Micro Robotics

Prof. Palani Iyamperumal Anand

Department of Mechanical Engineering

Indian Institute of Technology, Indore

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Lecture- lec41

Microsystems for Microrobots (Manipulation) - Module 01

Today we will discuss this microsystem for micro robots, focusing on manipulation-related applications and mechanisms. So, ideally, in the last module, we discussed most of the micro-engines, the micro pumps, and the different configurations of micro pumps. In the case of micro-engines, we had discussed this piezo-based system, thermal-based systems, and fluid-based systems. We also had some discussion about magnetic helical-based systems, etc. Now, the focus of this particular model will be on micro-manipulation. So that this micro manipulation can be effectively used for the movement of micro robots or to handle a certain amount of functionalities or products for a function-related application.

So, ideally, it is a kind of manipulation of the structure towards micro robotic systems. So, in this module, we will be discussing some of the key aspects where manipulation has taken a front seat to drive the micro robots for effective application. So, some of the manipulation methodologies ideally include acoustic manipulation and the atomic force microscope, which is used as a kind of micro and nano robot. So, we will discuss this in detail. Then we will also discuss micro manipulation in particle assembly. So, we will also have a detailed discussion about the 3D micro nano fibre pulley and how it is integrated as a nano tool carrier. So, we will also discuss some of the case studies relevant to this particular system. Now, as a first part, as far as these micromanipulations are concerned. So, the first fundamental of micromanipulation is in the form of particle assembly.

So, ideally, this micro-manipulation utilizes the domain of particle assembly to precisely arrange the microscopic particles to form a specific pattern or structure. So, either it might be a kind of periodic structure or it might be a kind of mechanism where we can have a kind of arrangement and through that we can deploy a particular solution or we can solve particular problems. For instance, there is a case study where the main focus is to remove the fat content inside. So, we have the host kind of arrangement. So, in this host, there is a kind of particle that is being collected over here.

So, we may need to remove this particle. One option is that we can align the micro-manipulated particle in terms of a grinding wheel so that this grinding wheel can be appropriately actuated to grind these kinds of particulates that are being collected in the tube. So, this manipulation it utilizes a different kind of controlling micro robots which manipulate the position of the particle using various physical interactions. So some of the physical interactions ideally include a magnetic field, light and acoustic interactions, and a mechanical interaction. Now, let us see some of the different strategies that are being deployed for such kinds of manipulation.

So, as far as this manipulation strategy is concerned, some of the key domains that are being effectively used are the magnetic field, the mechanical grippers, the optical field, and the acoustic field. Now, in this micromanipulation in part assembly and in particle assembly, when we try to consider the magnetic field, there are two different technologies that are being effectively used. One is called a magnetic field induced assembly, and the other one is called a magnetic assembly. So, in the case of a magnetic field induced assembly, some of the key features involve directional control, the nanoscale of the magnetic field, real-time tuning, high assembly efficiency, and long-range translational order. Similarly, in the case of magnetic assemblies, there is a kind of non-contact system that exhibits a reconfigurable formation.

It has a jamming-free assembly and is quite robust. From an application perspective, as far as these nanoparticles are concerned, it has a nanoparticle assembly, a one-dimensional anode, a two-dimensional monolayer, and a three-dimensional chiral assembly. It also has a type of polymer film and a type of mesoscale structure that is exhibited here. As far as applications are concerned, magnetic assemblies have a magnetic levitation limitation and a structural construction that are being effectively used for this or are effectively considered for this particular system. Now, if we closely observe, the other magnetic-based systems are concerned. So, there is a kind of magnetic assembly that exhibits basically; it is a type of jamming-free assembly. It has good error recovery, and it has a predictable orientation. So, ideally, when we try to apply a magnetic field appropriately, we can have a predictable orientation. From a technological perspective, it has magnetic micro-robots. So, when we try to look into the future, it has low toxicity and remote actuation and control.

It has a kind of reconfigurable locomotion mode. It has a tunable structure with morphological and chemical features. It has high maneuverability and long-term stability. As far as the application perspective is concerned, it has a structural construction, a quite good amount of self-transportation and drug delivery, and a form of bacterial inactivation that exists in these particular applications. Now, if we closely observe the overall advantage of this system, we find that it has a kind of biocompatible power supply.

