Microrobotics

Prof. Palani Iyamperumal Anand

Department of Mechanical Engineering

Indian Institute of Technology, Indore

Week- 1

Lecture No- 01

Micro Robotics Overview

Hi, I am Professor Palani Iyamperumal Anand from the Department of Mechanical Engineering, Indian Institute of Technology, Indore, Madhya Pradesh. So I will be handling this lecture on micro-robotics. As far as micro-robotics is concerned, micro-robotics is an interdisciplinary field that focuses on the design, development, and application of robots and robotic systems at micro-scale levels. These robots are typically smaller than one millimeter in size and are designed to perform tasks that are often too small, complex, or delicate for traditional robots. This field basically combines principles from robotics engineering, biology, physics, and material science to create systems capable of interacting with the environment at the micro and nano scale. Ideally, these kinds of micro robots are in the range of around 10 microns to less than 1 micron.

So wherever we have such applications where working in intricate areas is necessary, these robots can be efficiently employed for different functional aspects. On a larger scale, there are wide varieties of robots having their own potential applications in different fields. Now, the major challenge involved in developing such micro robotic systems is that we ideally need to scale down these robots and deploy appropriate actuators, appropriate sensors, and an appropriate control system for this environment. If we see the overall application of these micro-robotic systems, they are efficiently deployed in the medical field.

For instance, first let us talk about the drug delivery system. In the case of a drug delivery system, micro-robotics can be used to deliver drugs directly to the targeted tissues so that they minimize the side effects, improving the treatment efficiency. There are quite a good number of lectures as well as case studies where people have employed micro robots for cancer treatment and other therapy-related applications. The second important application with reference to the medical field using micro robotic systems is minimal invasive surgery, where micro robotics can be employed for precise surgeries inside the human body, navigating through blood cells or organs for minimal disruptions, so that the creation of marks or scars can be completely eliminated and the targeted regions can be appropriately addressed. The third important aspect is with respect to diagnostics.

The micro-robots could be used to collect biological samples or monitor internal health conditions at microscopic levels. With reference to the environmental perspective, these kinds of micro robotic systems are used for pollution detection. For example, here in this picture, it talks about micro drones that are developed by one of the universities for monitoring water and air quality by collecting samples and detecting the presence of pollutants. The second point is with reference to the oceanographic perspective. Small-sized robots can explore underwater environments and gather data in places that are too hazardous or inaccessible for larger robots and have potential applications towards different functional levels.

The first kind in this case is a micro drone, and the second kind is a swarm of micro robots which are used for pollution reduction as well as underwater environmental analysis. There are certain self-assembled drones readily available for such applications. Now, when we talk about other applications of micro-robotic systems, there is a need for manufacturing and assembly. In the case of micro-scale assembly, the micro-robots could be used to assemble small-scale electronic components or other delicate structures at a scale beyond human ability. For instance, if we need to assemble microchips or micro-manipulation needs to be applied, it will require microscale assemblies that can be efficiently employed. Basically, wherever we talk about microelectronic systems or microsensors, integrations, etc., these kinds of systems can be efficiently employed. There is another important point, i.e., precision handling.

The micro-robots also hold great applications in inspection and fine-tuning windows. For example, consider the case of an atomic force microscope (AFM) that uses micro-manipulators for its functioning. The AFM setup has a cantilever in place, and the cantilever takes care of the tunneling effect, as well as the impact of the tunneling; its characteristics need to be appropriately studied, and the system needs improved integration that caters to these functionalities; hence, micro robotic systems can be deployed for such applications. In biological research, particularly in terms of cell manipulations, these micro robots can be used for precise operations such as moving an individual cell, manipulating a biological sample, or even interacting with DNA at the molecular level. Further, in defense and strategy-related applications, these kinds of miniature robots can be used to take care of difficult locations as well as for the surveillance of challenging and hidden areas.

In certain cases, these disarmaments can also be deployed using micro robots, which can be used for diffusing the bombs as well as for inspecting dangerous environments. Nowadays there is a great discussion about drone and anti-drone capabilities. In all those conditions, micro robots have potential applications in different fields. The key aspects of a micro robotic system, i.e., miniaturizing these robots, are challenging tasks. For example, a simple pick-and-place operation robot is designed for specific materials with specific dimensions so that it can handle specific materials at varying payloads. Appropriately, the sensors are designed and integrated for them to work in a controlled environment, either in an open-loop environment or a closed-loop environment, based on the applications for which they are intended. On a macro level, we have certain amounts of laws that are governed, or there are certain amounts of design parameters. Based on these design parameters, we try to design the actuators or the sensors based on our requirements.

