Micro Robotics

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Micro-actuation and Micromanipulation - Module 05

Let us see this configuration. This configuration is called a scratch drive actuator inchworm-like walking sequence. In this actuator, there is a left clamp, a right clamp, and a plate in the middle. The actuator is in contact with the surface by the left and right clamps while the plate in the middle is in a hanging position between the clamps. It is basically used in MEMS technology with micro robotic applications by providing a kind of actuation to it. When you try to find an electrostatic charge in this, it will create an inchworm mechanism over here.

This inchworm mechanism or this inchworm displacement will be in the order of a few microns. This is one configuration. Apart from this, electrostatic actuators have potential applications and potential flexibility in developing a rotary-based system. Let us see some kind of rotary-based electrostatic actuators: top-drive electrostatic rotary actuators with ring-shaped bearings.

In this particular case, it has a stator configuration. Over the stator configuration, there is a dielectric material. This is a stator, a dielectric material. Then there will be slip ring arrangements, and then there will be a rotor ground. In this overall configuration, since it is actuated because of the electrostatic charge, different slots are entangled in this system.

Each and every slot is energized in such a way that this will result in the rotation of the dielectric material, and the slip rings that are available will be used for appropriate manipulation or control over the rotation. These are kinds of rotary actuators. So in the earlier cases, we have seen a certain number of linear actuators. These electrostatic actuators are now also configured in the form of a rotary actuator; in addition to this, this configuration can be extended in the form of a linear slider and a stator. These linear sliders will be integrated with interdigitated structures appropriately, and these sliders will also be integrated with the stator.

These linear sliders and the stator will be coupled in such a way that whenever there is a kind of linear motion, this will result in actuation. This is a kind of configuration; it is called a two-phase resonant electrostatic induction motor. These two four-phase resonant electrostatic motors will be helpful for us in a linear arrangement where they can be used for linear actuation in the form of linear motion. These configurations are well established based on the types of modes being reported, and electrostatic actuators are being developed accordingly. The comb drive actuator is a separate section that we will be discussing now.

The other set of electrostatic actuators is commercially used. One such electrostatic actuator is called an electrostatic foil actuator. In this electrostatic foil actuator, the overall configuration is a wall and a flexible conductive film, and there are two insulating layers. When a voltage is applied, this flexible conducting film will try to take a shape that will be helpful for the opening and closing of the wall. So, ideally, the actuator consists of two silicon electrodes forming a chamber; between the electrodes, a metallic foil made of steel or FeNI alloy is placed.

This foil is formed into an S-band that can travel from one end of the chamber to the other. From an operational perspective, a voltage is applied either between the upper electrode and the foil of the lower electrode so that these foils can be appropriately actuated to achieve the required displacement. In this electrostatic foil actuator, the electrostatic foil is pulled towards the respective electrode by an electrostatic force with an S-like bend traveling through a tamper. The large displacement can be achieved by increasing the volume between the electrodes, and mechanical means can also be used to control the flow of gases. So the larger displacement can be achieved by increasing the volume between the electrodes, and the mechanism can also be used as a wall to control the flow of the gas.

The gas inlets open into the space between the electrodes, and the two outlets are formed by the recess in the electrode. As the foil bend travels along the inside of the wall, it opens up a path for the gas on one side of the chamber and closes it to the other side of the chamber. So, this is a kind of bias that is being applied here. Since it's a kind of S-bend based electrode mentioned here, this S-bend based electrode will take an appropriate shape to have control over the wall exhibited here. There are upper electrodes, lower electrodes, and a spacer that is available.

By configuring this voltage appropriately, it can have a kind of construction. This is a kind of application in this case. The overall S-bend kind of structure is a thin foil base structure, and these thin foil base structures are capable enough to deflect it, so it doesn't require any load. Cantilever-based walls or deflection-based walls so that these deflection-based walls will deflect and appropriately give direction to the requirements. Now let us discuss an electrostatic micro positioner, which is one of the key devices from a functional perspective.

These micro positioners are concerned, so they are used in optical communication. These micropositioners are meant for holding the optical fiber, especially during the optical communication network, so that deflection or micromanipulation can be established using an electrostatic actuator, allowing the optical fiber to deflect appropriately, which will be helpful for manipulating the connection. These optical communication networks and optical computers need flexible optical coupling and interfacing techniques. Here, a very high precision is required to align and connect the optical fibers. Even the smallest deviation can lead to excessive light attenuation.