When we look into the advantages, one of the key advantages of this magnetic actuation is that it has a biocompatible power supply and relatively reliable operability. It has strong penetration and a long action time. So, these are some of the advantages which such kind of magnetic systems exhibits. However, when we try to look into the limitations from a perspective point of view. Fabrication is considered to be one of the key challenges for such kinds of systems.

The second thing is, if you have a swarm of micro robots that are actuated by a magnetic field, it is quite easy to handle. However, individually controlling it—that is, selective control will be highly difficult in such kinds of systems. So this is one aspect that we may need to consider when we try to select a magnetic field. Then we have a kind of mechanical gripper. So as far as the perspective point of view of these mechanical grippers is concerned, some of the key features ideally involve a closed-loop system, a position with offset compensation, and then there is a kind of hybrid force with position and visual servo.

It also has a kind of feedback control that exhibits. Then there is a kind of availability of multiple grippers and end effectors that exhibits here. As far as the application perspective point of view, it has a kind of 2D and 3D pattern construction, which is considered to be one of the key applications of this particular system. Optical field-based manipulation is also considered to be one of the key aspects of this particular micro-manipulation. So, in this concern, if we observe like we have the kind of a different manipulation strategies which exhibits.

So, in the case of the optical field, we have the light, and when we try to look into this feature's perspective point of view, there are going to be stable optical matter arrays that exhibit. It is a kind of hierarchically self-organized particles, and the particles are gathered in an aqueous medium. From an application perspective, it has an electrodynamic interaction, a photochemical micromotor, and a plasmonic antenna that exhibits. With reference to technology and the optical teaser perspective point of view, we have a multicellular organism-based capture. It has automated recalibration, is highly efficient, and has closed-loop control.

And with reference to the application perspective point of view, we have structure construction, patterning, cell recognition, isolation assembly, and transportation, which are considered to be some of the key applications of this particular system. Now, another important aspect from a micro-manipulation perspective is the acoustic field. So, in the case of an acoustic field, we have a kind of ultrasound-driven system. It is highly used for a kind of underwater application from a perspective point of view. So, when we try to look into the applications, these applications are like manipulation of living cells and organisms, and it is a kind of ultrasound-driven gripper that is highly used for targeted drug delivery.

So, like that, we will be discussing this acoustic-based system in more detail. So before going into it. Let us discuss some of the other type of actuation mechanisms which exhibits and which are being effectively participating in this overall micro system related application especially on micro manipulation perspective point of view. So, in this regard, let us make a small comparison; apart from the magnetic system, we also have biological actuation. So, some of the key aspects of this biological actuation are that it has a kind of biocompatible power supply, and it has a combination of actuation and sensing capabilities. It is highly useful for, and naturally suitable for, psychological and physiological fluids. It is relatively efficient in such kinds of fluids. However, with reference to the limitation perspective point of view, it is more prone to a specific environment that will be fueling the micro robots. Next, when we try to look into the perspective of chemical actuation, it has a fast actuation speed. So, it uses a kind of biocompatible fluid like urea, glucose, and H2O, focusing more on self-porotic propulsion.

Some of the limitations from a perspective point of view include a high risk of in vivo cross-reactivity; insufficient propulsion accuracy, a short action time, and a lack of instantaneous feedback. So, these are some of the key limitations from the perspective of chemical actuation. Let us discuss the acoustic perspective point of view when we discuss in more detail with reference to the acoustic system. So, let us see some of the different configurations of these acoustic systems. So, the acoustic system, as far as acoustic-based manipulation is concerned, is ideally because of a kind of bubble formation, as the name suggests.

So, these bubble formations, like it, have an impact on manipulating either the product or the micro robot based on the different needs. So, when we try to look into the overall configurations, there are different generations or different sources of this bubble formation. So, one of the sources of bubble formation can either be through chemical reactions or through a chemical reaction in a particular environment. In certain cases, we can also use a kind of optothermal effect. Through an optothermal effect, when we try to focus a beam in a particular medium where bubbles can be generated, it might also occur through direct acquisition.