When reduced to the micro scale or further below, scaling needs to be appropriately taken into consideration to address the requirements and characteristics. Ideally, when taking a sensor, an actuator, or a power system used on a macro level appropriately, we may need to use these sensors or actuators and scale down the sensors and actuators appropriately for efficient usage in the micro robotic system. For instance, the conventionally available robotic system uses relatively large motors and batteries; however, micro-scale robots would require an appropriate reduction in the motors and energy systems that can be efficiently used and deployed on micro-scale systems. The second point is with reference to the actuation and the power. So we are all aware of the actuator.

An actuator is basically a system that provides displacement. There are a wide variety of actuators classified based on their domains. In the case of an actuator, we have the mechanical actuator, electromechanical actuator, pneumatic actuator, and hydraulic actuator. We also have a smart material-based actuator. An engine is a mechanical actuator, whereas a motor is an electromechanical actuator. There are different types of motors, which include stepper motors and servomotors. Whenever we use a fluid power system or utilize fluid power to attain a certain amount of actuation, we ideally use a pneumatic and a hydraulic system. A pneumatic system uses compressed air for its functioning, whereas hydraulic systems use pressurized liquid to create actuation. As far as smart materials are concerned, they have potential applications in a wide variety of different micro-robotics as well as smart systems. There are wide varieties of smart material-based actuators which include shape memory alloys, piezoelectric materials, and magnetostrictive structures.

So these are a certain amount of smart material-based actuators that are available, and these smart material-based actuators have potential applications in different micro robotics as well as smart system-based development. So here, from our micro robotic perspective, we will be discussing more about these smart material-based actuators since they are quite efficient in handling some of the key functionalities and applications we discussed in the earlier slide. When we talk about control and sensing capability, it is due to the small size and complex environment that controlling micro robots presents a unique challenge; hence, micro robots often need to be controlled remotely using an external field like magnetic, electric, or optical fields. Moreover, the small size makes it difficult to integrate with the sensor; hence, they often require sophisticated feedback to ensure precision. For instance, therapeutic applications for cancer treatment are performed by applying an electrical source. However, future technologies will focus on cancer treatments using micro robots for targeted attacks on cancer cells. These are some simple examples where we can deploy such smart systems for micro robotic applications. Next, when we discuss propulsion and design in robotic systems, any robotic system would require propulsion for its intended applications; hence, propulsion plays a vital role in this context. The selection of propulsion is based on different functionalities as well as different applications. For example, navigating at the microscale requires overcoming challenges such as fluid dynamics and limited propulsion methods.

These micro-robots may rely on simple movements such as swimming through a liquid or crawling on surfaces and are even used in biochemical signals to sense their surroundings. So the material used in micro-robotic systems needs to be lightweight. It should be durable and capable of operating in challenging environments. For example, in the case of biocompatible materials, it is crucial for medical applications where micro robotics may need to interact with human tissues. Ideally, the propulsion and design of these micro robotic systems basically depend upon the functionality of the selected system. If we closely work on propulsion, the design is an important parameter, i.e., whether it consists of lightweight or flexible structures or insulated structures for electrically insulating purposes. In certain cases, the surfaces may be hydrophilic or hydrophobic structures. Therefore, based on the application or the characteristics, we can deploy these structures for our environment.

To understand the propulsion design, we must have better clarity on the micro mechanics of the system, and we should also have better clarity on the material selection. In fact, we should have wide exposure to micro fabrication of these structures so that efficient micro fabrication will be helpful for us to design the robot and deploy it based on the different functionalities as well as the different domains. This is a 12-week course where the first part of the course, i.e., the first module, will focus on the scaling laws of designing a micro robot. Ideally, on a macro level, we have sets of actuators and sensors in place, and these sensors and actuators are integrated appropriately, and appropriate control strategies have also been integrated. On a micro level, there is an external environment that participates; for instance, from a macro robot to a micro robot, let us consider a bigger Automated Guided Vehicle (AGV) to a smaller micro robot that passes through a tube. The body will automatically be exposed to the air resistance. So, in order to understand the overall fundamentals behind this particular process, there is a need to understand the scaling laws that are involved in different processes, which include fluid dynamics, electromagnetism, thermodynamics, optics, and quantum effects for the fundamentals of micro robotic systems. So, ideally, we will be discussing rigid body dynamics.

