

## **Microrobotics**

**Prof. Palani Iyamperumal Anand**

**Department of Mechanical Engineering**

**Indian Institute of Technology, Indore**

**Week- 06**

**Lecture No- 27**

### **Micro Sensors and Micro Transducers - Module 02**

The last class discussed the different types of micro sensors, the overall fundamental behind the micro sensors, and the different micro sensing elements. Also, we discussed the overall template for a micro sensor and different micro sensors used for micro robotic applications, which include a radiation micro sensor, a thermal micro sensor, a magnetic micro sensor, a mechanical micro sensor, and a chemical micro sensor. Some discussion about this hot wire anemometer, the materials commonly used, and the overall application of these micro sensors. A small introduction to this micro transducer. The current lecture will cover the different classifications of micro transducers for micro robotic applications. The first transducer that we will discuss is a pressure transducer. In the pressure transducer, there is a kind of diaphragm that is placed over here with a chamber. From the diaphragm, there is a strain gauge arrangement. Through the strain gauge arrangement, the strain gauges are balanced using a Wheatstone bridge. This is a special kind of sensor that converts the pressure force into an electrical signal.

These transducers are also called pressure indicators or manometers; they are also called as piezometers and transmitters. It is ideally called a strain gauge-based pressure transducer. These transducers are suitable for measuring extraordinarily high and low differential pressures. The differential pressure is the difference in pressure between any two given points. The transducer contains a sensing element and a diaphragm.

Any deformation of the diaphragm will cause a change in the resistance of the strain gauge. In this particular case, the diaphragm acts as a sensing element, the strain gauge acts as a transduction element, and the deflection in the strain gauges is appropriately measured by incorporating a Wheatstone bridge and balancing the Wheatstone bridge. As an extension of this, we can also discuss a piezoelectric transducer. In the lectures related to micromechanics, we discussed a lot about piezoelectricity and its applications, including the usage of piezoelectric materials as sensors and transducers. As far as these piezoelectric

transducers are concerned, these piezoelectric transducers are a special kind of sensor, and the main function of this transducer is to convert mechanical energy into electrical energy.

The piezoelectric transducer works on the principle of piezoelectricity. The face of the piezoelectric material is coated with a thin layer of conducting material such as silver, and when the stress is applied, the ions in the material move towards one conducting surface while moving away from the other. This results in the generation of charge. This charge is used for the calibration of stress. Thus, the polarity of the produced charge depends on the direction of the applied stress, which can be applied in two forms: compressive stress and tensile stress.

Some of the key examples include the piezoelectric ultrasonic sensor and the ultrasonic piezoelectric transducer, which work on the piezoelectric effect. In this effect, when electricity is applied to a piezoelectric material, it undergoes a physical deformation proportional to the applied change. In the previous lecture, we discussed two different types of piezoelectric configurations. One example, when a biasing is applied to it; there will be a kind of actuation that exists. On the other end, a load is applied to it, there is going to be a bias that is exhibited here.

Based on its capability and functionalization, it can appropriately deploy these piezoelectric transducers for different functionally related applications. In a capacitive transducer, the overall construction is shown in the figure. This capacitive transducer has a fixed metal block, a moving tube that is connected to an output, and the change in capacitance, whether an increase or decrease, will have an impact on the displacement. A capacitive transducer is a passive transducer that works on the principle of variable capacitance. It contains two conductive plates separated by a dielectric medium, with the capacitance varying due to changes in the plate area.

Distance or dielectric property makes it highly suitable for measuring displacement force and fluid levels. The capacitive transducer contains two parallel metal plates separated by a dielectric medium, which can be air, gas, or liquid. So, unlike a normal capacitor where the distance between the plates is fixed, the distance in the capacitive transducer varies. The capacitive transducer uses the principle of variable capacitance to convert mechanical movement into an electrical signal. The input quantity causes a change in the capacitance, which is directly measured by the transducer. Similarly, we also have the inductive transducer. In an inductive transducer, there is a core, over which the coil is wound, and there is a meter and the exciter available. Through the meter and the exciter, there is a power being generated out of it, and the armature movement is taken care. By giving an appropriate excitation, we can have an armature movement. It has a kind of simple inductance as well as a mutual inductance that is exhibited here.

An inductive transducer is one that works on the principle of electromagnetic induction or

a transduction mechanism known as an inductive transducer. A self-inductance or a mutual inductance is varied to measure required physical quantities like displacement, force, pressure, velocity, torque, acceleration, etc. For example, in a simple induction transducer, a single coil is used to measure the required parameters. The change in displacement alters the permeability of the flux produced in the circuit, resulting in a change in the inductance of the coil and the output. The output can be calibrated in terms of the measurement to be measured.

