Micro Robotics

Prof. Palani Iyamperumal Anand

Department of Mechanical Engineering

Indian Institute of Technology Indore

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Lecture-51

Bio Inspired Micro Robots (Propulsion and Locomotion) - Module 01

We have been discussing this biomimicking robot; this is the last model that I have discussed. We had discussed the various functionalities related to these bio-inspired micro robots, especially focusing more on the locomotion-related aspects. We have been discussing the mechanisms related to flagella for Microrobotics applications and how these are being applied. Also, we have discussed some of the different key functionalities with reference to this locomotion mechanism, which includes a flagella-based system. The cilia movement, insect-like walking and jumping, jellyfish, and soft body-based notions are being exhibited. Then we discussed sensory perception. So, it basically talks about the compound eyes, electroreception, and tactile sensing, which are being deployed. We also had some discussions about the energy and related actuation. We have focused on this gecko-inspired climbing robot. We have discussed this micro- and nano-scale gecko-inspired system, the gecko-inspired climbing robots, and the overall functionality.

Now, let us discuss the different mechanisms that are involved in this gecko-inspired climbing robot. So, as far as gecko-inspired climbing robots are concerned, if you try to look into the functionality of this gecko-inspired climbing robot, these robots can operate on a kind of vertically oriented surface, which allows the possibility of tasking. So, if we closely observe the kind of adhesion mechanism that is being deployed. There is a wide variety of researchers who have discussed or who have studied this adhesion mechanism. Most of the common types of mechanisms in adhesion are suction adhesion, where the robot carries an on-board pump or creates a kind of vacuum inside the cup, which is pressed against the wall or ceiling. This type of suction mechanism has a major drawback. The suction adhesion mechanism requires time to develop enough vacuum to generate sufficient adhesion force. So, this may reduce the speed at which the robot can locomote. Another issue associated with the suction adhesion is that any gap in the seal can cause the robot to fall. This is considered to be one of the key drawbacks of this system.

This drawback limits the suction and adhesion mechanism to relatively smooth, non-porous, and non-cracked surfaces. The suction adhesion mechanism relies on ambient pressure to stick to the wall; therefore, it is not useful in space applications, as the ambient pressure in space is essentially zero. So another common type of adhesion mechanism is magnetic adhesion. The magnetic adhesions have been implemented in a wall-climbing robot for specific applications, such as nuclear facility inspection. In specific areas where the surface allows, magnetic attachment can be highly desirable for its inherent reliability.

Despite that, magnetic attachment in a specific environment where the surface is ferromagnetic is often an unsuitable choice. In fact, many researchers have designed such suction mechanisms, like unconventional attachments, which are inspired by climbing. Therefore, new strategies can be developed for use in a climbing robot. In fact, many animals have the desirable ability to stick to various surfaces, like insect beetles, anoles, frogs, and geckos, which have been studied to understand the mechanisms, especially with respect to their sticking capabilities. When we try to investigate these geckos, they are most interesting because of their size. So let us consider a gecko called the Tokay gecko. These Tokay geckos weigh up to 300 grams, and they reach a length of up to 35 centimeters. Yet they are still able to run inverted and cling to the smooth wall. By studying and imitating the attachment mechanism of this gecko, a new generation of robots can be developed, making locomotion possible on almost any kind of surface without contaminating the environment. When we try to investigate the different types of adhesion mechanisms, one mechanism is called dry adhesion.

The other types of mechanisms are called dry elastomeric adhesion, electrostatic adhesion, and thermoplastic adhesion. Let us discuss one by one the mechanisms that are involved in this adhesion process. The dry adhesions work on the principle of the van der Waals force. Now we will try to closely observe how these geckos work with reference to dry adhesion. These geckos' feet are covered with millions of microscopic hair-like structures, which are called setae. We had discussed it earlier. Each seta branches into 100 nanometer-sized spatulae. We have seen the structure where a microfiber and a nanofiber are integrated in this region, and there is an increase in the contact area. These spatulae interact with the surface via Van der Waals forces, which are weak but cumulative when applied across millions of spatulae, resulting in strong adhesion. So, the adhesion is directional, which means it can be turned on or off by adjusting the contact angle.

From a mimicking perspective, these synthetic gecko adhesives are made by using materials like PDMS and carbon nanotubes to replicate the nanoscale and the adhesion effect. So, these materials are structured hierarchically from the micro to the nanoscale to mimic a natural gecko adhesion process. So, by designing the footpad with controllable orientations, the robot can grip and release the surface on demand. Suppose it is trying to fit onto a surface so that it can hold and create a suction. This suction can hold the complete payload, and it will loosen by releasing the suction. Alternatively, given the suction mechanism, climbing can be appropriately initiated. Now, a schematic representation of a climbing robot shows where gravitational force works in a particular orientation. So, there is a first adhesive foot, a second adhesive foot, a vertical structure, and a tail structure in force. The suction mechanism will alternate between the first adhesive foot and the second adhesive foot. So, there is a contact under separation that exists.