We will be discussing a mass, a volume, and then we will also be discussing other important key aspects including electrostatic force, electromagnetic force, thermodynamic force, etc. How it is scaled down and how it is considered for designing a robot, or what parameters are involved in designing this robot for a particular application. As far as the micro mechanics perspective is concerned, micro mechanics design and selection of materials for micro robotic systems and the control of surface workers will be investigated; we will also examine the micro mechanics behavior, the different types of materials involved, and the various characteristics of the materials for micro robotic systems and the overall aspects of the control of surface workers. A contact-based system and the function of contact-based systems being established and how they are being implemented will be discussed. Then, with respect to the microfabrication perspective, the major challenge exists regarding microfabrication, so let us explore some of the different types of microfabrication techniques that are being employed for micro robots.

We will try to expose you to the different microfabrication techniques, including the bottom-up and top-down approaches, as well as the various laser-based processes that are directly relevant to the microfabrication of microstructures for micro-robotic related applications. Then in micro actuation and micro manipulation, there are two modules that we will be covering in week 4 and week 5. In the case of micro actuation and micromanipulation, module 1, we will be discussing more about magnetic actuation, electrostatic actuation, and piezoelectric actuation in detail. Whereas in the following module, we will be discussing shape memory alloys, which are a class of smart materials. We will also discuss the influence of conducting polymer-based actuation, stick-slip, and comb-based actuators, for instance. Then in week 6, we will be discussing microsensors and micro transducers and their fundamentals. Especially, we will be discussing the optomechatronic system design, optical displacement sensors, sensors based on light, intensity modulation, and interferometry for micro sensing applications. The influence of optical fibers on the development of these microsensors will be discussed in detail, including the fundamentals as well as the applications. So, these are the different plans for the entire 6 weeks. In the next 6 weeks, we will be focusing on the key micro sensors and micro transducers.

Basically, like in module 4, peak 7, we will be focusing on the gyroscopic accelerometers, different configurations of gyroscopic accelerometers, different types of gyroscopic accelerometers, and the usage of these accelerometers for different micro-robotic related applications. So we will also discuss the mechanical switches, flow transducers, the haptic interface, and the sensory skin for robotic systems. In week 8, we will discuss the micro system for micro robots; basically, we will try to look into how these micro actuators and micro sensors are integrated for different micro systems that have direct relevance to micro robotic applications. Some of the micro systems include micro pumps, micro engines, magnetic helical micro machines, and micro machines, and some of the case studies are relevant to the topic. In week 9, we will be discussing module 5, which is the microsystem for micro-robotics part 2, where we will discuss the manipulation-related aspects.

Basically, the atomic force microscope as a micro and nano robot, micro-manipulation of particles, and assembling, along with 3D micro and nano fiber pulling integrated with nano tool carriers and case studies, will be discussed in this particular aspect, focusing mainly on manipulation-related applications. In Module 5, we will discuss micro systems for micro robots, especially focusing on integrated systems like micro assembly, micro air vehicles, multi-robot systems, and different case studies that are involved. In week 11, we will be discussing bio-inspired robots. Let us discuss the micro-scale propulsion, locomotion, and liquid modeling of propulsion systems, a micro-mechanical flying instinct, and some relevant case studies. These are some of the proven bio-inspired micro-robots that are efficiently used for different applications.

So, we will look into the overall micro-actuation principles involved, the micro-sensing principles involved, and the micro-based integration involved, in detail in this particular model of bio-inspired micro-robots. Module 6, Week 12 will be related to a gecko-inspired climbing robot, a bio-inspired fibrillar adhesive lizard-inspired water runner robot, a water strider-inspired water walker robot, and a magnetic swimming micro-robot for biomedical applications. A medical micro robot for endoscopy and other applications will be discussed. So, each case study will be analyzed, and the overall propulsion mechanism involved and the other sub-micro systems involved will be investigated and appropriately discussed during the class. So, overall the course comprises 2 hours and 30 minutes of lecture every week, which includes 2 hours of lecture and 30 minutes that may be a tutorial, demonstration, or case study that can be discussed.

I have a pool of people who are working under me as TAs for this particular course, and they will be involved in demonstrations, tutorials, and case studies, and they have been involved in preparing these course materials. Thank you. We will meet in the next class on module 1.