**Micro Robotics**

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**Lecture- lec48**

**Microsystems for Microrobots (Integrated Approach) - Module 03**

So, we have been discussing the different configurations of micro-assembly. In fact, we had discussed a lot about this manual and automated-based system, i.e., automated-based micro-assembly. So, we have seen some different configurations related to this microassembly. Now, in today's lecture, we will discuss this hybrid-based microassembly. So, as the name suggests, this hybrid is basically a system that integrates both manual and automated microassembly processes. So, one of the key importances includes reducing the assembly cost, accommodating fluctuating production demands, and enabling both prototyping and small to mid-volume production. So, these are some of the key importances of the system. So, as far as this application's area perspective point of view, these are automotive; it is highly used for automotive sensor-related applications.

It is used for medical kinds of microfluidic devices, and it is also used for telecommunications-related applications. Now, this will give us a kind of a fundamental with reference to a manual mode and an automated mode. So, as far as some of the key components of this hybrid micro-assembly system are concerned, it is a kind of teleoperated system. In this teleoperated system, it provides high precision manual control, and it uses force feedback control and high-resolution cameras. As far as these automated assembly systems are concerned, they use a sensor, robotics, and computer control for an efficient production perspective.

So ideally it includes a kind of modular micro-gripper and a positioning system, and as far as vision-based feedback systems are concerned, it has an integrated CCD camera with telecentric lenses for accurate alignment. So ideally, kind of auto-focus systems will be enabled. Now, if we try to look into the overall configuration of this particular manual mode system and an automated system, we have different sub-systems that are participating in this particular hybrid microassembly. So, one system basically includes the haptic and graphic user interface (GUI). This haptic and graphic user interface normally communicates with the teleoperated subdomains as well as the other subdomains.

So as far as this tele-operated subdomain is concerned, we have the four sensors in place. We have a Cartesian coordinate system, a kind of camera that is used for processing an image, capturing the image, and providing feedback to the appropriate system. Now, if we try to look into the overall aspects, we have the automation controller in place, then there is a programming GUI, and then there are forced feedback control sticks that are available. So, ideally, there will be an interaction between the manual mode and the automotive mode based on the requirement. So, as far as this manual teleoperated mode is concerned, it is used for prototyping and small batch production.

Some of the key features basically include a kind of operator control where micro-manipulation happens with reference to a joystick, and it has real-time force feedback that compensates for scaling effects. It also has cameras that provide multiple views for precise control. As far as the automated mode is concerned, it is used for a larger production volume. Some of the key features basically include the pre-programmed micro-assembly steps. It used a kind of closed-loop feedback from the sensor and a kind of AI-based adaptive control for precision adjustment. So, these are some kind of automated mode systems. Now, let us discuss one of the key aspects of this kind of case study; in the case of a micro-manipulation stage. So, when we try to look into this micro-manipulation, we can classify it into two categories. One is called a serial-based manipulation, and the other one is called a parallel-based manipulation. So in the case of a serial-based manipulation, there are some systems where there is a kind of integrated arrangement, and the overall end effectors are placed here.

So this is a kind of manipulation arrangement that exists. So, this is a complete micro-robotic system. So, this micro-robotic system, as far as this particular serial manipulation is concerned, deals with serial manipulation. It is deployed for measurement-related applications, or it has a kind of needle, and through the needle, we can do a kind of micro-manipulation, which is exhibited here. So here, from the overall movement perspective, we can have a kind of stick-slip phenomenon.So, if you remember, we have discussed the stick-slip phenomenon where we will have a leg-like arrangement. This leg will move back and forth. So, when this leg moves back and forth appropriately, you can see a kind of moment in the system. It is a kind of ploughing behavior that it exhibits. So, this ploughing behavior will catalyze the movement of this stage or the manipulator.