The whole device consists of two parts, the micropositioners and a stationary part with an integrated optical channel. It is the task of the micropositioner to align the fiber with its corresponding channels. The electrostatic micropositioner is concerned; the micropositioner has a base containing several v-shaped grooves into which the optical fiber needs to be aligned and placed. Along with the V grooves, different actuating electrodes are also available, and the optical fiber is coated with a thin conducting film with an insulating layer. So that the groove itself has a wider part and a narrow part.

The wider part is alignment electrodes on either side. The optical fibers are coated with a thin metallic layer so that they can be actuated electrostatically. The coating can be either through a kind of sputtering or through thermal evaporation. If an electric voltage is applied across one of the electrodes, the fiber is attracted by this electrode. Therefore, by controlling the voltage of both electrodes, the fiber can be exactly aligned, the metal layer of the optical fiber is applied using a sputtering process, and the groove is produced by a bulk micromachining technique on a silicon substrate.

The smallest distance between the optical fiber and the electrode is 50 to 30 TTM. The electrodes were produced by depositing a thin aluminum layer with a certain lift-off degree. So, this is a type of electrostatic positioner. Of course, there are other configurations of electrostatic positioners that are slightly above the micron's level. However, if it needs to have control over a higher order micron level, then electrostatic-based comb drive actuators are one of the potentials.

However, electrostatic-based comb actuators are deployed for various other function-related applications. To summarize this module, three different types of actuations, especially microactuation and micromagnetism, have been discussed: the electromagnetic actuator, the fundamentals behind this electromagnetic actuator and overall applications, and the different types of magnetic properties that can be efficiently used for microactuation. It started with diamagnetism, paramagnetism, ferromagnetism, and ferrimagnetism-based structures, anti-magnetism. In the case of diamagnetism, how these structures are deployed, and in the case of paramagnetism, what are the different applications of paramagnetism, what is the overall XR range for a paramagnetism that can be appropriately quantified A brief discussion was covered about these ferromagnetic structures, about anti-ferromagnetic structures, ferrimagnetic structures, and a Lorentz force actuator, which is being efficiently used here to take care of the flow inlet and overall process parameters involved in the same. A small case study of a middle ear implant hearing device was discussed.

By using this middle ear implant hearing device, it can be seen how the structures are implanted, how the actuations are taken care of, and the oval window and inner ear. A magnetic micro actuator has a planar coil where there are some spring arms available, and these spring arms will take care of the movement of the structure. The varying configuration of these magnetic structures is deployed in any kind of structure using a kind of active coating. In certain cases, these magnetic segments are integrated with the structures, and magnetic particles are dispersed in the structures. Now, the magnetic film is concerned, since it is already well-versed in the microfabrication techniques, with reference to microfabrication, E-beam, and physical vapor deposition or dip coating, which are available.

There are different magnetic segments being deployed here, such as electro deposition and oblique angle deposition. With reference to the micromanipulation technique for actuation, there are different designs that exhibit. As far as magnetic micromanipulation is concerned, it can be classified based on functionality and reference to torque actuators and force actuators. In the case of torque actuation, it has a time-varying magnetic field. In the case of force actuation, it has a non-homogeneous magnetic field.

In the case of a time-varying magnetic field, it can be classified as rotation, oscillation, and stepping. In the case of nonhomogeneous materials, there are particles that are available, and based on these particles, manipulation can occur. This origami-based magnetic actuator is for micro-robotic applications. These are kind of flexible origami-based actuators, and these magnetic particles are integrated with the hydrogel and appropriately programmed in such a way that whenever there is an actuation, an appropriate deflection is exhibited in the system. So, this structure can take on any shape based on its capability.

In the case of a magnetic actuator, these magnetic micro-actuator-based robots have potential applications in different biomedical-related aspects. In fact, this complete picture will give you clarity about what the different nodes or applications are, where these magnetic-based actuators can be deployed, and how they impact the characteristics. Previously, some discussion occurred on magnetic and magnetostrictive-based structures. With reference to piezo, the piezoelectric effect, the overall configuration of a piezoelectric effect, how mechanical deformation impacts the piezoelectric effect, the impact of electrical displacement on the piezoelectric effect, the generalized 3D space formulation of a type of piezoelectric impact, and the constitutive equation for piezoelectric actuation. The previous section discussed this configuration related to short circuit and an open circuit system, as well as piezoelectric actuation, including the importance of polling and how this polling will impact the functionality, thereby improving the structure's functionality.

