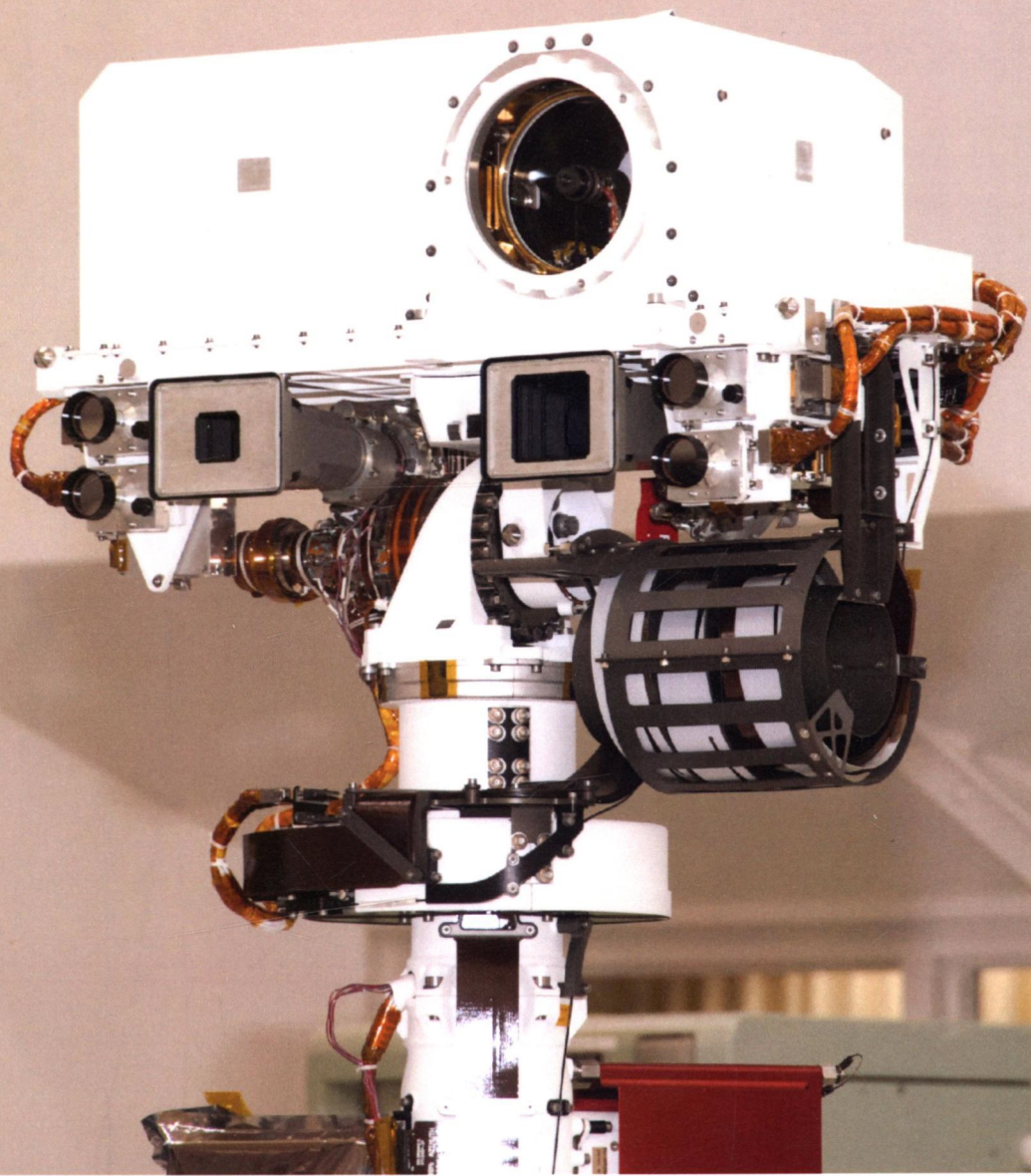




Sensors and Actuators Technology and Applications

Princeton Brown

Sensors and Actuators: Technology and Applications

The aim of this textbook is to provide in-depth information about the various applications and uses of sensors and actuators. It is designed in such a way that it provides the readers thorough insights about this subject. Sensors and actuators are combined to create an interface which is used for technological solutions. This textbook seeks to enumerate the technology and the future advances that are related to sensors to actuators. It mainly provides functional safety in machinery and emergency stop applications. This book is a compilation of chapters that discuss the most vital concepts in the field of sensors and actuators. It presents this complex subject in the most comprehensible and easy to understand language. While understanding the long-term perspectives of the topics, the text makes an effort in highlighting their impact as a modern tool for the growth of the discipline. For all those who are interested in this field, this textbook can prove to be an essential guide.

