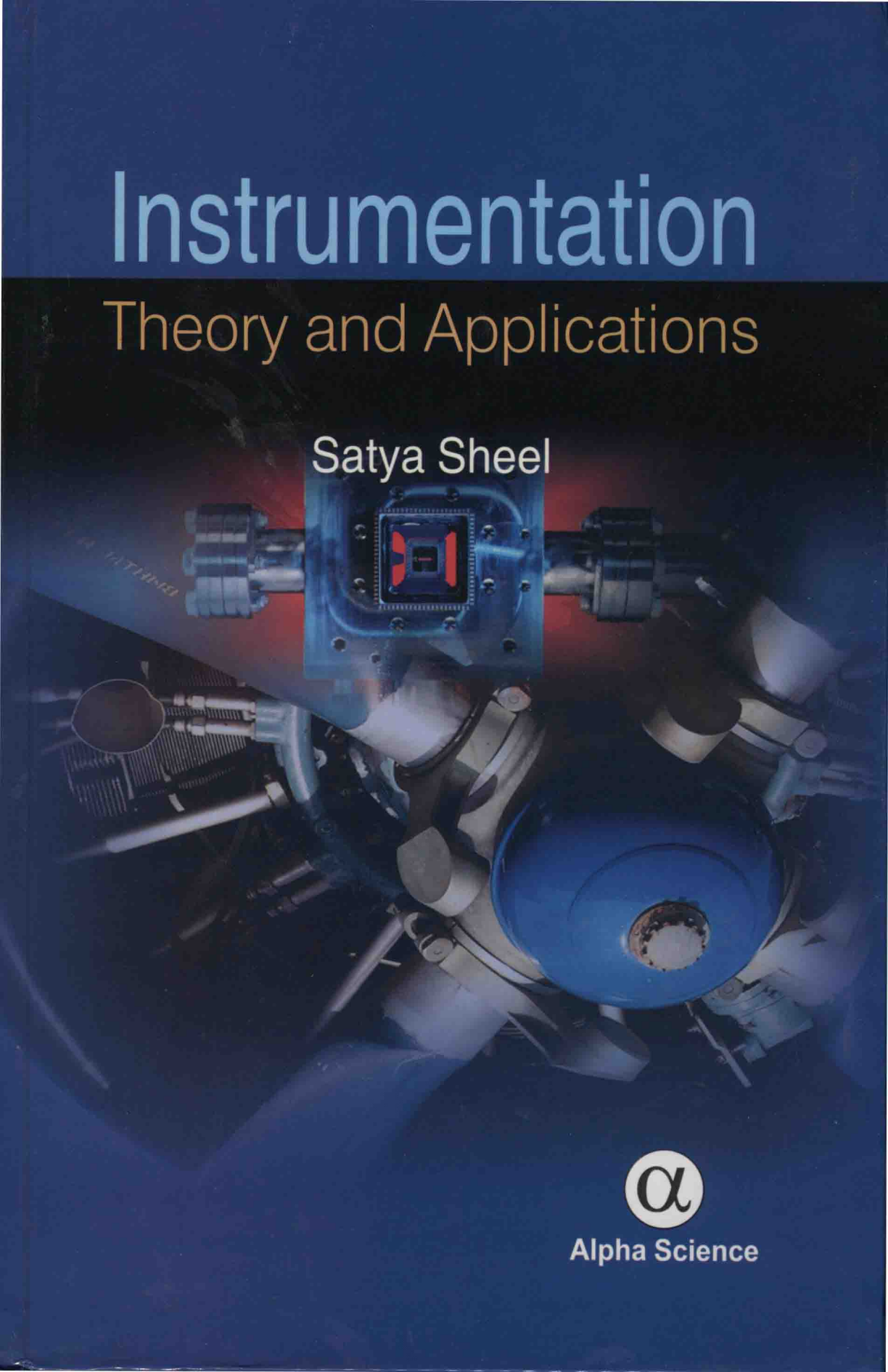
Instrumentation

Theory and Applications

Satya Sheel



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THIS CREATION IS DEDICATED TO
THE MEMORY OF

MY PARENTS

Preface

Instrumentation and measurement are part of all scientific and industrial activities. The theory of measurement involves sensing the phenomenon, obtaining electrical signals, their processing, and interpreting the information to make meaningful deductions about the system. The activity involves use of principles and information from several disciplines, and interestingly useful to all engineering/ scientific endeavors. The most important application of the signals is for monitoring the system/process and using this information to implement control actions. In industrial situation (and in many others) the measurement related activities are to be conducted perpetually in a pre-defined sequential manner. Such a group of activities performed with the dedicated hardware (and sometimes software too) is called an instrumentation (system). Instrumentation is an ever growing discipline with importance in all types of industries and scientific research. Its complexity has grown steadily with increasing importance of accuracy, precision, faster data acquisition & faithful transmission to ensure high product quality. This is evident from the glance at the major industries viz. Chemical units; Steel plants; Oil refineries; Cement factories; Sugar mills; Food processing & Beverages (both soft and hard) production centers; Pharmaceutical industry; Paper and pulp industry; Audio, radio, video communication; Consumer, entertainment, industrial, defense and medical electronics.

A large number of books related to various aspects of instrumentation, needs of different industries are available, but there has been shortage of a textbook which provides sound theoretical basis, followed by application and information of design/selection aspects involved, simple enough for students to understand and yet invoke minimum mathematics and electronics, so as to stress on applications, and be easily followed by practicing engineers from various disciplines and scientists. Normally to cover the necessary theory and the elements of instrumentation system architecture four to five textbooks are required. The need to reduce this problem has been felt for a long time. Also, the details required for students of

different branches/groups of engineering professionals vary largely. Looking at the developments in instrumentation, it is to be noticed that mechanical, hydraulic and pneumatic instrumentation have been in use for a long period with high success rate and also have common industry standard. However, over the last 20 years the electrical and electronic instrumentation have developed so much that all earlier techniques have become outdated and might be obsolete very soon. Therefore, in this text earlier technologies have not been discussed in this text, except for cursory reference at a few places. Biomedical instrumentation is related but very specialized on its own, and not considered. However for the first course the students and fellow teachers will find useful information.

The developments in electronic instrumentation have been very rapid and wide spread, as these involve several aspects, the choice of a single text been difficult. With this in view, this text has been designed with a flexible approach, so that the main text provides the necessary theory, yet assumes little mathematical background, with necessary knowledge presented and other details are included in appendices, so that depending upon the details actually needed by the reader, the appendices and bibliography may be appropriately referred.

