Microrobotics

Prof. Palani Iyamperumal Anand

Department of Mechanical Engineering

Indian Institute of Technology, Indore

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Lecture No- 46

Microsystem for Microrobotics (Integrated approach) - Module 01

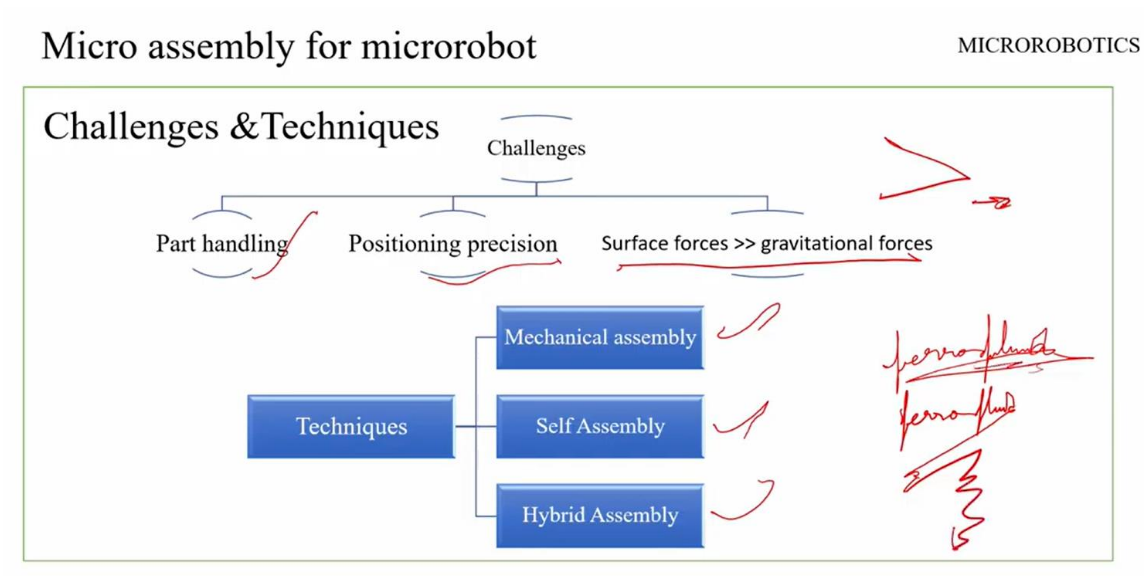
Today we will discuss the third part of this microsystem for micro-robot-related applications. Ideally, we have been discussing different functionalities related to this microsystem. In today's module, we will discuss the concept of integration, which is similar to what we have been discussing regarding actuation and the sensing mechanism. When we try to integrate it, it comes as a kind of complete system that caters to the required functionality. In today's lecture, we will be discussing the different assemblies, self-organized assemblies, and the various mechanisms involved in such assemblies in detail. In addition to this, we will also be discussing two important aspects: one is called a micro aerial vehicle and the other is a kind of multi-robot system.

These micro aerial vehicles have potential applications in some strategic areas, including defense and space-related applications. They are also effectively used for inspections, such as pipeline inspection, AC duct inspection, etc. We will discuss in detail the different classifications of these micro aerial robots, and then we will also discuss the multi-robot system. As a first part, when we are talking about these micro assemblies, they are defined as the process of assembling micro parts, ideally in the form of organizing, positioning, and collecting micro scale components with dimensions typically ranging from a few micrometers to several micrometers.

Ideally, what happens is that we have a kind of micro actuators, and when we try to assemble these micro actuators, we try to ensure that the entire system is within the limit and caters to the required functionality. Either we have a kind of micro sensors in place or the micro assembling of these micro sensors or the integrating of these micro sensors, appropriate feedback systems, etc., need to be taken into consideration. Now some of the major aspects we may need to look into are the manufacturing capabilities for individual micro components, which have advanced significantly, and the assembly of the components into complex functional micro systems, which has become a critical challenge in such micro assembly-based systems. Now, in this particular aspect, one way is through a kind of adhesion analysis, and another way is by applying a certain amount of magnetic field.

We can simply assemble these systems based on their functionality. Ideally, we try to take these scaling effect forces that are insignificant at the macro scale and consider them as a major dominant player when looking at a micro scale. Ideally, as we have discussed, we have talked a lot about the generation of electrostatic charges, etc. These electrostatic charges on a micro level can be helpful for manipulating the system for appropriate microassemblies or subassemblies. So, for example, when a part is handled or is less than 1 millimeter in size, the adhesive force between the gripper and the object can be significant compared to the gravitational force.

