Micro Robotics

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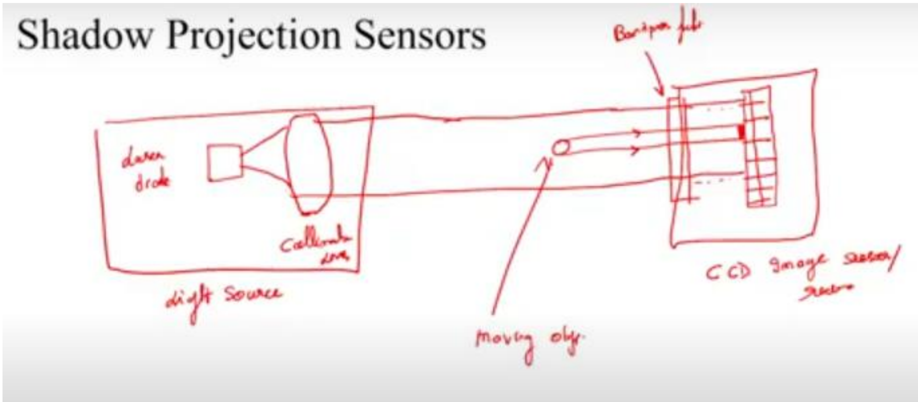
Week-6

Lecture-29

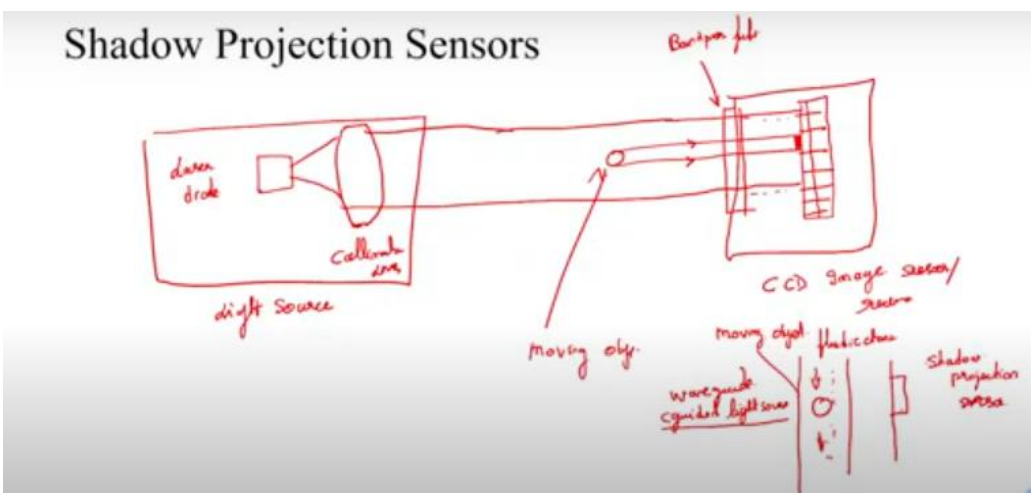
Micro Sensors and Micro Transducers - Module 04

We have discussed the overall functionality of an optomechatronic system and different functions of an optomechatronic system. Various functions involved in sensing, optical scanning, motion control, an optical actuator with visual inspection, three-dimensional shape construction, laser material processing, optical pattern recognition, and real-time monitoring control. We have also discussed an optomechatronic system, how it is used in the case of a robotic platform, in which we discussed different components and the subcomponents that are involved in the optomechatronic system. We had discussed the image acquisition, the different domains, which include the light source, the illumination angle, the image processing, and the overall domain to show how the images are captured. We also had a discussion about a simple system where a piezoelectric actuator integrated with a CCD camera, a tube, and a locomotion propulsion system is deployed for surveillance or for capturing images at localized locations. There is a wide variety. We also had a discussion about the MEMS-based optical sensor, the overall application of the optical sensor, specifically its application toward displacement measurement. There are different techniques that have been deployed for optical sensors, which have been categorized based on their working principle and their application. So the main types include the triangular motion-based sensor, interferometer displacement sensor, confocal sensor, time-of-flight sensor, and optical sensor. So we detailed the different categories of optical-based sensors, such as triangular-based sensors.