Princeton Brown attained his MSc in Mechanical Engineering from Boston University, Massachusetts, United States of America. He is actively engaged in the researches focused on analog sensors and biosensors. Brown is an active member of several scientific and technical societies; where he continues to share his expertise and knowledge in the field of microsensors. He has been presented the "Outstanding Professor Award" for his outstanding teaching service and the impact he has made on students worldwide.

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Sensors and Actuators: Technology and Applications

Preface

The aim of this textbook is to provide in-depth information about the various applications and uses of sensors and actuators. It is designed in such a way that it provides the readers thorough insights about this subject. Sensors and actuators are combined to create an interface which is used for technological solutions. This textbook seeks to enumerate the technology and the future advances that are related to sensors to actuators. It mainly provides functional safety in machinery and emergency stop applications. This book is a compilation of chapters that discuss the most vital concepts in the field of sensors and actuators. It presents this complex subject in the most comprehensible and easy to understand language. While understanding the long-term perspectives of the topics, the text makes an effort in highlighting their impact as a modern tool for the growth of the discipline. For all those who are interested in this field, this textbook can prove to be an essential guide.

To facilitate a deeper understanding of the contents of this book a short introduction of every chapter is written below:

Chapter 1- Sensors are used to detect fluctuations in the environment and then to provide an output. Actuators are devices that provide mechanical movement on command. They are a part of our everyday life. This chapter is an overview of the subject matter incorporating all the major aspects of sensors and actuators.

Chapter 2- Sensors are used in everyday objects. Some of the technologies related to sensors are explained in this chapter. Data logger, metal detectors, global positioning system, sonar, echo sounding and load cell are all technologies related to sensors. The topics discussed in the chapter are of great importance to broaden the existing knowledge on sensors.

Chapter 3- Actuators can best be understood in confluence with the major topics listed in the following chapter. Actuators are of five types, hydraulic, pneumatic, electoral, thermal and mechanical actuators. Actuators in machines are responsible for moving or controlling the system. The aspects elucidated in this chapter are of vital importance, and provide a better understanding of actuators.

Chapter 4- The chapter serves as a source to understand the technologies and devices of actuators. Some of the technologies and devices involved in actuators are hydraulic press, jackscrew, roller screw, and pneumatic cylinder. Tools and techniques are an important component of any field of study. The following chapter elucidates the various tools and techniques that are related to actuator technology.

Chapter 5- Remote sensing is the receiving of information about an object with no physical contact. The military, intelligence and economic planners usually practice it. This chapter is an overview of the subject matter incorporating all the major aspects of remote sensing. This chapter is a compilation of various ideas of remote sensing that form an integral part of the broader subject matter.

Chapter 6- Countries use radar to detect aircrafts, missiles, vehicles and spacecrafts. It is a system that uses radio waves to determine the objects in the area concerned. It has proven to be of great importance to the military complex. The diverse applications of radars in the current scenario have been thoroughly discussed in this chapter.

I owe the completion of this book to the never-ending support of my family, who supported me throughout the project.

Editor

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Introduction to Sensors and Actuators

Sensors are used to detect fluctuations in the environment and then to provide an output. Actuators are devices that provide mechanical movement on command. They are a part of our everyday life. This chapter is an overview of the subject matter incorporating all the major aspects of sensors and actuators.

Sensor

In the broadest definition, a sensor is an object whose purpose is to detect events or changes in its environment, and then provide a corresponding output. A sensor is a type of transducer; sensors may provide various types of output, but typically use electrical or optical signals. For example, a thermocouple generates a known voltage (the output) in response to its temperature (the environment). A mercury-in-glass thermometer, similarly, converts measured temperature into expansion and contraction of a liquid, which can be read on a calibrated glass tube.

Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base, besides innumerable applications of which most people are never aware. With advances in micromachinery and easy-to-use micro controller platforms, the uses of sensors have expanded beyond the most traditional fields of temperature, pressure or flow measurement, for example into MARG sensors. Moreover, analog sensors such as potentiometers and force-sensing resistors are still widely used. Applications include manufacturing and machinery, airplanes and aerospace, cars, medicine, and robotics. It is also included in our day-to-day life.

A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. For instance, if the mercury in a thermometer moves 1 cm when the temperature changes by 1 °C, the sensitivity is 1 cm/°C (it is basically the slope Dy/Dx assuming a linear characteristic). Some sensors can also affect what they measure; for instance, a room temperature thermometer inserted into a hot cup of liquid cools the liquid while the liquid heats the thermometer. Sensors need to be designed to have a small effect on what is measured; making the sensor smaller often improves this and may introduce other advantages. Technological progress allows more and more sensors to be manufactured on a microscopic scale as microsensors using MEMS technology. In most cases, a microsensor reaches a significantly higher speed and sensitivity compared with macroscopic approaches.