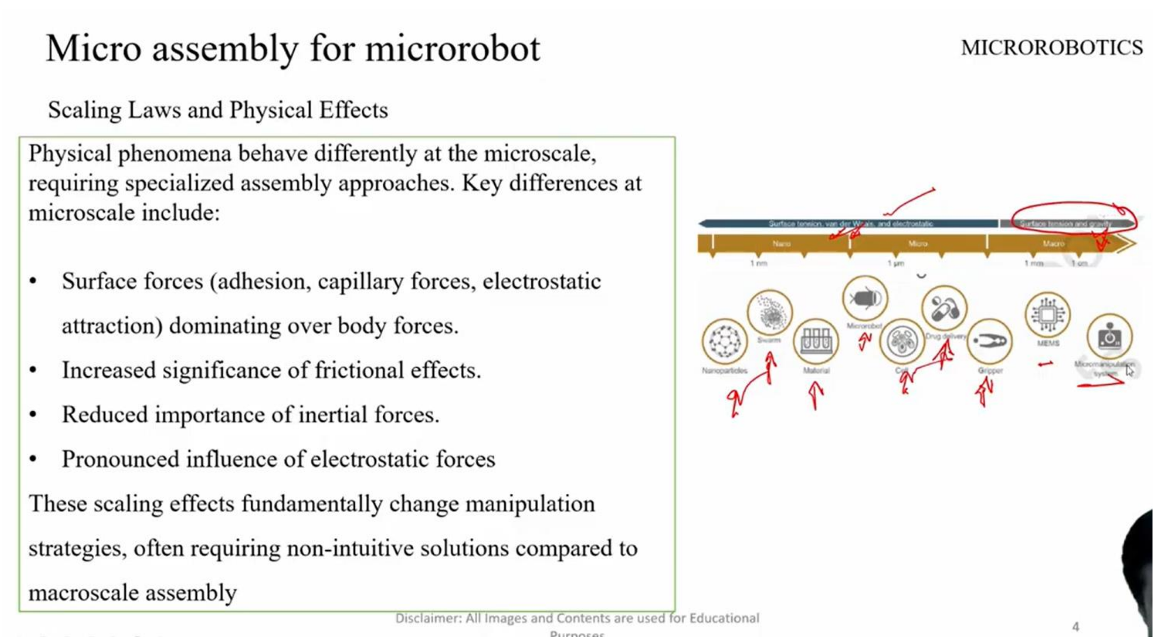
Through this concept, we can establish this kind of micro-assemblies or the micro-requirements. As far as these micro assemblies are concerned, some of the key challenges involved in micro assemblies include part handling, positioning precision, surface roughness, and gravitational force. When we try to closely observe this part, handling is something like a gripper that is deployed in such a micro robotic system. When we try to talk about positioning and precision positioning, So, as far as this particular case is concerned, let us suppose I have a kind of needle. This needle needs to be positioned for appropriate measurements or appropriate manipulation from a perspective point of view.



In those conditions, this kind of microassemblies plays a vital role. Next is with reference to the control of surface forces as well as gravitational force. So, when we try to consider a system, it is a kind of micro system. Ideally, one is a kind of intentional force that is generated, which we intentionally try to induce on the surface so that we achieve a kind of manipulation. Another one is a kind of undesirable force; in certain cases, there is a chance that we may need to develop a mechanism or a microassembly mechanism that will overcome this gravitational force for appropriate manipulation or control over the systems.

This is one of the key important aspects. We appropriately try to design the micro-mechanical systems for generating such kinds of forces, overcoming gravitational force, or utilizing these surface forces. Now, as far as this technique is concerned, we classify it into three types: one is a kind of mechanical assembly, the second is self-assembly, and the third is hybrid assembly. As far as mechanical assembly is concerned, we try to integrate these micro components to assemble the system based on our requirements. As far as self-assembly is concerned, these systems or subsystems get self-assembled by providing appropriate actuation or forces to create self-assembly.