How these triangulation-based sensors are deployed for Microrobotics-related applications is discussed. The interferometric displacement sensors, confocal sensors, and time-of-flight sensors are discussed. Now we will discuss the shadow projection sensor. The key component involved is a collimating lens. There is a laser diode collimating lens.

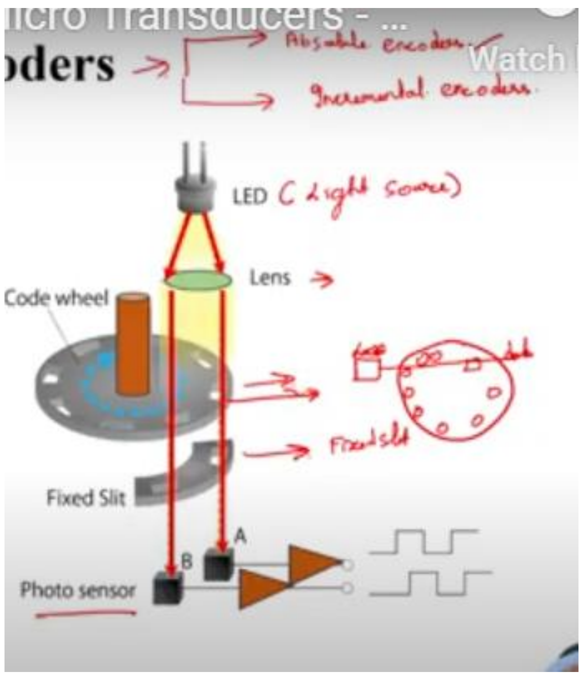


There are two components: one is a light source, and the other is a CCD image sensor and receiver. So, it comprised a small region with a bandpass filter, and the shadow coming out of it is projected onto a CCD array. Let us consider an object that is moving; this is the projected shadow, and this is the moving object. This is the overall construction of a shadow projection sensor. In the earlier cases, we were directly capturing the image and sensing the image from the front reflection. This is an arrangement where we are trying to capture the shadow, and these shadows are used for the visualization of a dynamic particle. So, when we observe the overall working principle of this shadow projection sensor, a collimated light beam is projected onto the CCD receiver. Any object that interrupts the beam projects a shadow on the receiver, which can be used to measure the displacement of the object passing through the beam. So, there is a wide variety of configurations. These kinds of shadow projection sensors can also be used to collect the transmitted light through a fluidic channel.



If we think of a construction, it shows a fluidic channel, and the object is moving; this is the shadow projection sensor. This is a waveguide, which is a guided light source, and the object is moving. In this shadow projection, let us consider that there are four quadrants. These four quadrants collect the transmitted light through the fluidic channel. So, when objects pass in the tiny fluidic channel, they partially or completely mask the light, thus modifying the transmitted signal.

By analyzing the signal collected from the shadow projection sensor, we can infer some information about the object passing through the channel. Guiding the object through the detector can be as small as a few microns, while the waveguide itself is a few microns in size. In this particular case, let us consider magnetic micromanipulation. When a series of magnetically manipulated actuators or micro-robots move through the system, we can easily observe the complete shadow-projected region using this particular technique. In fact, when we are discussing this movement of a magnetic micro-manipulated robot, we can see that there are similar features being observed. So these features can be visualized using this particular system. Now let us discuss the optical encoders. The optical encoders are used efficiently for measuring the rpm or the angular position. So the overall configuration of these optical encoders comprises a light source to focus the light, such as a lens, a fixed slit, and a photo sensor. This is a kind of code wheel where the RPM of the code wheel needs to be measured using this system.

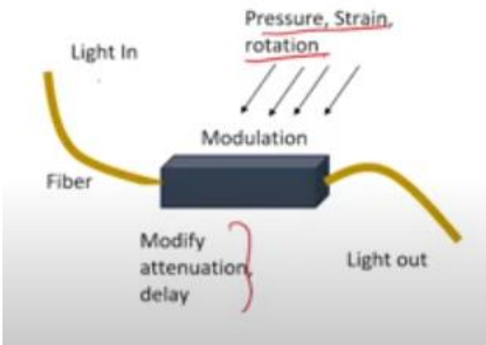


The optical encoders are motion-sensing devices that convert mechanical motion into an electrical signal using light to detect position or motion. They are widely used in applications requiring high precision and reliability, such as robotics, CNC machines, motor control systems, etc. The working principle is that the light source shines through the encoder disc, which has a pattern of opaque and transparent segments. As the disc rotates, the light passing through the transparent segments is detected by the photodetector, generating electrical signals. So the signals are processed to determine the position, speed, and direction of the shaft's encoder. Now, from an optical encoder's perspective, these optical encoders are classified into two categories. One is an absolute encoder, and the other is an incremental encoder. In the case of absolute encoders, let us consider a fixed slit. This slit is in the form of a particular slot, and there is a laser source and a detector. So now a light is passing through it.