Moreover, how the performance of piezoelectric actuation is studied with reference to strain and curve, hysteresis, and the amplification factor. So some of the key elements, which include a micro membrane pump, micro walls, and chopstick grippers, are used for a kind of micro manipulation. The piezoelectric actuator used for a type of optomechanical application has been discussed here. So, this is highly useful for dynamic loading and unloading. This is a type of piezoelectric-based manipulation.

It has a kind of piezoelectric beam based on the movement of the beam due to vibration. Through this vibration, there is a kind of displacement that persists. So, this displacement has a direct relevance towards the frequency. It has two different configurations; one is frequency-based, and the other is a micro-displacement phase for micromanipulation. Earlier, electrostatic actuators and their different configurations were discussed, including a vertical actuator with a parallel plate and a linear actuator with a lateral configuration using a parallel plate.

This scratch drive actuators, about the different operation modes of electrostatic actuators and the different types of electrostatic actuators that are being integrated into a customised system, have been discussed. One is a kind of multi-degree-of-freedom electrostatic actuator, a perforated intermediate electrostatic actuator, a bending plate actuator configuration, a scratch drive actuator with an inchworm-like walking sequence, then there is a top drive actuator, and then there is a linear slider-based actuator that exists. This electrostatic foil actuator, which is used as wall-based system, pertains to the configuration of an electrostatic micropositioner and the application of this micropositioner in optical communication-related applications. These are some of the references. So, I urge you to go through this YouTube video.

So, you will have better clarity on the magnetic-based actuator for micro-robotic-related applications. There is a wide variety of micro actuators with reference to different functions. Like shape memory, micro motors are used. Overall, to classify these actuators or micro actuators, they can be classified under three different categories. One is called a non-contact actuator, a solid-state actuator, and the third one is a stepper actuator.

As far as these non-conducting actuators are concerned, these electromagnetic or electrostatic structures are a kind of non-conducting actuator. This is because the energy input is produced by the work resulting from the presence of the forces. In the case of a solid-state actuator, the actuator includes a thermal biomorph and a smart material, such as shape-memory alloys and piezoelectric actuators. The work is produced through stress variation resulting from changes in material states. In the case of a stepper actuator, it includes the slip-stick slip actuator, then it has the impact drives and scratch drive-based actuator.

As far as these actuators are concerned, the work is produced incrementally. In the case of a solid-state actuator, it has the SMA and the piezoelectric actuator. SMA actuators similar to bimorphs, etc., will be discussed in detail in subsequent slides. In the case of solid-state actuators, the work is produced through stress variations resulting from a change in a material state.

In the case of a non-contact-based actuator, there are an electromagnetic actuator and an electrostatic actuator. In this amplification of motion, in many cases, the actuator motion ranges and/or resolution do not match the desired range of motion of the mechanism output. Hence, the interface mechanism to scale up or down the motion range of the actuator needs to be part of the mechanism, particularly in the case of a solid-state actuator. In all these configurations, wherever amplification is required, it can amplify these structures based on the functionalities. As far as the amplification of motion is concerned, or the amplification of these actuators is concerned, it is structurally trying to modulate these micro actuators so that they can have an appropriate amplification in the actuation.

With reference to the amplification perspective point of view, it can amplify these motions into three types. One is called a bimorph assembly; the other is called an in-plane motion amplification. This in-plane motion amplification is further classified into three types. One is called the lever mechanism type, the other is called the two-bar system, which basically focuses on the up-and-down mechanism, and the third is called a push-pull assembly mechanism. From the perspective of bimorph assembly, these bimorph assemblies, as discussed earlier, have two different layers.

In the case of this bimorph, it consists of a kind of sandwich structure made of two or more different materials with an asymmetric strain response to a common stimulus. One of the sandwich structures can be a smart material, and the other one itself can act as an activator. As in the case of bimetals. These structures will have different boundaries between them. The bimorph assembly perspective point of view has two mediums: material 1 and material 2.