So this is a kind of stick-slip-based phenomenon that exhibits a kind of serial manipulation. So as far as serial manipulation is concerned, since the manipulator is connected in series, that is why it is called serial manipulation. Such kinds of manipulations are effectively used from a locomotion perspective, like the locomotion of the end effector or precise manipulation of the end effector, where such a stick-slip phenomenon can be deployed. So,

these stick-slip phenomena are actuated either by a piezoelectric system or by a magnetic-based system. So, this is a kind of serial manipulator-based end effector. Now, let us discuss a parallel manipulator-based micro-manipulation. So, in the case of parallel-based micromanipulation, this is a kind of arrangement that exhibits, and this is used for the movement of the system. So, as far as this particular case is concerned, we can have multiple orientations. For example, this is a kind of SMA Biomorph-based actuator. Okay, so the actuation is happening to have a kind of manipulation on the top.

So ideally, we try to take the axis over here. So, with reference to this axis, we can have a kind of theta orientation to it or a kind of x-y movement to it. So, either with reference to a theta orientation or with reference to an x-y orientation, we can appropriately program the system for a kind of theta or x-y orientation for beam steering or for a certain amount of micromanipulations, and in certain cases, this configuration can also be deployed in a similar manner. and over this we can have another stage. So, the overall manipulation which exhibits over here in this bimorph will be in this direction. So, when you try to actuate it, it will try to expand in this particular direction. When there is an expansion, there will appropriately be an orientation along the X and Z planes for the manipulation perspective model of view. There are manipulations where both serial and parallel are deployed. In such kinds of manipulations, most of you might be aware of this steward platform. So this is a kind of steward platform arrangement.

On this steward platform, there is going to be an end effector. So, there is going to be a movement on the steward platform, and this is a kind of parallel manipulator that moves in an appropriate orientation. So based on the requirements, we will have 2 to 3 sets of manipulation. So, one manipulation is happening along the XYZ plane, and the other manipulation is happening along the end-effector plane. So, these are some of the different sub-micro-manipulation stages that are effectively used for various functional applications based on their characteristics.

So, ideally, I would like such kinds of micro-manipulation stages. So, it exists in a range of more than 1 micrometer. However, it has more to do with the manipulation range. So, there is precise control of this manipulation range, and the control of this manipulation range is well interfaced with reference to the actuator that we are using. So ideally, in most of these cases, as I mentioned earlier here, we are using a piezoelectric or magnetic-based system so that precise manipulation is recorded.

As far as this particular case is concerned, we are talking about a shape memory alloy that will have precise control over the orientation as well as over the axis. Now, let us discuss the different key parameters or various micro-operation-based platforms that are available in the literature. So, one is a kind of hexapod. So, as far as these hexapods are concerned, it has degrees of freedom in the x, y, z plane and it also has degrees of freedom in theta x,

theta y, and theta z. The overall envelope is in the range of 100 mm to 180 mm, which is the overall work envelope that represents the degrees of freedom size.

When we try to look into the resolution perspective point of view along the xy plane, it is in the order of 200 nanometers, and in the case of the z plane, it is around 80 nanometers. With reference to the theta perspective point of view, it is in 2.5 micro radians. And then, with reference to the xy plane, it is around plus or minus 17 mm; at the z-plane, it is around 6.5 mm; along theta x and theta y, it is around 10 degrees; and along theta z, it is around 21 degrees. So, it is a kind of open loop system. So, that is why the overall range is crossing more than 10 mm, and from the overall repeatability perspective, it is plus or minus 0.06 micrometers, which is the overall repeatability of this hexapod. Now, there is a kind of smart pod that is available. So, this smart pod is a kind of closed-loop system.

It has a higher-order repeatability. So, when we look at the overall degrees of freedom from a perspective point of view, it is 110 mm and 45 mm, and then x, y, z is around 1 nanometer, which is highly precise, and theta is 3 micrometer degrees. The XY plane is plus or minus 10 mm, and Z is plus or minus 5.5 mm; theta X and theta Y are plus or minus 13 degrees, and theta Z is 19 degrees. So, there are a few n-probers there. So, as far as n-probers are concerned, n is into this particular probe movement (n x XYZ + XYZ). So, it is a kind of open-loop system. It has a repeatability of around 0.05 micrometers, and it has a resolution of approximately 2/100 nanometers. So, XYZ is in the range of 12 mm, and it goes around 28 mm.

