compromises among different constraints. Final product prices and quality are of course two relevant and competing factors which can determine the market success of an industry. Strictly related to such aspects are topics like power and raw materials consumption, especially because of the ever growing price of crude oil. Moreover, the observance of safety rules (according to several studies, inadequate management of abnormal situations represents a relevant cause of loss in industry) and environmental pollution issues contribute to increase the complexity of the outlined scenario.

In recent decades, people and politicians have focused their attention on these topics, and regulations have been promoted by governments. Companies are required to respect laws that enforce more and more strict limits on product specifications and pollutant emissions of industrial plants.

A relevant example is the Kyoto treaty, which is a legal agreement under which industrialized countries agreed to reduce their collective emissions of greenhouse
gases by 5.2% compared to the year 1990. The goal of the treaty is to lower overall emissions of six greenhouse gases – carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulfur hexafluoride (SF₆), hydrofluorcarbons (HCFs), and perfluorocarbons (PFCs) – calculated as an average over the five-year period 2008–12. The treaty came into force on February 16, 2005 following ratification by Russia on November 18, 2004. As of September 2005, a total of 156 countries have ratified the agreement (representing over 61% of global emissions). Although notable exceptions include the United States and Australia, the agreement clearly shows that environmental issues are recognized as global problems.

The constraints mentioned above represent a continuous challenge for process engineers, politicians and operators; adequate solutions require a deep, quantitative knowledge of the process and of relevant process parameters. The importance of monitoring a large set of process variables by installing and using adequate measuring systems (generally in the form of distributed monitoring networks) is therefore clear.

Unfortunately measuring devices are generally required to work in a hostile environment that, on the one hand, requires instrumentation to meet very restrictive design standards, while on the other hand a maintenance protocol has to be scheduled. In any case, the occurrence of unexpected faults cannot be totally avoided. Nevertheless, some measuring tools can introduce a significant delay in the application that can reduce the efficiency of control policies. To install and maintain a measuring network devoted to monitoring a large plant is never cheap and the required budget can significantly affect the total running costs of the plant, which are generally biased to reduce the total number of monitored variables and/or the frequency of observations, though in many industrial situations infrequent sampling (lack of on-line sensors) of some process variables can present potential operability problems. A typical case is when variables relevant to product quality are determined by off-line sample analyses in the laboratory, thus introducing discontinuity and significant delays (Warne et al., 2004).

Cases can be mentioned where it is impossible to install an on-line measuring device because of limitations of measuring technologies. Also in such cases the variables that are key indicators of process performance are determined by off-line laboratory analyses.

Mathematical models of processes designed to estimate relevant process variables can help to reduce the need for measuring devices, improve system reliability and develop tight control policies.

Plant models devoted to the estimation of plant variables are known either as inferential models, virtual sensors, or soft sensors.

Soft Sensors offer a number of attractive properties:

- they represent a low-cost alternative to expensive hardware devices, allowing the realization of more comprehensive monitoring networks;
- they can work in parallel with hardware sensors, giving useful information for fault detection tasks, thus allowing the realization of more reliable processes;
- they can easily be implemented on existing hardware (e.g. microcontrollers) and retuned when system parameters change;