Third is a kind of hybrid assembly, where both mechanical assembly and self-assembly work together to create a form of micro-manipulation in such a way that the system is organized to achieve appropriate functionality. In fact, regarding this, we will be discussing it in the upcoming case studies as well, where there is a certain amount of magnetic nanoparticles. When we try to create a kind of force to it, appropriately these magnetic nanoparticles will try to align themselves to form a structure, and those structures can be efficiently deployed for different applications. In fact, there is a concept called ferrofluid-based structures; these structures have pillar-like combinations. These pillar-like combinations are attracted by a certain amount of magnetic force that is being deployed, so that they form a kind of structure, and using this structure, it can be used for different manipulation-related applications.



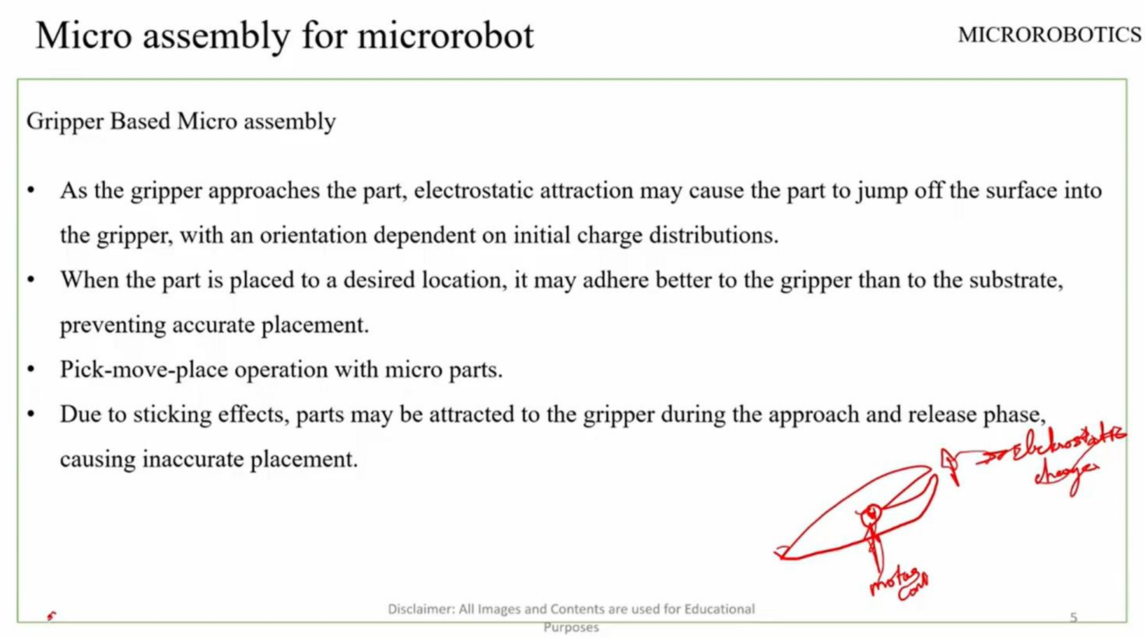
Of course, we have also discussed this in the earlier classes. Now, let us see, or let me just try to correlate with reference to the scaling laws and the physical effects. When concerned with physical phenomena, they behave differently at the micro scale, and it requires a specialized assembly approach. There are different key differences at the micro scales; some of the key differences include the surface forces. Some of the surface forces include adhesion, capillary forces, and electrostatic attraction, which dominate over the body surface.

Then, there is an increased significance of the frictional effect that is being imparted here. However, the importance of the inertial force that is generated is reduced. This pronounced influence of electrostatic force is one of the key aspects that is also considered for the microscale. These micro scale effect fundamentally change manipulation strategies. They often require a kind of non-intuitive solutions compared to the macro assembly.

If you closely observe this micro assembly, you can classify this micro assembly into two parts: one is called surface tension, van der Waals forces, and electrostatic forces, which contribute to the micro assemblies. The other part refers to surface tension and gravity. Now, when we try to look into the overall scale of this particular micro-robotic related application, we also consider the nano, micro, and macro levels. The surface tension, wonder wall forces, and electrostatic forces are all well-participating in the nano and micro range. However, the surface tension and gravity are well represented along the macro range.

So in the case of a macro range, ideally between 1 mm and 1 cm, where there is a kind of surface tension and gravity that try to participate, we aim to develop the system. Whereas in the case of the nano and micro levels, there is going to be a kind of surface tension, van der Waals forces, and electrostatic charge, we try to contribute towards development. Now, as far as a nano level is concerned, we have the nanoparticle in place, then there is a swarm of structures, and there are a few magnetic-based materials or a few electrostatic charge-generated materials available that are heavily contributing to this surface tension, van der Waals forces, or the electrostatic charge. When we slowly try to look into it, and when we increase the scale to the micro-level perspective, we have micro robots, cell structures, an appropriate drug delivery system, and some mechanical grippers. So, these systems are well controlled by these kind of nanoparticles which are available.

