Micro Robotics

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Lecture- lec39

Microsystems for Microrobots (Actuators) - Module 04

We have been discussing this microsystem for micro-robotic related applications. We have been discussing the different micro actuation strategies that have been deployed and the different technologies that have evolved from a microsystem perspective. In fact, we have seen some case studies where we have used a type of micro-motor for the movement of biomedical-related applications. We have also checked some case studies where people have used micromagnetic systems for different applications. In fact, we had discussed the different configurations of micro pumps and the applications of micro pumps in detail. In today's lecture, we will discuss about one of the key aspect which is called as piezoelectric based micro engines.

So, as far as these piezoelectric-based micro engines are concerned. So, piezoelectric microengines harness the mechanical deformation of piezoelectric material under an applied electric field. These engines can produce a precise, high-frequency motion with relatively low voltage requirements. Some of the common designs include the ultrasonic motor and the inchworm motor.

So, as far as these ultrasonic motors are concerned, they are used for traveling or standing waves in piezoelectric-related elements. However, in the case of the inchworm, it employs a sequential clamping and extension of a piezoelectric actuator. For instance, if you remember, we had discussed this inchworm mechanism, where there will be a kind of opening and closing of an actuation alternatively, by opening and closing these actuations. So, appropriately, we can get a kind of displacement that is on the order of a few microns. Now, this will be helpful for us in appropriately sequencing this opening and closing.

So, we have the capability to change the directions appropriately, and it also helps us to change the frequency and the voltage according to our requirements or characteristics. So, as we had discussed the stick-slip phenomenon. So this stick-slip phenomenon is one such example where inchworms have been used for different applications. Now, in today's lecture, we will discuss more about this ultrasonic motor. So, as far as this piezoelectric-captured ultrasonic motor is concerned, it uses an ultrasonic frequency with piezoelectric-vibration-generated waves. And these waves are used to be transformed into electrical energy in the form of rotary or translating motion. So, the USM receives more attention because it offers distinct qualities over the traditional magnetic coil-based motors, such as miniaturization. It also has greater accuracy. Most importantly, it has quite a good amount of speed. It is nonmagnetic in nature.

It has a silent operation and a straightforward construction board with temperature operations and adaptability. So, let us see some of the key characteristics of this piezoelectric-based motor. Let me just take you around the basic operation of this piezoelectric-based ultrasonic motor. So, as far as these piezoelectric-based ultrasonic engines are concerned, there is going to be a stator, a rotor, and a runner come rotor which has a moving direction, and there are some connections over here that have been integrated into the system. So, ideally, this is the stator, and this is going to be the driving foot, and it has a rotation something like this.

Let us represent it as A, B, and C. Now, if we closely observe these operating principles, this ultrasonic piezoelectric motor comprises two primary components: a stator and a rotor. A stator, as we all know, is an immobile part that contains a kind of piezoelectric component, and the stator, or traveling wave motor, while the rotor is a mobile part that works with the stator to produce either a rotation or a linear movement. Now, this ultrasonic piezoelectric-based ultrasonic system is a kind of concept that converts the spiraling drive foot motion to the movement of the rotor through the friction interaction that occurs between the rotor and its stator. So, it is something like this: the pushing element of the circular motion moves the runner with a friction force while the pressing element shifts the force that is normal within the driving foot and the runner on a periodic basis.

So the pushing and pressing elements are parallel and perpendicular to the runners, which is a kind of traveling trajectory, respectively. Now, as far as this particular case is concerned, if you see the overall classification or if I try to look into the overall advantage of this particular system. So, when I try to categorize with reference to different parameters from a perspective point of view, when I consider a voltage, it requires very little voltage. With reference to size and weight, it is highly compact and light. It can work in both air and vacuum environments, and it has a kind of silent operation.

Most importantly, from an electromagnetic perspective, it does not have any kind of electromagnetic interference and has a high torque at low speeds. The most important aspect of these piezoelectric and ultrasonic-based systems is that they have a very fast response time compared to any other systems. And basically, these are some kind of simple designs. They have a stable performance across a wide range, and they have a high efficiency, especially at low speeds. So, these are some of the advantages of such systems.

However, with reference to the disadvantageous perspective point of view, they usually generate a small amount of power with low efficiency that involves two-step energy conversion techniques. In this particular case, there is a transformation of stator vibration into a macro one-directional motion of the rotor via the friction between its rotor and the stator, which may cause a kind of energy loss. Now, let us see some of the classifications of this particular system. So, if we closely observe the classification based on functionality, these systems are classified. So, if you try to look into the overall classification of the system, the ultrasonic piezoelectric motors are classified based on the degrees of freedom, either as 1-DOF or as multiple DOF.