Classification of Measurement Errors

The sensitivity is then defined as the ratio between the output signal and measured property. For example, if a sensor measures temperature and has a voltage output, the sensitivity is a

constant with the unit $[V/K]$; this sensor is linear because the ratio is constant at all points of measurement.

For an analog sensor signal to be processed, or used in digital equipment, it needs to be converted to a digital signal, using an analog-to-digital converter.

Sensor Deviations

If the sensor is not ideal, several types of deviations can be observed:

- The sensitivity may in practice differ from the value specified. This is called a sensitivity error.
- Since the range of the output signal is always limited, the output signal will eventually reach a minimum or maximum when the measured property exceeds the limits. The full scale range defines the maximum and minimum values of the measured property.
- If the output signal is not zero when the measured property is zero, the sensor has an offset or bias. This is defined as the output of the sensor at zero input.
- If the sensitivity is not constant over the range of the sensor, this is called nonlinearity. Usually, this is defined by the amount the output differs from ideal behavior over the full range of the sensor, often noted as a percentage of the full range.
- If the deviation is caused by a rapid change of the measured property over time, there is a dynamic error. Often, this behavior is described with a bode plot showing sensitivity error and phase shift as a function of the frequency of a periodic input signal.
- If the output signal slowly changes independent of the measured property, this is defined as drift (telecommunication). Long term drift usually indicates a slow degradation of sensor properties over a long period of time.
- Noise is a random deviation of the signal that varies in time.
- Hysteresis is an error caused by when the measured property reverses direction, but there is some finite lag in time for the sensor to respond, creating a different offset error in one direction than in the other.
- If the sensor has a digital output, the output is essentially an approximation of the measured property. The approximation error is also called digitization error.
- If the signal is monitored digitally, limitation of the sampling frequency also can cause a dynamic error, or if the variable or added noise changes periodically at a frequency near a multiple of the sampling rate may induce aliasing errors.
- The sensor may to some extent be sensitive to properties other than the property being measured. For example, most sensors are influenced by the temperature of their environment.

All these deviations can be classified as systematic errors or random errors. Systematic errors can sometimes be compensated for by means of some kind of calibration strategy. Noise is a random

error that can be reduced by signal processing, such as filtering, usually at the expense of the dynamic behavior of the sensor.

Resolution

The resolution of a sensor is the smallest change it can detect in the quantity that it is measuring. Often in a digital display, the least significant digit will fluctuate, indicating that changes of that magnitude are only just resolved. The resolution is related to the precision with which the measurement is made. For example, a scanning tunneling probe (a fine tip near a surface collects an electron tunneling current) can resolve atoms and molecules.

Types

- Pressure sensor
- Ultrasonic sensor
- Humidity sensor
- Gas sensor
- PIR motion sensor
- Acceleration sensor
- Displacement sensor
- Force measurement sensor
- color sensor
- gyro sensor

Sensors in Nature

All living organisms contain biological sensors with functions similar to those of the mechanical devices described. Most of these are specialized cells that are sensitive to:

- Light, motion, temperature, magnetic fields, gravity, humidity, moisture, vibration, pressure, electrical fields, sound, and other physical aspects of the external environment
- Physical aspects of the internal environment, such as stretch, motion of the organism, and position of appendages (proprioception)
- Environmental molecules, including toxins, nutrients, and pheromones
- Estimation of biomolecules interaction and some kinetics parameters
- Internal metabolic indicators, such as glucose level, oxygen level, or osmolality
- Internal signal molecules, such as hormones, neurotransmitters, and cytokines

- Differences between proteins of the organism itself and of the environment or alien creatures.

Chemical Sensor

A chemical sensor is a self-contained analytical device that can provide information about the chemical composition of its environment, that is, a liquid or a gas phase. The information is provided in the form of a measurable physical signal that is correlated with the concentration of a certain chemical species (termed as analyte). Two main steps are involved in the functioning of a chemical sensor, namely, recognition and transduction. In the recognition step, analyte molecules interact selectively with receptor molecules or sites included in the structure of the recognition element of the sensor. Consequently, a characteristic physical parameter varies and this variation is reported by means of an integrated transducer that generates the output signal. A chemical sensor based on recognition material of biological nature is a biosensor. However, as synthetic biomimetic materials are going to substitute to some extent recognition biomaterials, a sharp distinction between a biosensor and a standard chemical sensor is superfluous. Typical biomimetic materials used in sensor development are molecularly imprinted polymers and aptamers.