It is slightly a kind of probe that is used from a manipulation perspective point of view. In fact, it is a kind of serial manipulator with appropriate actuators that are being established in these end probers. So, this MM3AEM is also focused on the XYZ and theta Z. It is a kind of open loop system which has a repeatability of less than 2, and PS8e is a very specialized micro-operation platform that is available. Now, in addition to this, there are other platforms like ANSxyz50, which have a resolution of 0.03 mm and 0.0043 mm. There is a kind of LifeForce-based micro-operation platform that has degrees of freedom in the XYZ plane of 127 mm, 127 mm, and 30 mm, which is slightly on a macro scale. However, the resolution is on the order of a few nanometers, and the XY plane is restricted to around 10 mm. So, it has a very restricted plane, and a good part of it is that it has a very good closed-loop system with a high repeatability of around 0.001 micrometer.

There are few hybrid hexapods. So, these hybrid hexapods have a kind of orientation in the XYZ plane as well as an orientation in theta X, theta Y, and theta Z. The resolution is on the order of a few nanometers, and it has X, Y, and Z with theta X and theta Y at plus or minus 30 degrees, and theta Z is 360 degrees. So, it has a kind of closed loop with a

repeatability of less than 0.08 micrometers and a drifting system. So, Imina is also a kind of small micro-operation platform, which has T, x, y, z, and theta z, and it has dimensions of 20.5 mm, 22 mm, and 12.5 mm. It has an open loop system with good repeatability, and drift is less than 1 nanometer. So now, from the overall micro-assembly perspective, when we try to categorize these micro-assemblies, we categorize them under different features. One is with reference to flexibility, the second is with reference to the overall production volume, the third is with reference to the overall precision of this particular system, the cost involved, and the level of automation. A flexibility perspective point of view: in manual mode, we have a high level of flexibility, whereas in automated mode, it is low. From a production volume perspective, it is small in manual mode, and in automated mode, it has a larger system, which is one of the key aspects that results in a reduction in flexibility.

From a precision perspective point of view, it is high when in manual mode, and in the case of automated mode, it is moderate. From a cost perspective, it is a high cost per unit in manual mode, and it is low per unit in automated mode. From an automation level perspective, it is low in manual mode, and in automated mode, it is high. So, some of the key takeaways from this micro-assembly of micro-robots are concerning. This hybrid micro-assembly enables both prototyping and mass production.

It reduces the cost and transition time between the manual and automated product processes. So, from a future improvement perspective, it will enhance adaptability and efficiency based on the characteristics. Now, let us discuss the different micro-assembly challenges that are evolving with reference to this micro-assembly perspective. Now, when we try to address these challenges, one is simple and practical. So the appropriate choices for establishing a simple and practical actuation perspective are a magnetic field, magnetization, and the manipulation equipment, which are relatively mature.

However, an inappropriate choice that refers to a simple end perspective is a mechanical gripper, which requires open space and mostly requires a bulky controller. Next, with reference to a kind of micro-object perspective, this typical micro-object perspective point of view shows that these mechanical grippers have high precision, a high degree of freedom, and are mainly meant for selective operation. However, from an acoustic perspective, it is very difficult to control the micro-manipulation. So that is one of the major drawbacks of the acoustic field. So basically, the acoustic field of specially shaped objects makes it difficult to isolate the irrelevant parts.

With reference to feedback from the close environment perspective, these mechanical grippers have the possibility of integrating with micro-sensors. So, all the field-based methods mainly based on visual feedback or other information feedback are highly limited. With reference to the autonomy perspective point of view, these mechanical grippers have high accuracy and diverse information feedback. Whereas the inappropriate choices

basically include a field-based method, automation is completely a kind of vision-based system that is highly limited but feasible. From a safety concerns perspective, special modifications are required, and there is almost no thermal effect that can be considered.

Now, magnetic field and light field magnetization are required, and the photo-thermal effect is an unavoidable process. So, to give you an overview of these microassemblies, we discussed the different configurations of microassembly. Ideally, we had discussed the different losses through which these micro-assemblies are governed. So, we had discussed the surface tension.