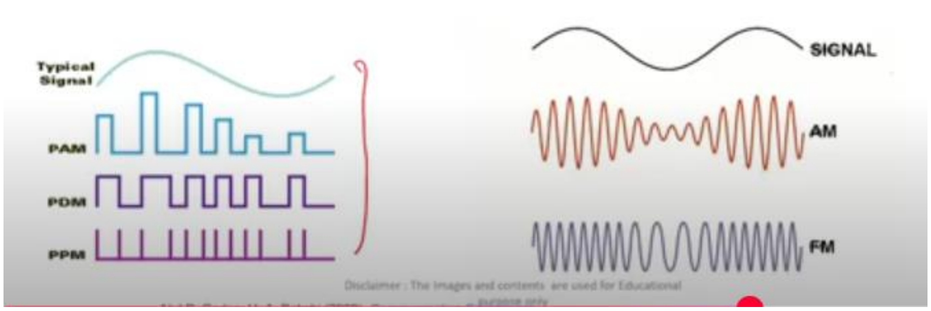
If I need to measure the angle of a single rotation, then such types of absolute encoders can be employed. However, for multiple rotations, for example, if I want to know the rotation of a servo motor, an incremental encoder can be deployed. If I want to know the rotation, the RPM, or the angular value theta with reference to a stepper motor, then an absolute encoder can be efficiently deployed. So, with reference to the overall construction, it is a highly compact system, and it does not require any kind of complicated signal processing. So, it is a go-no-go gauge kind of process, which can be helpful for us to understand the overall RPM which is being generated. Now, from an application perspective, these optical encoders or optical sensors are widely used for industrial automation and robotics, primarily for positioning a robotic arm with high accuracy and detecting product misalignment. Next, it has potential applications in semiconductor manufacturing, especially for micromanipulation, where measuring the wafer thickness and position can be easily monitored using this. So these kinds of systems are efficiently used or deployed for aligning a photo mask for a lithography process. With reference to precision engineering and metrology, it is used for measuring the surface roughness of a machine part, as well as checking the flatness and alignment of the component. With reference to the automotive industry's perspective, it is highly used for wheel alignment and suspension testing, measuring brake disc thickness, and from a medical application point of view, it is used for analyzing eye movement for medical diagnostics and high precision positioning in surgical robots.

So these are some of the key applications where such kind of optical systems can be employed. Now, let us discuss the next concept, which is called developing a sensor or analyzing a sensor based on the light intensity module. So in the light intensity module, a sensor based on light intensity is used to detect the changes in the environment as well as the changes in varying light intensity. These sensors are common in fiber optic systems and are categorized based on their operating principles as well as their applications. Now, in light intensity modulation, these systems are based on the intensity of light, which is modulated according to the measurement and the quantity.

This can be achieved by changing the amplitude or current of the light source, such as a laser diode. In fiber optic sensors, modulation can occur through mechanisms like micro-bending, evanescent wave coupling, or external perturbations affecting the optical path. So for detection, the modulated light is detected by a photodetector such as PIN or APD photodiodes, which convert the optical power variation into a corresponding electrical current or voltage variation. So, the detected signal is processed to determine the change in measurement. In this particular case, signal processing is considered to be one of the key characteristics that take shape.



So, in signal processing, the electrical signal generated by the photodetector is often weak and may require amplification. So the amplified signal is further processed to extract a kind of useful information, such as the intensity or wavelength of light, which corresponds to the measured quantity. So in this case, most of these modulations can be useful for measuring the pressure strain or rotation. The light entering and leaving the fiber can be monitored efficiently. Besides, there are different types of modulation techniques with reference to light, such as amplitude modulation, pulse modulation, optical intensity modulation, frequency and wavelength modulation, and digital intensity modulation.