Now, slightly when you try to increase the capability with reference to the micro level, like with reference to the scale, we have the MEMS and the micromanipulation system, which play a vital role in developing a kind of macro structure. So, in all these cases, these are some of the applications where micromanipulation and its relevant microrobotic development come into the picture, and the appropriate forces that are involved or the appropriate forces that can be used for controlling these systems include surface tension, Van der Waals forces, electrostatic charge, and gravity. Now, in this entire module, we will discuss some of these forces and how they contribute to the development of such structures in detail. Now, in addition to this, let us discuss a simple mechanical system. So, before going into this, let us discuss a simple mechanical system, which is called a gripper-based microassembly.



So, as far as this gripper-based microassembly is concerned, we are all aware of this gripper-based micromanipulation. So, in this gripper-based micro-manipulation, either this micro-manipulation can happen by motor control or the manipulation can happen because of the electrostatic charge. So, what happens is that as we go for a finer size of the structure, these particles will try to leverage a certain amount of adhesion or a certain amount of repulsion, and appropriately we can observe a kind of variation that exhibits. So, these are called gripper-based microassemblies. So, as far as this gripper-based microassembly comes.

As the gripper approaches the part, the electrostatic attraction may cause the part to jump off the surface into the gripper, with an orientation dependent on the initial charge distribution, so when the part is placed at a desired location, it may adhere to the gripper more than to the substrate, preventing its accurate placement. So, it is a kind of pick, move, place operation with microparts, and due to the stiff sticking effect, parts may be attracted to the gripper during the approach and relief phase, causing inaccurate placement. So, this is one of the major impacts with reference to these gripping microassemblies. Now, let us see some of the different technologies that exhibit, and we can also discuss the appropriate key applications of this micro assembly-based system. So, as far as the overall technologies that are being deployed for these micro assembly systems are concerned.

Overview of the main technology and key applications of micro assembly system

MICROROBOTICS

Building Blocks	**Micro-Particle**	Micro components of various materials and shapes are used to build micro-structures for verification or practical purposes. Micro or nano particles with swarming behaviour for multi-dimensional manipulation. transport, and delivery.
	Multiple object	Micro components of various materials and shapes are used to build micro-structures for verification or practical purposes.
	Cells	Natural cells, microparticle-modified cells, and artificial cells are all important targets for micro assembly such as screening, packaging, and transportation.
Techniques	**Structure Construction**	Builds intricate 2D/3D microstructures with different functions, relying on the precision, efficiency, and repeatability of the micro assembly system.
	MEMS Operation	High-precision and stable micro-assembly technology, mostly completed by commercial micro-operation platforms.
	Biomedical engineering	Provides the prospect of targeted delivery minimally invasively or non-invasively.

So, first let us consider the simple building blocks. So, as far as some of the key building blocks that are participating in this microassembly, the microparticle, the multiple objectives, and the cells are included. These microparticles are microcomponents of various materials and shapes used to build microstructures for verification or practical purposes. Micro or nanoparticles with swarming behavior for multidimensional manipulation, transport, and delivery may be considered for these microparticle-related applications. Now, when we consider this multiple objective, we have micro components of various materials and shapes used to build these microstructures for verification or for certain practical purposes.

Overview of the main technology and key applications of micro assembly system

MICROROBOTICS

Applications	**Magnetic Field**	**The most common and mature non-contact microoperation method, with strong compatibility. The need for objects to be magnetized is a limitation.**
	Optical Field	Excellent in-laboratory solution that enables batch automation. Suitable for integrating with other technologies.
	Acoustic Field	A gentle, non-contact technology that is effective against clustered particles. Feasible for application in fluid environment.
	Mechanical Operation	Serves as functional end effectors for complex systems has the possibility of inheriting multiple sensing functions and the prospect of intelligence.

Now when we try to talk about the cells, there are a wide variety of cells, such as natural cells and microparticle-modified cells, which means that we have a cell structure that is completely encapsulated with a kind of microparticle so that it can cater to the appropriate micromanipulation. Then there are some artificial cells that are an important target for micro assembly, such as screening, packaging, and transportation-related applications. Now, these are the primary building blocks for any kind of microrobotic system, basically catering to the microassembly concept of these microrobotic systems. Now, when we try to look into the overall techniques that have evolved with reference to this assembly perspective point of view. So, we have the structure of construction.