The book is considered useful for the following type of users:

(*i*) Students having their first course in instrumentation in any branch of engineering and needing a text complete in itself.

(*ii*) Scientists needing background of various aspects – theory, mathematical formulations and approach for development of typical need based of instrumentation systems.

(*iii*) Professors conducting course in this subject and wish to adopt a single text for one semester course at UG or at graduate level with appropriate choice of chapters compatible to the background and composition of the class of students.

(*iv*) Practicing engineers who wish to undergo self-study and update their knowledge.

The material has been organized into nine chapters and ten appendices. Author has aimed to provide concise and reliable information about the basics, technique available with emphasis on the modern ones. The principles are stressed more and applications are included as the logical use of theory, as he feels required in a first course on the subject. The details have been included considering the fact that such courses are offered at senior level in sixth or seventh semester in most universities almost, in all disciplines.

The first chapter includes the basics and scope of the subject while the second chapter on system specifications and tools provides background material for understanding analysis methods and tools. This may be omitted if the students have already undergone a course in measurements and control.

The third chapter provides background of measurement principles, errors and their analysis relevant to instrumentation systems and techniques to achieve desired quality. This may be gone through briefly for students who have undergone a course in electrical measurements. Chapter 4, 5, 6 detail the principles of sensors and transducers in detail, to be utilized for application to common physical variables later. The transducers constitute the interface between the real system and process with the electrical signal domain. Their application to common physical variables will be the subject matter of chapter 7.

Chapter 8 includes signal conditioning which is one of the most important activities responsible for improving accuracy, sensitivity, linearity and convenience of use by adding processing capability. Developments in electronics have contributed very significantly in modernizing the instrumentation systems. Selected topics from this chapter should be used depending upon the background of students *i.e.*, very little for electronics engineering to almost whole for mechanical and chemical engineering students.

Last chapter on telemetry and networked systems includes the content matter to complete the flow of information *i.e.*, from field to control room. This includes various data transmission schemes in practice along with current trend towards computer-based data transfer network systems and the standards. These topics are most often not included in the undergraduate text books and discussed only in brief to provide a complete scenario. At the end data acquisition systems (DAS) are included in brief.

It is strongly felt that data acquisition aspects should be covered in detail but if it is difficult to cover in one semester then it must be recommended for self-study as an assignment.