The circuit of a simple inductor is shown in the figure. In mutual inductance, two coils are used for mutual induction. One for generating excitation and another for output. So the voltage difference between the two coils depends on the movement of the armature. When the armature position is changed by connecting it to the movable mechanical element, the inductance changes due to the air gap between the armature and the magnetic material, and the voltage induced in the coil depends on the change in the armature position. Ideally, a good part of this inductive transducer is that it is capable enough to have control over the micron displacement. This is one advantage of this particular inductive transducer. Now let us discuss this ultrasonic transducer. The ultrasonic transducer is a type of sound-related sensor. These transducers sense the electrical signal to the object.

Once the signal strikes the object, it reverts to the transducer. In this process, the transducer measures the distance to the object, not by the intensity of the sound. This transducer uses ultrasonic waves for the measurement of a few parameters. When an electrical signal is applied to this transducer, it vibrates around a specific frequency range and generates a sound wave. These sound waves travel; wherever any obstacle comes, these sound waves will reflect back towards the transducer in the form of an echo. At the end of the transducer, this echo converts into an electrical signal. The sensor sends the ultrasonic pulse at 40 kilohertz, which travels through the air, and these transducers are better than the infrared sensors because these ultrasonic transducer sensors are not affected by smoke or any kind of material. Whereas in the case of lasers or optical systems, the material property plays a vital role, especially with reference to reflection or transmission. However, with reference to the ultrasonic perspective point of view, this is one major advantage of ultrasound, which basically involves applying a short pulse, resulting in a reflection that is more focused on the echo receiving. From the echo received appropriately, it can be used for further analysis.

Now let us discuss some of the materials that are used for these kinds of transducers. So the primary material that is used in most of the transducers is a type of piezoelectric ceramic that is categorized as lead zirconate titanate. It is mostly used due to its high piezoelectric coupling coefficient and ability to be manufactured in various shapes. Similarly, barium

titanate is an older piezoelectric ceramic that is still used in some applications. Quartz is a kind of naturally occurring piezoelectric material often used in high-precision applications due to its stability as well as its characteristics.

Now let us discuss the different applications of micro transducers, such as the transducers used in electromagnetic applications like antennas, magnetic cartridges, Hall effect sensors, and disc read and write heads. The electromechanical applications include accelerometers, LVDTs, galvanometers, pressure sensors, load cells, MEMS potentiometers, air flow sensors, and linear and rotary potentiometers. From an electrochemical perspective, electrochemical applications like oxygen sensors, hydrogen sensors, and pH meters are some examples of these particular microtransducers. The transducers are used in electro-acoustic applications like speakers, piezoelectric crystals, microphones, ultrasonic transceivers, sonars, etc. The photoelectric applications like LEDs, photodiodes, laser diodes, photoelectric cells, LDRs, fluorescent lamps, incandescent lamps, and photo transistors are some of the different applications of microtransmissions.

In addition to this, thermoelectric applications like thermistors and thermocouple resistance temperature detectors are some of the key applications of these microtransducers. And radioacoustic applications like Geiger-Muller tubes, radio transmitters, and receivers are some of the examples of these microtransducers. Appropriately, while using these microtransducers for micro robotic applications, these kinds of subdomains and applications can be referred to in relation to their functionality. The micro sensors and micro transducers, there are various parameters that come into existence. So, based on the types of parameters and characteristics of an instrument, appropriately it needs to integrate it to achieve the required functionality. So, the integration of a micro sensor and micro transducer into a system is a crucial aspect of modern technology which enables precise sensing, signal conversion, and automation. The sensor selection is identified with reference to the different physical parameters that are being employed. It also chooses an appropriate micro sensor based on our requirements. It also considered the sensitivity, accuracy, and response time for the relevant sensor selections. For an instrument, both the static characteristics and the dynamic characteristics are considered for its functionality.

The static characteristic of an instrument is concerned, the static characteristics do not include time  $t$  in the consideration, such as reproducibility, repeatability, accuracy, precision, resolution, etc. So, these are some of the characteristics that we call static characteristics. In the case of dynamic characteristics, it includes the time  $t$ ; in the response of the system or an instrument with reference to time  $t$ , it is known as the dynamic characteristics of the instrument. These are considered to be one of the key aspects regarding sensor selection. Now, in the case of signal acquisition, there is a physical change, the conversion of the physical change into an electrical signal, and then a micro

transducer amplifies and conditions the signal based on the requirements.

This sensor should appropriately signal the need for an appropriate signal conditioner to create different transformations or parameters to handle various parametric conditions, such as sensing physical changes, etc. It can include the signal processing process. Two important aspects that come into the picture are either analog-to-digital conversion or, in certain cases, digital-to-analog conversion. The second important signal processing characteristic is filtering and noise detection. In the case of filtering and noise detection, it needs to appropriately filter out the signals, and then it can proceed to noise reduction, followed by data interpretation and output.