These techniques are classified under three different domains. One is a kind of structure construction, where it is mainly meant to build intricate two-dimensional and three-dimensional microstructures with different functions relying on the precision, efficiency, and repeatability of these microassembly systems. Now, with reference to MEMS operation, we have a high precision and stable micro assembly technology mostly completed by the commercial micro-operational platforms. Now, from a biomedical engineering perspective, it provides the prospects of targeted delivery through minimally invasive or non-invasive systems. So these are some of the key techniques that work along with the building blocks to cater to the assemblies.

Now let us see with reference to actuation and from an application perspective point of view. So, with reference to the application perspective point of view, the microassembly is categorized under four different fields. One is a kind of magnetic field-based system; it is the most common, mature, and non-contact micro-cooperation method with strong compatibility. The need for an object to be magnetized is a major limitation of this particular system. Now, when we try to consider the optical field, it is a kind of excellent laboratory solution that enables batch automation suitable for integration with other technologies.

Characteristics and applications **of magnetic fields and mechanical grippers.**

MICROROBOTICS

External field	Technology	Feature	Application
Magnetic	Magnetic field-induced assembly (MFIA)	Direction control; nanoscale MMs; magnetic properties improvement; real-time tuned; high assembly efficiency; long-range translational order.	Nanoparticle assembly; 1D anode; 2D monolayer; 3D chiral assembly; polymer films; mesoscale structure construction.
	Magnetic assemblies	Noncontact; program and reconfigure formations, predictive model; jamming-free assembly; good robustness and error recovery; predictable static orientations	Magnetic levitation orienting; collective behaviors; structure construction.

From the perspective of the acoustic field, a gentle non-contact technology is effective against clustered particles and feasible for application in a fluid environment. From a mechanical operation perspective, it serves as a function and effector for a complex system, and it has the potential to inherit multiple sensing functions that contribute to the intelligence of this particular system. So, these are some of the key applications that are being catered to regarding the overall application of micro assembly-related systems. Now, among all these systems, like we had discussed a lot about optical based users and optical based manipulation. But from an assembly perspective, magnetic-based systems have been considered a potential player in terms of assembly.

Now, as far as these magnetic assemblies are concerned, they are classified as magnetic field induced assemblies, which is a kind of very niche technology that has been effectively used for different applications. So as far as this magnetic field-induced assembly is concerned, some of the key features of this magnetic field-induced assembly include direction control, nanoscale-based systems, magnetic property improvement, real-time tuning, high assembly efficiency, and long-range translational order. From an application perspective, it has a nanoparticle assembly with a one-dimensional anode, a two-dimensional monolayer, and a three-dimensional chiral assembly; polymer films and mesoscale structural constructions are some of the key applications of this system. Now the next system is called the magnetic assemblies; this is a kind of non-contact based system, and you can program it and reconfigure the formations based on the requirements. Next, it has its own predictive models, and it has a kind of jamming-free assembly.

Characteristics and applications of **magnetic fields** and **mechanical grippers.**

MICROROBOTIC

External field	Technology	Feature	Application
Magnetic	Magnetic microrobots	Low cell-toxicity; remotely actuated and controlled; reconfigurable locomotion modes; tunable structural, morphological, and chemical features; high maneuverability; long-term open-loop stability.	Structure construction; cell transporting; bioartificial; drug delivery; bacterial inactivation.
Mechanical	Mechanical grippers	Close-loop; position offset compensation; hybrid force/position/visual servo feedback control; available for light microscope and SEM; multiple microgrippers and end effectors.	MEMS assembly; 2D/3D pattern construction.

And one important point is with respect to good robustness: it has error recovery and is predictable at static orientations. So, from an application perspective, it has a kind of magnetic levitation orientation. It has collective behavior, and it is a type of structural construction that is exhibited here. These are some of the applications that have a direct relevance to the magnetic assemblies, and these are some of the features that exhibit with reference to these magnetic assemblies. Now with reference to the magnetic field, there is a technology for magnetic micro robots.