Biosensor

In biomedicine and biotechnology, sensors which detect analytes thanks to a biological component, such as cells, protein, nucleic acid or biomimetic polymers, are called biosensors. Whereas a non-biological sensor, even organic (=carbon chemistry), for biological analytes is referred to as sensor or nanosensor. This terminology applies for both in-vitro and in vivo applications. The encapsulation of the biological component in biosensors, presents a slightly different problem than ordinary sensors; this can either be done by means of a semipermeable barrier, such as a dialysis membrane or a hydrogel, or a 3D polymer matrix, which either physically constrains the sensing macromolecule or chemically constrains the macromolecule by bounding it to the scaffold.

Actuator

An actuator is a component of machines that is responsible for moving or controlling a mechanism or system.

An actuator requires a control signal and source of energy. The control signal is relatively low energy and may be electric voltage or current, pneumatic or hydraulic pressure, or even human power. The supplied main energy source may be electric current, hydraulic fluid pressure, or pneumatic pressure. When the control signal is received, the actuator responds by converting the energy into mechanical motion.

An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple (a fixed mechanical or electronic system), software-based (e.g. a printer driver, robot control system), a human, or any other input.

History

The history of the pneumatic actuation system and the hydraulic actuation system dates to around the time of World War II (1938). It was first created by Xhiter Anckeleman (pronounced 'Ziter') who used his knowledge of engines and brake systems to come up with a new solution to ensure that the brakes on a car exert the maximum force, with the least possible wear and tear.

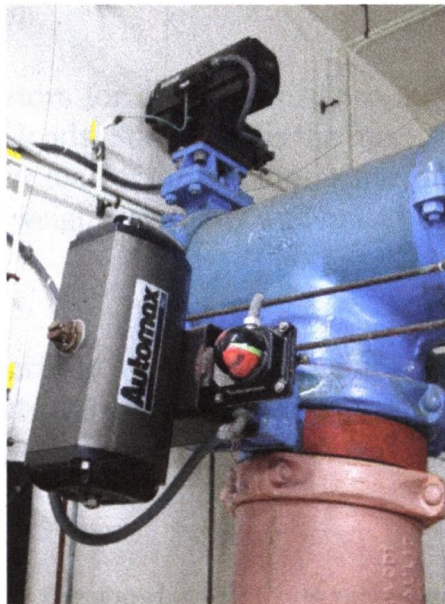
Hydraulic

A hydraulic actuator consists of cylinder or fluid motor that uses hydraulic power to facilitate mechanical operation. The mechanical motion gives an output in terms of linear, rotary or oscillatory motion. Because liquids are nearly impossible to compress, a hydraulic actuator can exert a large force. The drawback of this approach is its limited acceleration.

The hydraulic cylinder consists of a hollow cylindrical tube along which a piston can slide. The term *single acting* is used when the fluid pressure is applied to just one side of the piston. The piston can move in only one direction, a spring being frequently used to give the piston a return stroke. The term *double acting* is used when pressure is applied on each side of the piston; any difference in pressure between the two side of the piston moves the piston to one side or the other.

Pneumatic

A pneumatic actuator converts energy formed by vacuum or compressed air at high pressure into either linear or rotary motion. Pneumatic energy is desirable for main engine controls because it can quickly respond in starting and stopping as the power source does not need to be stored in reserve for operation.



Pneumatic rack and pinion actuators for valve controls of water pipes

Pneumatic actuators enable considerable forces to be produced from relatively small pressure changes. These forces are often used with valves to move diaphragms to affect the flow of liquid through the valve.

Electric

An electric actuator is powered by a motor that converts electrical energy into mechanical torque. The electrical energy is used to actuate equipment such as multi-turn valves. It is one of the cleanest and most readily available forms of actuator because it does not involve oil.

Thermal or Magnetic (Shape Memory Alloys)

Actuators which can be actuated by applying thermal or magnetic energy have been used in commercial applications. They tend to be compact, lightweight, economical and with high power density. These actuators use shape memory materials (SMMs), such as shape memory alloys (SMAs) or magnetic shape-memory alloys (MSMAs). Some popular manufacturers of these devices are Finnish Modti Inc., American Dynalloy and Rotork.

Mechanical

A mechanical actuator functions to execute movement by converting one kind of motion, such as rotary motion, into another kind, such as linear motion. An example is a rack and pinion. The operation of mechanical actuators is based on combinations of structural components, such as gears and rails, or pulleys and chains.

Examples and Applications

In engineering, actuators are frequently used as mechanisms to introduce motion, or to clamp an object so as to prevent motion. In electronic engineering, actuators are a subdivision of transducers. They are devices which transform an input signal (mainly an electrical signal) into some form of motion.

Examples of Actuators

- Comb drive
- Digital micromirror device
- Electric motor
- Electroactive polymer
- Hydraulic cylinder
- Piezoelectric actuator
- Pneumatic actuator
- Servomechanism
- Thermal bimorph
- Screw jack