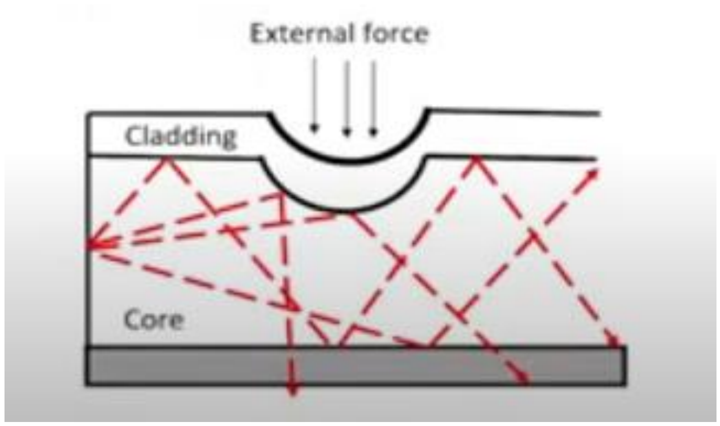


So, these are the different configurations of the modulation techniques that are being employed. Overall, if we consider a signal, this is a kind of amplitude modulation, and this is a kind of frequency modulation. Now, the fiber optics in intensity modulation play a crucial role with reference to an intensity modulation sensor by enabling the transmission and modulation of light to detect changes in the environment. So in that aspect, we have light transmission, intensity transmission, and sensor configuration. Now, let us discuss light transmission and reflection.

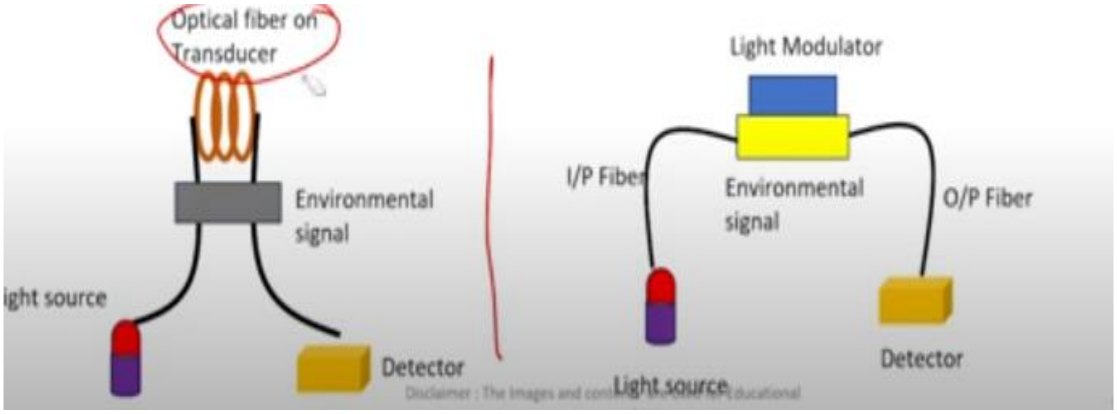
So, in the case of light transmission in a fiber optic sensor, it involves guiding the light through the optical fiber to detect changes in the environment. The light is confined within the fiber core due to total internal reflection, which has a higher refractive index than the cladding. This principle allows the light to travel long distances with minimal loss. So, with reference to a light source, typically an LED, laser diode, or superluminous diode that generates the light, a reflective surface is used to modulate light intensity. The distance or position of the reflector affect the amount of light reflected by the detector.

It is commonly used in displacement and vibration sensing, where changes in the reflector portion modulate the light intensity. If we detail the overall construction of this optical fiber sensor, this is called a core and this is the clad. The complete clad is made out of highly reflective material. So the light passes through the core, with multiple reflections, and the receiver will receive the signal. So when a bending is employed, it changes the parameters of light. So, it is something like a kind of tube. The light is passing through it. Any change in the parameters of this tube or any influence of parameters on this tube will impact the receiving end, a detector. Now let us discuss the intensity modulation. Let us consider an optical fiber in which there is a core and a cladding.