The key features of these magnetic micro robots include low cell toxicity, the ability to be remotely actuated and controlled, reconfigurable locomotion modes, a tunable structure, and morphological and chemical features that exhibit high maneuverability and long-term open-loop stability. So, from an application perspective, it has a structured construction with cells transporting a bioartificial substance, and it includes drug delivery and bacterial inactivation. In most cases, this has potential applications in biomedical-related domains, focusing more on cell transportation and targeted drug delivery. These are some of the key applications where these magnetic micro robots effectively play a vital role. So, from a mechanical perspective, we have a mechanical gripper in place.

Characteristics and applications of **optical fields, acoustic field, and other** technologies.

MICROROBOTICS

External field	Technology	Feature	Application
Optical field	Light	Stable optical matter arrays; hierarchically self-organize; g ather in aqueous media.	Electrodynamic interactions; photochemical micromotors; plasmonic antenna.
	Optical tweezers	No stiction; multicellular organism capture; automated recalibration routines; high efficiency; closed-loop control.	Structure construction; patterning; cell's recognition, isolation, assembly, transportation, deposition; cell-cell adhesion with hydrogels.
Acoustic field	Acoustic field	Close-loop; position offset compensation; hybrid servo force/position/visual feedback control; available for light microscope and SEM; multiple microgrippers and end-effectors.	Microparticles assembly and separation; synthetic nanomotors; Protein detection.

When a mechanical system comes into the picture, the system must be completely inspected. So, there should be a kind of in-situ monitoring in this system. So, that these in-situ monitoring will be helpful for us to monitor the overall performance of this gripper. So, either this in-situ monitoring can be done through a kind of image processing, or in certain cases lasers can be used to measure the displacement in such structures. Ideally, in these features, we have a closed-loop system; there is a position offset compensation in place, a hybrid force, a position, and a visual servo feedback control, which is exhibited here.

Basically, it is available for light microscopes and scanning electron microscopes; multiple microgrippers and end effectors can be efficiently used. As far as the application perspective point of view, it is used for MEMS assembly. It is also used for 2D and 3D pattern construction. So, these are some of the applications and the fields that are used.

Now, if we try to consider the optical field, we have discussed a lot about these optical tweezers.

So, as far as this technology is concerned, we have the light and then we have optical tweezers in place. When we try to consider the light, there are going to be stable optical matter arrays hierarchically self-organized and kind of trying to gather in an aqueous medium. So, from an application perspective, there is going to be a kind of electrodynamic interaction, a photochemical micromotor which exhibits, and then there is going to be a kind of plasmonic antenna which is going to exhibit here. When we try to look at the optical tweezer perspective, it is a kind of no-stick shunt system. It has the capability to capture a multicellular organism-based capturing system.

It also has a kind of capability for automated recalibration routines, and it has high efficiency and a closed-loop control. As far as the application's perspective point of view, it has a structured construction and a kind of structured patterning. It has a kind of cell recognition and isolation assembly, transportation, deposition, and cell-to-cell adhesion with the hydrogen. So, these are some of the key applications from the perspective of the optical field. As far as the acoustic field perspective point of view, which we had already discussed in detail, regarding a kind of acoustic-based manipulation.

In the case of an acoustic field, we have features that include the closed loop and the position offset compensation, which is considered to be a part of this closed loop for appropriate deviation in the displacement. Then, there is going to be a kind of hybrid servo force or portion, and the visual feedback control will also participate; certain amounts of light microscopes, multiple micro grippers, and end effectors are considered to be some of the key features. From an application perspective, the assembly and separation of these microparticles, along with a synthetic motor and protein deductions, are considered to be key applications. So, ideally, if you look at this, these regions are more focused on bio.