And in certain cases, we can also use a kind of acoustic oscillation to generate certain amounts of bubbles, and then there is a technology called electro-wetting dielectric technology that is being effectively used for Generating such bubbles requires a generator; through a catalytic reaction, it is also possible, which has an impact on the chemical reaction. Then we have a kind of acoustic oscillation where, through a certain number of mechanically stable acoustic oscillators, bubbles can be generated that can be effectively used for a certain level of accuracy. Now, when we try to look into some of the key domains of such kinds of bubble generation in robotics. So, one is with reference to a kind of bubble-based micro robot, where the micro robot system itself will have a kind of bubble-based actuation. So, by appropriately generating the microbubbles, there will be a kind of propulsion mechanism that exhibits.

Second is through a kind of generation and control, where we can generate a bubble and then appropriately orient the micro-robot in that orientation. So that the moment can be appropriately displaced and effectively controlled. Second, the next important aspect is the kind of bubble micromanipulator. So, the main function of this bubble micromanipulator is something like this: for example, if I want to, if there is a kind of domain that exhibits over here and there is a kind of debris that is available. So, if I try to manipulate this debris, I can generate continuous bubbles, and through these bubbles, there will be a kind of dispersion which happens; a pressure that tries to come out of it.

Through this pressure, the debris will try to move, or the debris will try to be manipulated, okay. Now, these are some of the operations which exhibit a kind of micro-manipulation in a particular environment. The most important aspects with reference to these bubble-based systems are that a kind of bubble propulsion is effectively used for different acoustic-based systems. So, when we try to investigate bubble propulsion, the operation is ideally through a kind of microfluidic operation. So, in the case of a kind of acoustic-based micromotor that is efficiently used for microsurgery, there is a kind of sharp-edge system.

For example, an acoustic-based sharp-edge system is highly used for targeted drug delivery, and in addition to this, there are two other modes. So, one mode takes care of the particle separation, and the other modes take care of the self-assembly. So, in simple terms, if this is going to be a kind of acoustic micro-robot, we have bubble propulsion, an in-situ micro-motor, and a sharpened system. So, this bubble propulsion will come under the microfluidic domain. This (in-situ micro-motor) will come under the micro-surgery domain, and this (sharpened system) will come under the targeted drug delivery domain.

Now, let us see some of the different configurations of these micro-robots, as well as the acoustic manipulated perspective point of view, especially focusing on the bubble proportion. So when we closely observe the working principle of the system, the vibration is excited by the acoustic field which reaches a kind of resonant frequency of the bubble. So, these bubbles vibrate outward and inward, and the liquid in the device will be discharged and sucked based on the kind of pressure difference or with reference to the bubble manipulation or the bubble propulsion. When we try to closely observe the flow pattern from a perspective point of view. So, the flow pattern generates a source of net momentum to drive the force that pushes the entire device forward.

So, the acoustic waves can provide powerful propulsion forces and acoustic excite the bubble, producing high streaming forces. So, if we try to investigate the overall construction of the system. So, this is a kind of bubble column that is available; this is going to be propulsion, and this is going to generate flow. So, through a generated flow, this is going to be a bubble column. So, these bubbles are generated by different modes, such as the photo-thermal effect, catalytic base, etc. So, these are the different sources through which bubbles will be generated, and through the generation, there is going to be a flow that will try to come out of it, and then there is a kind of forward propulsion that exhibits over here. So, the speed of this system can go in the range of 45 mm per second, and the overall propulsion force exerted will be in the order of 6 micronewtons. Now, let us see some of the case studies where there is a kind of acoustic actuated micro robot wave bubble propulsion system. If we closely observe this, it is called an armored microbubble system. So, in this armored micro bubble system, we have a transducer in place, a kind of water medium, and the PDMS structure that is available.

To have a kind of actuator, there is a saltwater and bead arrangement that is exhibited here. In this case, the vibration of the bubble interface under the ultrasonic force results in a strong acoustic streaming jet of passive particles suspended in the fluid and is seen flowing from the back and sides of the fixed armored micro bubble towards their opening before being pushed forward away from the AMB. So, as far as this case is concerned, the fluid jet is directed away from this armored micro bubble, and basically, these armored micro bubbles provide the basis for a propulsion mechanism and give the order of magnitude of the velocity for a free-swimming device. So, ideally, this is a kind of arrangement that is exhibited here.