This contact separation will be helpful for this robot to climb against the gravitational force, and it will be helpful for the system, as the structure pulls the tail towards a particular direction. So, this is a simple schematic representation of the structure. Now, let us discuss the models involved in the gecko-inspired climbing robot. These models basically explain the design requirements. There is a structure where a certain number of distinct microstructures exist in the form of an adhesive. So here, based on the suction mechanism, if you try to rotate, there will be different forces exhibited. The result of these forces is the outcome that is represented here. There are different suction cups that are being placed. These are a kind of micro suction cup. These micro suction cups will try to interact with the surface, and then they will try to induce a kind of suction, and from the suction, we can observe the overall moment or the overall resultant force.

Now, let us discuss this model, which is involved in this gecko-like arrangement. It is a proposed model where there is a rigid tile arrangement. Then there are a kind of compliance support and a tile tender available. So, this is a structure where a pressurized sack and a pressurized plate are available. This pressurized plate is designed to move back and forth. When this plate moves back and forth, we have a pulley-like arrangement, and then we have a main tendon-like arrangement. Therefore, there is a rigid tile and a complex compliance structure that is available. So, the movement of these pressurized sacs is appropriately transferred to the compliance structure, and the movement of the compliance creates a kind of adhesion mechanism. The overall mechanism is controlled by the pulley and the main tendon, so appropriate movements are monitored. This compliance structure is slightly flexible so that it can create a kind of pull-and-push arrangement.

These rigid tiles are kind of a support that would be involved in the movement in a climbing fashion. Now let us discuss the next-level mechanism called an elastomeric mechanism. The elastomeric mechanism is like it has a two-layer structure. So there is a base and an elastomeric attachment. Let us consider this as a soft flat elastomer with a radius A and thickness T. So, there is a kind of Wittler flux elastomer which is noted as E, and it is mainly meant to create a kind of smooth surface S. So, when a compressive load sigma c is applied, the attachment of the Wittler flux elastomer to a rough surface y with an amplitude h and the roughness and the wavelength lambda. So, the detachment process of this vitreous elastomer forms a smooth surface when a tensile force, Fp, is applied. So, this detachment possesses the vitreous elastomer from a rough surface when a tensile force, Fp, is applied. So, we are trying to apply an attachment and a detachment process with these Wittler flux elastomers so that there will be a kind of elastomeric adhesion exhibited.

These elastomeric adhesives will be helpful for appropriate movement in the system. So, if we closely observe the different parameters that affect this system, one is the thickness, another is the wavelength, and then there is the amplitude; it also depends on the force applied to it, noted as Fp. Now let us take the other mechanism, which is called electrostatic adhesion. So, as far as the electrostatic adhesion is concerned, we are aware of this comb drive actuator. So almost here, it also works on the same principle. So, it has a kind of hybrid adhesive anchor that is being kept over here. So here, if you closely observe the metal process, the fabricated process of the fabricated hybrid adhesive anchor. A metal is deposited, giving the required electrode shape on the substrate, which constitutes section 1, section 2, and section 3. So, a layer of PE and film over the positive electrode acts as a kind of insulator. These put this gecko-inspired adhesive on the front surface, finishing the adhesive pad, which consists of 4 and 5.

So, the fabrication of this full anchor is achieved by employing a kind of foam-backed magnesium bracket, which is shown here as 6 and 7. So, what happens is that we have a mechanism, and then there are a 4 and a 5 placed over here. So, which is a kind of adhesive pad that is helpful for an interaction to create a kind of electrostatic structure. Now let us discuss the third mechanism, which we call thermoplastic adhesion. So as far as thermoplastic adhesion structures are concerned, if you closely observe, there are certain amounts of pellets available.

So, these are called thermoplastic elastomers, which are formed by thermocompression molding. So, these thermoplastic elastomers lie on a glass slide that is melted using slide pressure, which forms a kind of TPE melt, and the silicon mold is placed on the single SESB TPE melt with the desired force. So, the silicon mold and the glass slide are removed from the hot plate, and they are allowed to cool; later, the TPE adhesive fibers are formed. So, as far as this case is concerned. So, we have a TPE pellet in place, and then there is a glass slide with a hot plate, and the TPE pellet will be capable enough that when a force is exerted appropriately, we get a single TPE melt.

Now, when you try to apply uniform pressure on this, which is in the form of a single silicon mold, the silicon mold will take a shape that is a kind of TP adhesive fiber. So these kinds of structures are deployed for appropriate adhesion or for appropriate locomotion. So, these are called thermoplastic adhesion. Now let us discuss the locomotion mechanism of this gecko-inspired lobe. So, as far as when we try to closely observe the locomotion mechanism to climb effectively, this robot must distribute its weight, control movement, and detach its feet without slipping. So, various locomotion strategies are included. One of the locomotion strategies includes leg climbing. So as far as this leg climbing is concerned, there is going to be a kind of gecko-like movement, which uses four or more legs to distribute its weight. It also has a kind of foot pad, which is designed to apply and release the adhesion in a controlled sequence. It mimics the gecko gait cycle, where at least two feet are always in contact.