Also included in each chapter are solved examples to illustrates the application/computational aspects and problems for exercise are provided in all chapters with answers to selected problems included toward the end. At the end of each chapter, a list of references has been included for more detailed study by interested readers, along with a bibliography at the end. Glossary of the important terms has been provided to assist the first time reader of the subject to avoid

cross referencing and make continuous reading possible without the distraction, to refer to some other book or material.

It is hoped that this text shall be able to meet the long felt need of the user community to have all aspects of industrial instrumentation from the point of view of learning the subject. The feedback for improvement and any queries are welcome at the e-mail address of the author.

I am thankful to my wife Kumud for patience and encouragement, graduate students Tarun Varshney, Omhari Gupta, Alok Kumar, Shivam Bhardwaj, Madhulika Phatak, Gunjan verma, Neha Srivastava, Honey Joshi, Mayank and Vipul Agrawal for assistance at various stages of preparation and many UG students who provided the feedback to improve upon the explanations.

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APPENDICES

CHAPTER 1

Instrumentation Systems

"If you cannot measure it, you cannot control it.
If you cannot control it, you cannot manage it.
If you cannot manage it, you cannot improve it."
Conclusion is - if you cannot measure it, you cannot improve it.

Dr. H. James Harrington International Quality Guru

INTRODUCTION

For any industry to be successful, quality control and scale of production at the viable economic level is a must. The quality control depends on the monitoring of vital processes and associated variables. The economy of operation is controlled by material and energy inputs into the production process/system. The monitoring of variables, the process thereby, energy and materials need instrumentation systems finally to achieve the automatic control of the given industrial process.

Inside the Chapter

- Role of Instrumentation
- Elements of Instrumentation system
- Use of Monitored Information
- Types of Instrumentation Systems
- Standards of Instrumentation Design and Telemetry
- Industry Standard for Analog Signal Transmission
- Current Loop Telemetry Systems
- Other Electrical Standards
- Other Standards
- Calibration
- Recent Trends
- Review Problems
- Problems for Exercise

The integration of monitoring elements/devices and systems for each individual variable in the process is referred as data acquisition channel and a combination of all such channels is referred as Data

Acquisition System (DAS). With the integration of DAS and the process being monitored and controller the DAS acquires the level of Instrumentation system, as shown in Fig. 1.1.

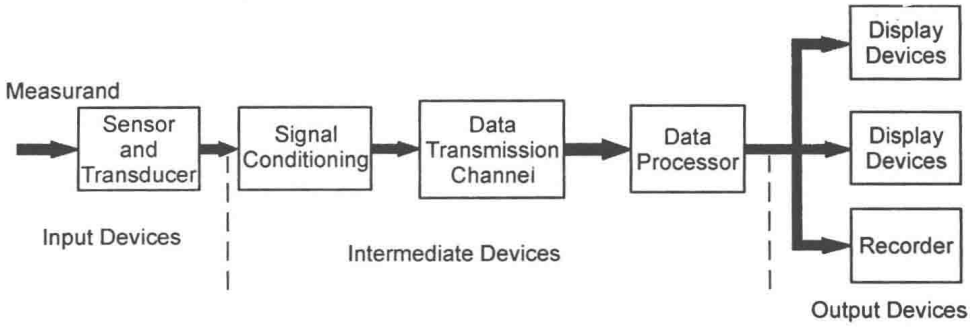

Fig. 1.1 Elements of Instrumentation System

1.1 ROLE OF INSTRUMENTATION SYSTEMS

In any industrial system, measurement of variables, provides the information about their magnitude and time of occurrence viz. The status which may be utilized for one or more of the following activities:

(*i*) Monitoring

(*ii*) Control

(*iii*) Behavioral analysis

Instrumentation professional is required to have appropriate choice of the system (or process, used synonymously) variables, measuring devices, their arrangement and method of utilization of the measurands so as to meet the desired objective(s). An arrangement satisfying the desired objective may also be called instrumentation system.

The objectives need to be defined more specifically, depending upon the type of system and the priorities associated with them. For example, the detailed objectives in the cases of oil refineries system, municipal water supply system, electric power generation system, meteorological system, aerospace vehicle system or a human physiological system have widely different objectives and therefore may lead to widely different instrumentation systems.

Objectives in general would be:

(*i*) Smooth plant operation

(*ii*) Monitoring at every stage to ensure end product quality

(*iii*) Safety of plant and community