So, this is a kind of insert image. So, where there is water and the particle that is available, by using a kind of transducer, these transducers will excite and create a propulsion mechanism; ideally, a bubble will be generated. So, these bubbles will try to align these beads in a particular fashion, and because of the movement of the beads, we can expect a kind of propulsion mechanism, and this overall propulsion mechanism will have an impact on the magnitude and the velocity. So, ideally, these transducers will act as a source for generating or orienting these bubbles in a particular direction, which will take care of the magnitude and velocity for appropriate propulsion. So, this kind of configuration is called an armored micro bubble configuration. So, this is a kind of bubble-based micromanipulation.

So as far as this bubble-based micromanipulation is concerned, we have a kind of electrowetting on the dielectric. So here, if we closely observe this system, there is going to be a piezoelectric actuator. Over this piezoelectric actuator, we have electrowetting electrodes and then there is a dielectric layer that is available. Then, we have a kind of micro-object where there are bubbles that are kept, and there is a hydrophobic layer and a liquid medium available. There is a kind of top ITO glass plate that is being placed.

Now, what is happening is that this is a kind of ideal state. In this ideal state, the piezoelectric actuator is off, and now, when we try to switch on the piezoelectric actuator, there is going to be an oscillation that exhibits. which will try to have control over the micro-object that is available here. So, ideally, the micro-object will take up a kind of micro-manipulation stage, and then there is a kind of piezoelectric actuator that is on. So, that like on and off will be highly helpful to generate a kind of bubble which will be generated, and this will be helpful for appropriate manipulation.

So, ideally, this is an electro-wetting on dielectric system. The principle behind this particular system is that even though a bubble is generated, the mechanism of proper manipulation is determined by this mode, where we have a kind of electro-wetting on the dielectric system. The contact angle between the droplet and the dielectric layer is changed; it can be used to manipulate the generation, transportation, mixing, and splitting of droplets. So, when an electric voltage V is applied between the aqueous sessile droplet and the electrode, the droplet spontaneously spreads out on the dielectric surface, and the contact angle is modulated by the applied voltage, which is exhibited over here. So, the overall magnitude, overall frequency, and overall displacement are completely taken care of by this electrowetting behavior as well as the electric voltage applied to these piezoelectric structures.

Now, this is a kind of bubble-based propulsion mechanism. So, in this bubble-based propulsion mechanism, we have two different mechanisms: one is called the dispersion-based mechanism, and the other one is called the aggregation-based mechanism. So, the aggregation-based mechanism is aimed at manipulating a particular region; the dispersion-based mechanism is something like dispersing the particles in a kind of cloud in a kind of environment. So, in both these cases, there is a need to go for a kind of source to generate a bubble. So, one is through a kind of sono electrode that is basically meant to enable a dual swimming mode, which includes both dispersion and aggregation that are exhibited in this system.

So overall in today's lecture, we discussed the different types of micromanipulations that are exhibited. So we had discussed the different configurations of micromanipulation strategies like magnetic field, mechanical gripper, optical field, and acoustic field-based systems. So, we had individually discussed different manipulations of particle sub-assemblies, which include the magnetic field-induced assembly, the magnetic assembly, the overall features of magnetic assemblies, and magnetic microrobots. So, we had also discussed these grippers and the overall features of these grippers. We had also discussed this application of the optical field. So, with reference to this application field, what are the different features and characteristics that are employed? Acoustic field, and we had also discussed this concept called direct self-assembly, which is more meant for a certain amount of non-spherical particles with suitable applications. And then, there is an ultrasound-driven system which is basically a kind of acoustic field. We have discussed a lot about this acoustic field-based system. We also had a discussion about the other type of actuation, ideally a kind of biological actuation or a chemical actuation. The overall advantages involved in this biological actuation and the overall aspects involved in chemical actuations.

We also discussed some of the limitations related to this actuation. Now, since we have discussed this acoustic-based actuation, let us discuss the advantages and limitations of this acoustic-based actuation. So, in the case of acoustic-based actuation, one of the major advantages is that it has a kind of biocompatible power supply. The second important advantage is that it has the capability to control a micro robot deep inside the body. And third, with reference to the flexibility perspective, it has high flexibility, low power consumption, and good long-term action.

With reference to the limitations, a perspective point of view is required; there is a need to have proper instrumentation for in vivo use, and one of the key challenges is that the material and design requirements, especially from a micro-robotic perspective, are relatively strict. So, these are some of the key limitations with reference to an acoustically based system. So, in the next class, we will discuss an AFM, the overall principles of an AFM (atomic force microscope), and how it is effectively used for micro-robotic related applications.