So let us consider that there are 4 feet; 2 feet will be in contact, and 2 feet will be helpful for propulsion. So appropriately, there will be a release in the suction, and then there will be a kind of forward displacement that can be observed over here. Now, let us talk about rolling and sliding motion. So, in the case of rolling and sliding motion, instead of legs, some robots use continuous tracks coated with gecko-inspired adhesive. So, these rolling mechanisms allow for a smooth hard action and detachment as the robot moves, and they are used where rapid climbing is needed. So, in this case, the rolling mechanism allows for smooth adhesion, and then there is going to be a detachment that will appear over here. When we try to talk about the suction-type gecko hybrid climbing, some robots combine these gecko-inspired adhesives with suction mechanisms. For improved grip on rough or curved surfaces. So, when we have a suction mechanism that is going to be exhibited here, there will be an improved grip that we can observe in the suction gripping mechanism. Let us discuss some of the commonly used Gecko-inspired materials for such kinds of adhesive fabrication.

The first adhesive effectively used is a PDMS structure. These PDMS structures have the advantage of high elasticity, easy curing, and being cheaper. However, it has low productivity and a bending problem. From an application perspective, it is mainly meant for a certain number of wall-climbing robots, etc. With reference to the PMMI perspective, it has high mechanical strength and easy applications. The major disadvantage is that it is brittle and is widely used for a kind of climbing robot, as well as for grippers. From PS's perspective, it has a high aspect ratio, low surface energy, and limitations in accurate replication, and it is mainly meant for certain types of medical adhesives. It also provides similar mechanical properties to those of KECO in terms of low environmental sensitivity, and it is complex to prepare; however, it is widely used for different robotic applications. As far as PE is concerned, it has a high aspect ratio, low surface energy, and good biomedical applications. As far as PPE is concerned, it also has a high aspect ratio and a low surface energy. It is widely used for climbing device-related applications. With reference to PU, which is polyurethane, it has a high surface energy. It has a long curing time, and it has a leg dropper. With reference to the silicon perspective, it is easily available and durable with high quality.

Besides, it has poor clarity and space equipment. From the CNT perspective, it has a high mechanical modulus and high aspect ratio, but it is complicated, costly, and a highly preloaded structure. From an application perspective, it is mainly meant for different health care monitoring-related applications, which are some of the key applications of the system. So, if we closely observe, these are some kinds of wide varieties of adhesive-based materials that are used for fabrication. The selection of these materials depends on the type of mechanism that is deployed and the appropriate applications. Now, let us see some of the applications of this gecko-inspired climbing robot.

These gecko-inspired climbing robots are used for inspection and maintenance. Climbing robots for inspecting buildings, bridges, wind turbines, and spacecraft are some of the key applications of this kind of climbing robot. Sometimes it is used for search and rescue operations; that is the robot that climbs the collapsed structures to locate survivors. It can be used for surveillance, and it can be used for identifying a particular person. It can be integrated with a camera for a kind of face recognition system that can also be deployed in this structure. It has a potential application in medicine. Wherever there is a need for a miniaturized climbing robot for endoscopic procedures inside the human body, it can be easily deployed using these kinds of structures. It also has a potential application in space exploration. NASA has tested a gecko-inspired addition for a robotic arm and for a type of zero-gravity climbing robot, where such space explorations are conducted. For military and surveillance, a silent and wall-climbing robot for spying and patrolling-related applications is one of the key applications that can be explored. The challenges are that it has a limited load capacity, a multilayer adhesive, and better weight distribution.

From a surface roughness perspective, it is flexible, adaptable, and the adhesive that conforms to uneven surfaces can also be explored. From a dust and contamination point of view, it has a kind of self-healing adhesive surface inspired by the gecko's natural cleaning ability. From a soft actuator perspective, it has a detachment control where we have a soft actuator that is mainly meant for a directional peeling-based mechanism. These are some of the various applications of gecko-inspired climbing robots. To summarize, we discussed the overall functionality of these gecko-inspired climbing robots, especially as this acts as a base for establishing such gecko-inspired climbing robots. We discussed the different applications and subsystems of these gecko systems. We have also discussed the different mechanisms that are involved in such gecko-inspired climbing robots. So, we have classified these mechanisms into four different categories: one is called a dry fibrillary adhesion-based system, and then there is a kind of elastomeric adhesion that is contributing to it. We have also discussed electrostatic adhesion and thermoplastic adhesion. In dry adhesion, we discussed how it works and how it is biomimetic.

This is the overall schematic structure of such movement. These are some of the models that are involved with reference to the Gecko Gecko-inspired climbing robot. Now, there are certain models that exhibit. One of the models is with reference to the pressure plate. The other model refers to an elastomeric adhesion, and the third model refers to an electrostatic adhesion, where we have a plate and a moment is being kept. In thermoplastic adhesion, there is a different locomotion mechanism that persists. Another locomotion mechanism is leg declining, rolling, or sliding motion, suction, or gecko-based hybrid motion, which exhibits some kind of hybrid climbing-related applications. We have also discussed some of the commonly used materials for gecko-inspired adhesive-related systems. We have also discussed different fabrication techniques that are being employed for gecko-related applications. So, we have discussed some of the other case studies with reference to such system. As we have discussed magnetic swimming-based micro robots and their applications in the upcoming lectures. Thank you.