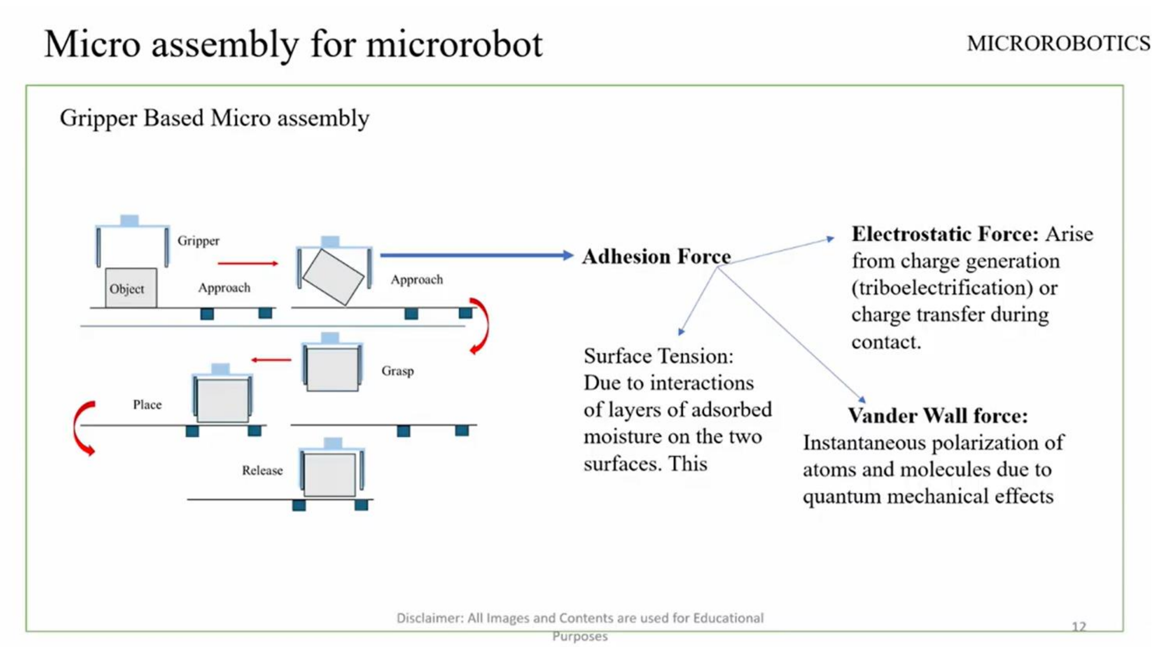
Characteristics and applications of **optical fields, acoustic field, and other** technologies.

MICROROBOTICS

External field	Technology	Feature	Application
Acoustic field	directed self-assembly (DSA)	Water environment; orientation control; nonspherical particles; quantify and reduce position and orientation error.	3D printing material; nanoparticle assembly; structure construction.
	Ultrasound driven	Noncontact; design for weak substrates; underwater environment.	Manipulation of living cells and organisms; ultrasound-driven gripper; targeted drug delivery.
Others	Bubbles	Liquid environment; module posture control.	Multicellular microstructures build; microparts assembly.
	Water droplets	Capillary forces; low requirements on precision.	Cantilever structures build

However, these are for other domains. Now, with reference to the acoustic field perspective, there is one technology called directed self-assembly technology. So, as far as these directed self-assembly technologies are concerned, an appropriate magnetic field is induced to self-assemble for a specific application. It is more focused and oriented towards a specific application. From a features perspective, the water environment has a kind of orientation control, non-spherical particles, and most importantly, it quantifies and reduces the position and orientation error. From an application perspective, we have 3D printing of materials, nanoparticle assembly, and a kind of structured construction that exhibits.

In addition to this, when we try to look into the technology, we have a kind of ultrasound-driven base system. When we try to look into the features, we have a non-contact base, a design for a kind of weak substrate, and a kind of underwater environment. From an application perspective, the manipulation of living cells and organisms, ultrasound-driven grippers, and targeted drug delivery are considered to be some of the key applications of this. In addition to this, the bubble-based systems are there; then there are water droplet-based systems; bubble-based systems were discussed in the last module also. It is a kind of liquid environment, basically, it has a kind of module posture control, and it is a kind of multicellular microstructure built, and it is a kind of micropart assembly.



When we try to look into the water droplet, the capillary forces with low requirements on precision are considered to be one of the key features. Now, with reference to the application perspective point of view, the cantilever structures are built and appropriately oriented to this particular system. Now, let us see the overall fundamentals of this gripper-based microassembly. So, as far as this gripper-based microassembly is concerned, this is a simple gripper-based microassembly where there is a kind of object that is moving, and the overall orientation of the object is controlled by the gripper. Now, it can grasp; it can perform three operations: one is grasping, placing, and releasing.

Now, as far as the force that is involved in this, it is a kind of adhesion force that exists. So, within this adhesion force, let me just classify this adhesion force appropriately: one is a kind of electrostatic force which arises from charge generation, or a kind of triboelectrification, or a kind of charge transfer during contact. Then we have a Van der Waals force; it is a kind of instantaneous polarization of atoms and molecules due to quantum and mechanical effects. From a surface tension perspective, this surface tension is due to the interaction of layers of observed moisture on the two surfaces. So, these are some of the forces. So, we will discuss these forces in detail in the upcoming lectures.