We have discussed the Van der Waals forces. We have discussed the electrostatic charges. We also had a discussion about surface tension and gravity and what the different subsystems are that participate in creating such an environment or its characteristics. So, we also had some discussions about the different building blocks and the techniques that are being evolved. So, under the building blocks, we have discussed micro-particles, multiple objects, and cells. From a technical perspective, we covered structure construction, MEMS operation, and biomedical engineering.

We discussed the different applications. One of the applications was the magnetic field, the optical field, the acoustic field, and the mechanical operations. From a characteristics perspective, as far as magnetics is concerned, we are discussing the key features, technologies, and applications. It has wider applications and is highly focused on targeted drug delivery. So, we had discussed the mechanical, optical, and acoustics fields. So, optics and acoustics have a wider application in the biomedical-related domain.

And then, we also had some discussion about the overall approaches as far as gripper-based micro-assembly is concerned. What are the different forces that exert on these gripper-based micro-assemblies? So, we have some discussion about the different parameters that are impacting the electrostatic force, especially at a micron level from a micro-gripping perspective, as well as Van der Waals forces and hydrophilic forces. So, it is a kind of consolidated features or a consolidated influence parameters perspective point of view with reference to force and object radius. So, we had a discussion about serial microassembly, parallel microassembly, and the overall comparison between serial microassembly and parallel microassembly. The stochastic-based microassembly is basically a kind of self-assembled system that is being connected.

And then, we also had a discussion about this directed micro-assembly, the capillary, and

the magnetic-based micro-robots, which exhibit. So, we also had a discussion about these magnetic assemblies with arbitrary geometries. So, we took an example where there is a kind of magnetic micro-robot. It is self-propelled using a kind of magnetic field and the optical field.

So, it has a two-component $Fe_2O_3$ and alpha $TiO_2$. Alpha $TiO_2$ is coated on the $Fe_2O_3$. This $Fe_2O_3$ is manufactured through a hydrothermal process, and $TiO_2$ is produced through ALD. So that it becomes a kind of subsystem for a micro-robot, and these subsystems are assembled by applying an appropriate magnetic field as well as a kind of light propagation. So, there are three different stages. One is a kind of phoretic interaction, another is a kind of active cluster generation, and the third is a kind of magnetic dipole-dipole interaction, which results in a self-assembled system, and this self-assembled system highly participates in photocatalytic reactions.

So, we made a comparison with respect to direct microassembly and traditional microassembly, and then we also had some discussion about this hybrid microassembly, where we concluded it is a kind of combination of both manual and automated systems. What are the different subsystems participating with reference to this manual and automated system, like what are the different key features and how they are being calculated? As far as the perspective of micro-manipulation stages is concerned, we can classify them as serial manipulation and parallel manipulation. We can also consider a hybrid manipulation that involves both for appropriate functionality. As for serial manipulation is concerned, we have taken the case study in which a kind of serial manipulator, which is a type of end effector, is placed, and the movement or manipulation actuation happens because of the piezoelectric effect. As far as this parallel manipulation is concerned, these shape memory alloy structures are integrated with the structure.

By actuating these shape memory alloy structures, there will be a deflection, and these deflections can be efficiently recorded. So, there are different micro-operation platforms that are available. So, this chart will give an overall characteristic about whenever we are designing a kind of micro-operation platform, what the different degrees of freedom are that it exhibits, what the different motion ranges are that it exhibits, and what the different control loops are that it exhibits over here. So, we also had a discussion about this manual mode and an automated mode, and we also had a discussion of some of the key challenges which evolved with the reference to a micro-assembly perspective point of view. One of the challenges includes simple and practical aspects, and beyond the typical micro-object, information feedback, the level of autonomy, and the safety concerns are discussed.

So, in the upcoming classes, we will be discussing the micro-aerial robots, micro-aerial vehicles, how these micro aerial vehicles are designed and how they are being used, and what the different classifications involved in it are, in detail in the upcoming lecture.