Chapter 7
Sensor Integration and Data Fusion Theory

In previous chapters, the engineering scientific foundations of manufacturing intelligence (such as the knowledge-based system, Multi-Agent system, data mining and knowledge discovery, and computing intelligence) have been discussed in detail. Sensor integration and data fusion is another important theory of manufacturing intelligence.

With the development of integrated systems, there is an urgent requirement for improving system automaticity and intelligence. Without improvement, the complexity and scale of systems are increased. Such systems need to be more sensitive to their work environment and independent state, and obviously, single sensor technology hardly meets these requirements. Multi-sensor and data fusion technology are therefore employed in automatic and intelligent manufacturing as it is more comprehensive and accurate than traditional single sensor technology if the information redundancy and complementarity are used reasonably. In theory, the outputs of multi-sensors are mutually validated. Multi-sensor integration is a brand new concept for intelligent manufacturing, and without doubt, sensor integration-based intelligent manufacturing is the development orientation of manufacturing in the future.

With reference to the information fusion problem of the multi-sensor integration system, the development state, technical background, application scope and basic meaning of the multi-sensor integration and the data fusion are first reviewed in this chapter. Secondly the classification, level, system structure and function model of the data fusion system is discussed. The theoretical method of the data fusion is then introduced, and finally, attention is paid to cutting tool condition detection, machine thermal error compensation and online detection and error compensation because those are the main applications of multi-sensor data fusion technology in intelligent manufacturing.

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INTRODUCTION

Background and Development

Multi-sensor integration is a system-controlled process based on integrating information from

different sensors when a multi-sensor system completes a task. It emphasizes the conversion of different data and the overall flow structure for the system. Multi-sensor fusion is a specific stage in the process of multi-sensor integration, in which sensor information is merged into unified comprehensive information. The specific methods and procedures of data conversion and merger are emphasized.

Multi-sensor integration and fusion technology is actually a comprehensive technology of multi-source information. In multi-sensor integration and fusion, the most consistent estimate of a measured object and its nature are obtained through analysis and comprehension for data information from various sensors.

Multi-sensor fusion research started as early as 1973, when research institutions in the United States, funded by the Department of Defense, started to study sonar signal understanding systems. From then on, multi-sensor fusion technology developed rapidly. Apart from being used in the C^3I (Command/Control/Communication Intelligence) system, many kinds of sensors are now widely used to gather information in industrial control, robotics, air traffic control, marine surveillance and management Multi-sensor fusion research has become an issue of concern in the military, production and high-technology development areas.

In 1988, the U.S. Department of Defense listed the C^3I multi-sensor fusion technology as one of 20 key technologies of research and development in the 1990s. The C^3I expert group led by the U.S. Secretary of Defense set up a specialized data fusion group and organized a number of thematic plans to study multi-sensor fusion technology, and since 1992 some 100 million U.S. dollars annually have been invested in multi-sensor fusion technology. Related journals are also published and specialized conferences are held internationally, so that there is a well researched environment for multi-sensor fusion technology. In October 1994, the first international conference on multi-sensor fusion and integration for intelligent systems, launched by IEEE, was held in Las Vegas (Dasarathy B.V., 1997). It signals that research and application of multi-sensor integration and information fusion have come into prominence.

Multi-sensor fusion theory is divided into numerical approach research of similar information fusion, and symbol approach research of information integration of different types. Numerical approach research of similar information fusion, especially distribution of all kinds of optimal, sub-optimal or part dispersed algorithms, is more dominant, while symbol approach research of information integration of different types is more difficult in theoretical research mainly oriented to exploratory research. There are many application systems with the feature of multi-sensor information integration, such as the early warning integrated navigation system, using INS, or Inertial Navigation System and the Global Positioning System (GPS) to improve accuracy by multi-sensor data fusion.

Basic Principles and Its Process

Basic Integrated Principles

Because design requirements for individual systems vary, different forms are used for the process of multi-sensor integration, although some basic principles are shared by many of the implementation processes. Figure 1 presents the framework of multi-sensor integration which is composed of these basic principles. A certain-process is detected by many sensors. Suppose the number of sensors is n. Here n is a variable. Before integration, each sensor data is modeled effectively. Sensor models represent the uncertainty and error of each sensor data, usually assuming that the uncertainty of sensor data is subject to the Gaussian distribution. After sensor data modeling, three different perception treatments can be applied, such as fusion, separate operation and guiding or cueing to integrating.