There will be multiple reflections in this particular system. If we are applying an external force at a particular point or a small pressure on top of it, there are going to be multiple reflections that exhibit. This multiple reflection will affect the cladding and the core. So when the external force impacts the clad, there is a bending that persists, and when the light falls on this clad, it will affect the internal reflection passing through it. So, without the external force, we will have a reference signal.



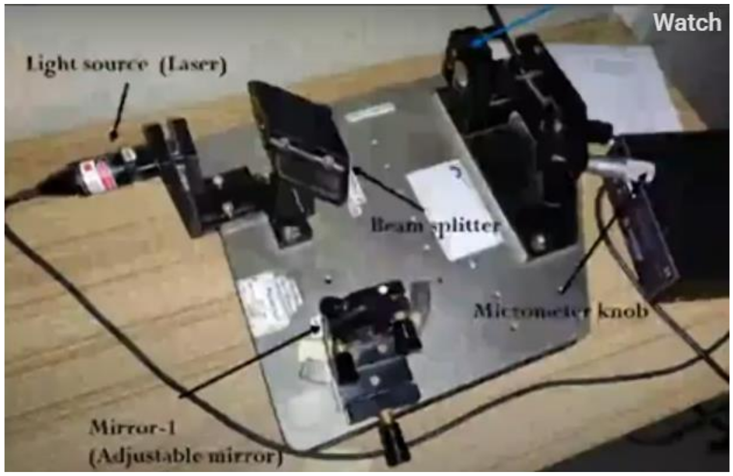
After applying the external force, there will be a change in the light signal. The difference between the reference signal and the light signal will give us the amount of force exerted on the optical fiber. So if I have an optical fiber and I am bending the fiber, it will have an impact on the intensity system. This is how optical fibers can be used as a sensor. So during intensity modulation, when we try micro-bending, it involves bending the fiber to create micro-bending losses, which modulate the light intensity. So, the degree of bending affects the amount of light transmitted. It is used in pressure, vibration, and displacement sensing where external forces cause micro-bending. Now we will discuss the wave coupling mechanism. So this utilizes the evanescent field of light in a single-mode fiber to interact with the external medium. Change in the surrounding media modulates the light intensity.



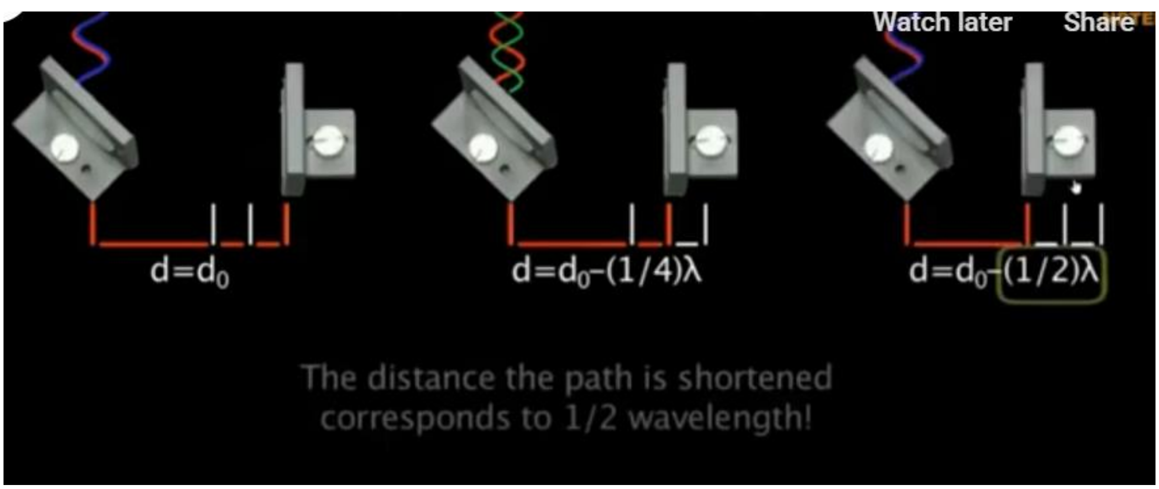
It is used in chemical sensing or biosensing, where a change in the refractive index of the surrounding medium affects the evanescent field of the wave. Now, when we talk about the optical fiber-based sensor configuration, there are two different sensor configurations: one set of sensor configurations includes optical fiber on the transducer, and the other set of configurations is with reference to a light modulator. Now the sensor uses the fiber as a sensing element. Changes in the fiber properties, for example, microbending, include the modulator and the light intensity. Hence, the external components that modulate the light intensity are the reflective intensity-modulated sensors, such as mirrors or reflective surfaces, to modulate light based on displacement or pressure.