So, in the case of a one DOF (1-DOF), it is classified as rotary motion, and this is classified as linear motion. In the case of multiple degrees of freedom from a perspective point of view, it is classified as spherical motion, planar motion, and cylindrical motion. Now, in addition to this, it is also classified based on wave propagation; it can be a kind of traveling wave, standing wave, or hybrid wave. So, in the case of a traveling wave, it is a kind of radial mode of a cylinder. Based on the geometric shape, it can be considered a radial mode of a cylinder; then, we have the axial bending mode of a disc and the axial bending mode of a ring shape.

Similarly, in the case of standing waves, it is based on the rotary direction. We can classify them as unidirectional motion and bidirectional motion. With reference to the hybrid wave perspective, it can be classified as longitudinal-based, longitudinal bending, and longitudinal torsion. So these are some of the classifications with reference to these piezoelectric ultrasonic-based micro engines. Now let us discuss the concept of thermal micro engines.

As far as these thermal micro engines are concerned, they are mainly meant for converting one form of thermal energy into mechanical work. So, it is often used to leverage the high surface area to volume ratios at micro scales for efficient heat transfer. So, some of the examples of these thermal micro engines basically include a bimetallic actuator. So, the main function of this bimetallic actuator is that it tries to take advantage of the different thermal expansions that occur within it. As we are all aware, a bimetallic actuator works.

So, ideally, a bimetallic actuator looks something like this. It has two different combinations of two different materials. Basically, we are trying to encash the specific heat capacity of the material; the thermal conductivity of the material appropriately can initiate a kind of actuation that we are looking for. From the perspective of shape memory alloys, we are trying to utilize the phase transformation. In fact, we had discussed a lot about shape memory alloy-based transformation. It is something like switching between an austenite phase and a martensitic phase. So, we are trying to utilize the phase transformation in materials like Nitinol. And then we can also have this thermo-pneumatic engine, which basically uses a kind of gas expansion in a sealed chamber. So, we have a chamber in place. Inside this chamber, there will be a kind of thermal material.

When this thermal material gets heated up, it will result in a kind of expansion. So, this expansion will lead to a kind of actuation in the system, and further, we can have control over the actuation by providing appropriate thermal sequencing to the system. With reference to this thermal sequencing, we can have control over the motion. So as far as these particular cases are concerned, these engines can generate a significant force, but basically, they typically operate at low frequency due to this thermal cycling limitation. For instance, we have discussed the shape memory alloys, which have their own limitations from a frequency perspective.

The maximum frequency that is reported is close to 15 hertz, which itself requires a kind of bonding that can be exhibited only in the case of bimorph-based applications. Now, as far as the shape memory alloy-related heat engine is concerned, there is a concept available called Johnson's heat engine. So, as far as this Johnson heat engine is concerned, there are two concentric circles, or it is like a kind of wheel. The spokes of the wheel are made out of a shape memory alloy. So, to give a better understanding, the spring looks something like this; what happens is that this spring is in a deformed state, and this wheel is connected to an axis.

Let us consider that we are half immersing it in hot water. So, when these wheels are immersed in hot water, they are basically half immersed in the hot water. So, what happens is that there will be a kind of contraction and expansion in the spring. This spring will try to expand and then this spring will try to contract. So, the expansion is already there, the spring is under tension, and when we try to put it in hot water, it will try to actuate; it is trying to contract.

When this particular set gets contracted, let us consider that we have three sets of springs. When these three sets of springs try to contract, there is automatically going to be a shift in the center of gravity of this particular wheel. When there is a shift in the center of gravity, a rotation will be enabled as a result. Now, if we closely observe this particular construction, the input is in terms of heat, the input is in terms of temperature gradient, and the output is in terms of rotation. So, when there is a kind of temperature gradient that exists, this will result in a continuous rotation in the wheel, and these continuous rotations can be used for appropriate applications.

So, I can either connect a kind of cooling fan arrangement, fix up a dynamometer over here, or sometimes encash this displacement for appropriate application. So, I can just connect a small shaft to this system. When I try to connect a small shaft to this system, the wheel will rotate. This translated rotation, the rotation generated by the shape memory alloy-based wheel heat engine, can be appropriately translated in the form of a displacement, which is one way of achieving a kind of rotation. And the second important aspect is that the input for this system is due to the variation in the temperature gradient.