As far as data interpretation is concerned, it has a process signal sent to the microcontroller, the data analyzed for decision-making, and then there is an output that will be displayed. The last element is the system feedback. The system feedback and optimization take care of the requirements as well as the overall different parameters, which include sensor selection, signal acquisition, signal processing, data interpretation, and system feedback. In the system feedback and optimization, we have three different parameters that contribute. One is called evaluating system performance, another is called adjusting sensor parameters, and the third is a kind of optimized signal processing technique that is being efficiently deployed for analyzing the system feedback. So, overall aspects of micro sensors or micro transducers, these are the different sub-parameters that contribute towards the overall integration of the system. Now, let us discuss the opto-mechatronic system design. In the sensors and signal conditioning are concerned, micro sensors, especially for micro robotics, play a vital role in the opto-mechatronic system. Since the integration of this opto-mechatronic system has an impact on the applications in micro robots. One important point with respect to an opto-mechatronic system is its flexibility.

These opto-mechatronic systems are flexible enough that the micro robots can easily manipulate the signal based on the requirements or characteristics. In an optical system, it has the flexibility to divert the beam, manipulate the beam flexibly, or integrate the beam flexibly for different requirements. Now, in opto-mechatronic system design, a system ranges from telescopes to microscopes, from wafer steppers to electron microscopes, and from high-end 3D printers to gravitational wave observation systems that depend on cutting-edge mechanical engineering. Opto-mechatronics is a discipline that combines mechatronics design principles, system engineering, and optics. Opto-mechatronics is a field that investigates the integration of optical components and technology into mechatronic systems. The optical components in the system are used as sensors to measure mechanical quantities, such as surface structure and orientation, and optical sensors are used in a feedback loop as part of a control system in mechatronic devices. In addition to

this, opto-mechatronics has applications in areas such as adaptive optics, automation, optofluidics, and thin film technology. So, mechanics and optics join together to form an optomechanics system, while mechanics and electronics join together to form a mechatronic system. The overall interface of all three of these opto-mechanics, optoelectronics, and mechatronics will result in a new domain known as opto-mechatronics. Let us discuss the evolution of this optomechatronic system.

In the evolution of this optomechatronic system, initially, it started with holography. These kinds of holography processes are initially deployed from an authentication point of view. This is exactly how the holography was taken into consideration. Next, there is a kind of fiber optic endoscope that is being established. The main function of this fiber optic endoscope is that an optical fiber is integrated for biologically related applications. Then in the 1960s, there was an evolution of the helium-neon laser. Especially, the advent of lasers started coming into the picture. The advantages of lasers were taken up with different applications; some of the key laser systems include helium-neon lasers, semiconductor lasers, and tunable lasers. For measurement, moiré topography was the first invention that was taken up for application.

Then optical lithography came into existence. Then a kind of CCD image sensor came into existence. The innovation in this optical system has taken on a new shape with reference to the development of products, which has led to a kind of sensor called an optical fiber sensor. Now, optical fiber sensors are used in communications, which are used for sensing-related applications and other related areas. An optical display is being established. So it is mainly meant for the optical fiber sensors integrated with optical displays.

Then it has optical communication in place, and later, in due course, optoelectronic processors have taken on a good shape. Now, let's discuss micro-optics, MEMS-based micro-optics, etc., and there are different formations of these optomechanical systems from a macro level to a micro level. It has its own wings for different applications, including biomedical and automobile-related applications, etc. Now let us discuss some of the functional fundamentals, which are the basic rules of these optical elements. As far as the optical elements are concerned, the major functions and roles of the optical components or elements in the optomechatronic system can be categorized into several technologies. One method is through data transmission using an optical fiber. To give you a brief overview of optical fiber, it has a core and a cladding. It works on the principle of total internal reflection. The total internal reflection, if it gets stretched or if it bends, will cause a kind of deviation in the electrical signal in the optical fiber.

Let us consider that there is a laser source and a detector that is available. Through the laser

source, the light is transmitted within the optical fiber, and the detector senses the light. When there is an appropriate bend, the signal will change. Next, in the case of an actuation, there are different light-based polymers or optical-based polymers that are available as light-sensitive polymers. These polymers are widely used for various applications. The light-sensitive polymers have a tube or a system in which such polymers are embedded. When light is illuminated, there will be an expansion or contraction in these polymers, which will result in a certain amount of actuation in them. These illuminations will be highly helpful for appropriate actuation and the overall displacement exhibited by this particular system. The light source plays a vital role in actuating such kind of systems. For a sensing perspective point of view, let us take an example of an AFM.