So, the fiber optic sensor can be configured for various applications, including structural monitoring and biomedical sensing. Many configurations are highly sensitive to environmental changes and allow for simultaneous measurements of multiple parameters using a single fiber system. Now, this light intensity modulated sensors offer several advantages, making it a widely used technique for measuring various physical, chemical, and environmental parameters. Some of the parameters are high sensitivity, simplicity of detection, immunity to electromagnetic interference, long-distance sensing capability, and non-contact, non-intrusive type measurements, which are some of the key advantages of using such sensor configurations. Next, we will be discussing the interferometers for micro sensing.

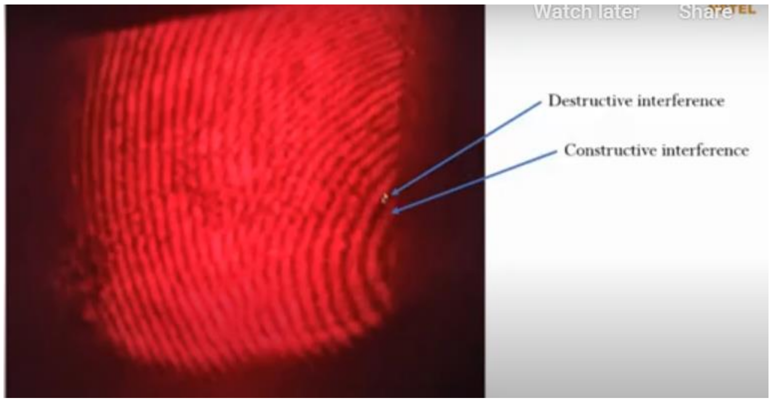
This is a Michelson interferometer. There is a light source and two mirrors, mirror one and mirror two. There is an adjustable mirror and a movable mirror that moves with the help of this micrometer node. There is a beam splitter that splits our laser beam. A laser beam is incident on the beam splitter, and it splits into two parts. After reflection from both mirrors, the waves interfere here.



Light will be split with the help of this beam splitter, and these are the two mirrors from which the reflected light waves will interfere, resulting in constructive and destructive interference. The constructive interference occurs when we move the movable mirror by 1/4 wavelength with the help of a micrometer. We can see here that the maxima of both waves are on opposite sides. So initially, the distance is D naught between the beam splitter and the mirror. When we move the mirror by one fourth of the wavelength of the light, destructive interference will occur.



And when we move our mirror by one half of the wavelength, constructive interference will occur. So, what happens when interference occurs is that we see these fringes. So, the dark one is because of the destructive interference, and the brighter one is because of the constructive interference. The biomorph integrated optical fiber sensor was designed by integrating optical fiber with a biomorph. SMA coating was done on the fiber by placing it in its holder during deposition in a thermal evaporation unit and rotating it at a fixed rpm to ensure uniform coating all around the fiber.



The SMA-coated optical fiber appears strained because of its martensite phase retention. This is a holder for keeping a Kapton polyimide sheet for depositing SMA on it and developing a bimorph using this sheet. The developed bimorph appears strained because of its martensite phase retention. The curvature is due to the SMA thin film. The thermo-mechanical actuation of a biomorph can be tested on a hot plate; during heating, it expands because of the austenite phase, and while cooling, phase retention occurs. This phase transformation behavior was observed in the window of SMA between 80 and 120 degrees Celsius. The smart actuation of the bimorph has been captured by integrating it with optical fibers using optimal dimensions. Initially, the optical fiber remains in a microband state, and upon heating, bimorph actuation results in band release, which increases the optical signal, and this band is retained again upon cooling. This real-time actuation of optical signals can be captured on LabVIEW or other signal processing devices, and smart sensing can be integrated with alarm systems or IoT for real-time monitoring of the systems. We have tested the sensor performance on a hydraulic power pack and real-time temperature monitoring under the influence of pressure and load through IoT. The work area where the sensor was placed is.