So, by adjusting the temperature gradient appropriately, we can expect a rotation. So, now we have a flexibility. So, as we have seen, the commercially available shape memory alloys are basically nickel-titanium-based (NiTi) materials, and these nickel-titanium-based materials can be efficiently actuated within the range of approximately 40 to 60 degrees Celsius, which is sufficient enough for us to supply localized heat in a particular concentrated region. So, what happens is that the spring will get actuated as and when it gets actuated. So, we can appropriately see a kind of rotation that is exhibited here, okay.

Now, here in this particular case, what we are observing is a kind of rotation because the geometry is in the form of a wheel. However, alternatively, we can also deploy such arrangements where we have a two-legged system made out of SMA bimorph. So, these SMA bimorphs, as we have seen, have a kind of thin film integrated with a polyamide structure. So that when the actuation happens, this polyamide structure gets actuated, and appropriately, we can achieve a displacement. So this is going to be a kind of SMA biomorph.

Let us consider that we can prepare a small inchworm-based SMA biomorph, and then we can appropriately supply a type of relay circuit to the system, which will provide a form of joule heating to this particular SMA biomorph. So, what happens is that when we try to give a small pulsative heating to this particular SMA biomorph. This SMA biomorph will try to displace in a particular orientation. This displacement will result in the actuation of such structures where we can see an appropriate displacement exhibited here. So, the same technique can be deployed for a bimetallic-based inchworm.

If we closely observe the SMA bimorph and the bimetallic-based inchworm, they will almost have the same thermal cycle. However, in the case of shape memory alloy, we have the capability to tune the thermal cycle by appropriately applying a strain percentage to the system. So, now that we have come back to this SMA-based heat engine, it is concerned. So, the actuation of this SMA-based heat engine is highly controlled by the amount of temperature gradient that exists. Now we have a provision in place that this temperature gradient can be generated either through a liquid or through air.

So, by appropriately generating a kind of actuation through hot air, we can create a rotary system. For example, let us consider an arrangement like this. This is a kind of SMA spring. This SMA spring is connected to a roller. Now we have focused air that is made to hit this particular surface.

So, when the hot air with a temperature in the range of 40 to 50 degrees Celsius strikes this shape memory alloy spring, what happens is that this shape memory alloy spring will contract, which will result in a shift in the center of gravity that will allow the wheel to move in a particular direction. Similarly, when I try to cut off the hair, this shape memory alloy will expand and, finally, it will result in the stoppage of this rotation. So, here in this particular case, whenever we are considering a kind of small mobile robot, where there is going to be thermal heat. When we consider thermal gradient as our input, appropriately supplying a thermal gradient, we can generate a kind of rotation. Even, we can use it for a certain amount of mobile platforms, etc.

Another aspect with reference to this shape memory alloy-based heat engine is that, suppose we have a kind of circuit and these circuits are generating quite a good amount of heat. So now we can have a kind of SMA-based cooling fan system. This SMA-based cooling fan system is connected with a fin arrangement, and when heat is generated, the fan starts rotating and appropriately tries to quench the heat being generated here. So, these are some of the applications where SMA-based heat engines can be deployed. Now, let us take one more case study where it is a kind of micro heat engine that is being deployed.

So, as far as these go, if you try to look into the construction of this micro heat engine, there is going to be a polymer gasket available. Then there is going to be an expander membrane, a saturated mixture, and a liquid reservoir. Now, there are going to be two important structures; one is a kind of wicking structure, and the other is a kind of evaporator membrane that is available. So, in this case, an individual microengine consists of a cavity filled with a saturated two-phase working fluid bounded on the top and bottom by thin membranes.

So the bottom membrane acts as an evaporator. A capillary wick fabricated on the top of the membrane controls the layer of the liquid-phase working fluid on the evaporator. So, the top membrane of the cavity is the expander and fluxing, and it will result in a kind of mechanical work. So ideally, in this particular case, we get a kind of resonator displacement coming out of this, using this particular system. So, in this particular system, if we keenly observe, there is going to be an expander membrane, and then there is going to be an evaporator membrane and a liquid reservoir.

So, this will result in a kind of peristaltic motion. So, this perislatic motion will be helpful for us to create a kind of an inchworm mechanism, what it is expected. So, these are some examples where thermal-based systems can be deployed to generate a certain amount of micro-actuations. These are kind of integrated systems that can be integrated with the systems for developing particular applications.