The actuation happens in such a way that both material 1 and material 2 will move along the structures. The two materials with different responses are meant to provide a stimulus for a continuous interface. From the perspective of asymmetric strain, these asymmetric strain responses to a stimulus could either be a kind of thermal stimulus or a kind of electric or magnetic field. This will cause the assembly to bend on the sandwich material and not expand at the same rate. So, this mechanism forms an efficient propulsion mechanism.

Although, a kind of in-plane bimorph is conceptually possible at the design level, it remains very difficult and is not possible to fabricate in very small dimensions. Therefore, most of these bimorphs are kind of on a micro scale, which leads to a kind of out-of-plane motion amplification. Now, in a similar fashion, from the perspective of a lever mechanism, this is a kind of lever mechanism. Let's take a look at the overall configuration; it has a solid-state actuator and two joints.

This is the kind of solid state actuator. It has joints in place, and this is a kind of amplification. This is the kind of solid state actuator, and it has two joints with levers. This is the structure where the solid-state actuator is represented, and it has a kinematic standpoint, which is called one-axis translation. In this arrangement, it is called a liver amplification mechanism.

It is based on the four-bar mechanism. From the viewpoint of kinematics, in this design, the actuator can be seen as one of the axis degrees of freedom, and it is almost equivalent to a prismatic joint. So the lever amplification is realized by using a pivot joint. A lever pivots around a point anchored to a fixed body. Two pivots are used to interface the linear motion of the actuator with the angular motion of the pivots. The actuators forming the input of the mechanism are attached at one end, while the output of the mechanism can be any point on the lever.

The output point can be taken so that the displacement amplitude from the actuator is either amplified or reduced. The scaling ratio between the input and the output is simply the relationship between the distance from the input to the lever pivot and the distance from the lever pivot to the output. Here in this case, so this is one arrangement. So, it has one more arrangement.

In this arrangement, it can be something like this. This is the solid-state actuator. It is dry over here. It has a kind of mechanism. This moves back and forth. So, this is the solid-state actuator, and here we can see an amplification that is exhibited over here.

So, this is a kind of translation that exhibits. So, it is noted that to convert this into linear motion, it requires a kind of linear guidance. If the arm is long enough and the displacement is still small, the circular end effector motion can be neglected in the first approximation. So, as far as this case is concerned. It is a kind of kinematics of a bar with two pivots that can be used to accommodate the linear motion produced by the linear guidance of the system, with the angular motion of the lever.

Now, let us see the next category. So, this is called a two-bar system. So, as far as this two-bar system is concerned. In this 2-bar system, this is connected something like this, and the overall theta is governed by this mechanism, and this is the actuator. Now, it is a kind of double-beam motion amplification where various implementations exist based on the principle. So, this is based on the length of the base of the triangle. Now, as far as this 2-bar system is concerned. So it consists of a symmetrical triangular assembly with two arms of equal length. The actuator forms the basis of the triangle. When the length varies, it induces a displacement in the perpendicular direction. Whether the motion is in the perpendicular direction, it is either amplified or, on the contrary, reduced.

The motion amplified is a function of the angle, which is nothing but theta; therefore, the ratio between the lengths is appropriately adjusted. This is one mechanism that we call a two-bar system mechanism. It has its own integrities, and appropriately, when you try to deploy it from a field perspective, it gets adjusted. Ideally, wherever you want to have a kind of linear amplification to a theta amplification, to a rotary amplification.

It can deploy to this mechanism. The other mechanism that is available is what we call a push-pull mechanism or a push-pull assembly. So, as far as this push-pull assembly is concerned, the configuration looks something like this, where it has a solid-state actuator. So, this is a kind of push-pull assembly. In fact, you can also have such configuration. In this configuration, this is a kind of translation which exhibits and let us consider this as a solid-state actuator A1 and solid-state actuator A2.

This is an arrangement that is available, so this is a kind of combination used for a push-pull configuration. In this configuration, we have two actuators mounted so that when one shrinks, the other elongates; the amplification is gained by the lever with a pivot. So, the push-pull configurations can be adapted to any configuration so that these two actuators can move the same amount in the same direction. So based on the requirements, it can appropriately manipulate the moment in both directions. These are some of the different amplification mechanisms that are available, which relate to the micro actuators that get integrated based on the different functionalities.

Of course, from the biomimicking perspective, it will be going through many more amplifications that have been directly deployed in the field. So those are similar mechanisms, but it will be a kind of upgraded configuration, which we will discuss as and when we come to that module.