AFM is a very good example of an opto-mechatronic system that is mainly meant for studying the surface roughness parameters. It has a cantilever, over which is a small mirror, and the light will be incident on this mirror while the cantilever moves back and forth; the overall roughness pattern being generated on this particular structure is being evaluated by the detector. The tunneling effect in the cantilever and the deviation in the overall reflection from the mirrors are appropriately sensed in a particular domain. So ideally, it's a kind of image acquisition and image processing system to study the overall characteristics of the image being captured. It's a kind of well-established technology. In fact, nanomanipulation is performed in an atomic force microscope. The upcoming module will have a separate section for nanomanipulation in an atomic force microscope and its impact on precision measurements. There are two different parameters that come into the picture. In fact, two different domains come into the picture. One domain discusses a kind of measurement, and the other domains talk about the processing.

Identifying a certain mechanism, when there is a deflection exhibited from this mechanism, provides the overall image characteristics with reference to deflection or with reference to the images, etc., which can be taken care of by this optomechatronic system. And these images need to be processed. So in order to process this image, several steps are involved, such as image restoration, image thresholding, etc. There are many steps, including edge deductions. These are some different kinds of steps that are involved. To process this image and acquire the information that is available in the image. So this is a kind of separate study that is being established. Next, we can also talk about the case of computing.

It has an optical transistor that is available over here. These optical transistors use a nonlinear material, and they have a reference beam and a probe beam. From this, they can estimate the behavior of the material. Next, they have a kind of data memory like CDs, Blu-ray discs, etc. So, these are some of the systems that have been established, which also come under the category of this optomechatronic system. Now, to consider the practical optomechatronic system, these optomechatronic systems are found in many areas of control and instrumentation, inspection, and testing.

This optical manufacturing includes consumers and industrial electronics products, as well as MEMS, especially in the case of automotive, bio applications, and many other fields of engineering. Some of these applications include cameras and motors, which are typical examples that have been operated by optomechatronic components, such as the autofocus system in a camera module. In the case of autofocus, an image is observed, an image is captured, and then the image is processed based on the distortion in the image. It is mapped with the reference, and the distortion is analyzed. Based on the distortion, the signals are appropriately fed into the motor, which is connected to the lens arrangement.

This lens will manipulate appropriately to capture the image again. An image is taken, and then, based on the distortion in the image as well as the distortion in the edges, an appropriate signal is fed to a motor that is connected to focusing optics. The focusing optics adjust themselves to get better clarity on the image. So this is a good example of an optomechatronic system. We discuss the different types of optomechatronic systems; optomechatronic systems are categorized into three classes depending on how the optical element and the mechatronic systems are integrated. One is called an optomechatronically fused system, another is called an optically embedded mechatronic system, and the third is called a mechatronically embedded optical system.

These are the three different classifications that are being efficiently applied in the practical application. There are a wide variety of applications that are being embedded into the system. As far as this optomechatronically fused system is concerned. In this system, optical and mechatronics elements are not separable in the sense that if an optical or mechatronics element were removed from the system, the system could not function properly. The system that belongs to their class is auto camera, adaptive mirrors, tunable lasers, CD pickup, optical pressure sensors, etc.

It is trying to integrate an optical system fused with the main system, like an example of autofocus. The working of autofocus is a good example where an optomechanically fused system will be implemented. Next, we can talk about the optically embedded mechatronic system. As far as this optically embedded mechatronic system is concerned, this system is basically a mechatronic system that is mainly composed of electronic components, so in this system, the optical element is embedded in the mechatronics. For instance, the optical element is separable from the system, yet the system can function with a decreased level of performance.

Example washers, vacuum cleaners, and monitoring and control systems for manufacturing machines, etc. It has a system in place, and an optical system will be

embedded into it. This optical system, which is being embedded into it, takes care of the precision measurement. However, if it removes this optical system, it appropriately tries to disturb the precision measurement based on the variation in the pressure measurements; the efficiency of the system may come down. This optical system will act as a kind of element in this system. So, even if you remove this optical system, it acts as an accessory in the system. Even if you try to remove it, the main system still works. Now the third category is called a mechatronically embedded optical system. This system is basically an optical system whose construction is integrated with mechanical and electrical components. Many optical systems require positioning or surveying optical element devices to manipulate and align the beam and control its polarization.

The cameras, optical projectors, galvanometers, series, parallel scanners, line, polygon, etc. Like in the case of optical projectors, it has manipulating mirrors or lenslets of mirrors that are available. These kinds of systems are called mechatronically embedded optical systems. Similarly, a galvanometer that is used for manipulating a laser beam is a good example where mechatronically embedded optical systems can be deployed for different applications. Let's discuss the different components of the optomechatronic system, and we will go one by one through how these optomechatronic systems are well established, as well as the different classifications, their functionality, operation, and details in the upcoming classes.