Micro Robotics

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Lecture 44

Microsystems for Microrobots (Manipulation) - Module 04

Last class discussed the different modes of AFM and the concept of fiber pulling with different mechanisms. In fiber pulling is concerned, it is quite an interesting manipulation. So, this by deploying this manipulation appropriately, it can control over the fabrication of these fibres. These fibers have potential applications in different fields, especially with reference to a micro-robotic perspective; they are being effectively used for various sensing elements. In fact, the mechanism that is evolved in AFM-based fiber pulling, like those mechanisms, can also be deployed for manipulating a micro robotic system. We had discussed the different types of micro nano fiber pulling.

So, one of the microfiber pulling methods involves AFM, another one involves a kind of flame-heated tapper drawing, and the third one involves a kind of tungsten probe-based pulling. In the tungsten probe, a liquid layer is applied in such a way that the tungsten probe is made to touch the liquid, and then a fiber is extracted from the system when it is pulled from the liquid. Then there is a polymer drawing system integrated into the molten polymer, and when we try to pull it, you get a fiber coming out of it. So, we have been discussing the different applications of these fibers.

Some of the applications include gas absorption spectroscopy, the Mach-Zehnder interferometer, the gratings involved, the resonators, and some couplers that are involved. One of the configurations of the coupler involves two sets of ports that are being used for monitoring from a perspective point of view. From an application perspective, it is highly used for optical sensing, biosensing, and feedback-related systems. Let's consider another application, which is called a tweezer. The mechanical tweezers have a type of manipulation on the order of a few microns.

When a force is exerted on top of it, a manipulation can be observed, which can be used for the movement of the system. From a fiber perspective, the overall construction includes an optical fiber, a taper region, and the space in between where the system needs to be manipulated. Appropriately, control over this optical fiber Leads to manipulation of the

structure. The classification is based on the configuration, so one is called a dual fiber optic tweezer and the other is called a single fiber optic tweezer. In the case of a dual fiber optic tweezer, it has two taper regions, and there is a system in place that allows for control over the structure by manipulating it.

In the case of a single fiber optic tweezer, it can control the manipulation of a particular point. These tapered fibre tips can be produced by either chemical etching or heating and drawing. The principle of tapping a particle in stable conditions between dual beam tweezers is the balance of the scattering force in the axial direction and a centripetal force in the radial direction. When there is a slight unbalancing of these optical forces, this will result in a motion of the particle. When the ratio of the optical power from two fibers is adjusted, the particle will be pushed to the side with weaker optical power until a new balance point is formed.

The single fiber tweezer works on a gradient trap at a tight focal spot near the fiber tube, and tweezers are used for trapping and manipulating biological samples based on the need or the application. Optical tweezers are concerned; they have effective applications, especially with reference to the micro-manipulation perspective. Such kinds of optical tweezers have potential applications with reference to the micro robotic perspective. Now let's discuss optical manipulation, especially the use of optical tweezers for microrobotic-related applications. So, as far as these optical micro robots, these optical tweezers, and this optical manipulation technology that enables accurate manipulation of micro robots even in a fluidic environment.

That is one advantage of this particular system. So, these optical microrobots, which can be used as a kind of micro tool to perform indirect micro-object manipulation via optical tweezers, have been employed for various biomedical applications. The support of the latest advances in three-dimensional microfabrication allows micro robots with sophisticated structures to be created with good reproducibility and yield, further expanding the use of optical tweezers for manipulating micro robots. In this particular field, the optical system can also be called optical micro robots. These optical microrobots can be fabricated using a shape-changing material.

The shape change material has been discussed in some sections as optically sensitive polymers. These optically sensitive polymers are capable of being actuated when light falls on them. So these optical micro robots can be fabricated by using a shape-changing material such as light-sensitive polymers and the deformation of the materials. The deformation of micro robots acts as a body component and therefore, they can control the movement of the micro robot. However, this mechanism is difficult to enable 6 degrees of freedom, like a kind of dexterous manipulation of a micro robot, as the material properties can be non-linear, which makes it difficult to ensure precision for closed-loop control.

Another popular optical manipulation method is to leverage the momentum carried by the laser beam to enable the optical trapping of microobjects, which is the basis of optical tweezers. So, when a scale below 100 micrometer, and the force generated by the light induced a mechanical effect becomes the significant part of this particular system. Now, these optical micro robots represent a kind of intersection of two fields coming into the picture. So, one is a kind of photonics field and the other one is a kind of robotic field that comes into the picture. So, it will try to create a kind of micro device that we are looking for.

Now, let us discuss in detail this kind of optical manipulation. Let us take a small block diagram of this optical manipulation. So, let us consider our input parameters: the perception, which is nothing but the sensing, and then the output is in the form of manipulation, which is a control. This is a kind of interaction that exhibits between the robotic techniques. Now, if we closely observe the different interactions. There are four different modes that come into existence. One is based on the light type, which ideally includes UV light, a visible band, and infrared. It has scale, in micrometers and nanometers in place. Similarly, in the control modes, one important aspect is related to optical trapping, and the other is light responsiveness. With reference to the robot material perspective point of view, it has polymers, metals, and organic matter.

So, when we try to closely observe this particular system. So, these are the different parameters which are being deployed with reference to this optical based tweezers etcetera. Now, let us see two important modes of this optical-based system that is used for micro-robot-related applications. Let us see the schematic. It has a multiple beam splitter in place. This is a kind of conventional optical tweezer system that can generate multiple laser spots based on time sharing. There is going to be a probe laser, and then there is going to be a fiber laser. From a probe laser, it has a deflector, and from the fiber laser, it has a deflector. This deflector moves through a system called AOD, which is referred to as an acoustic optical deflector. Through this acoustic optical deflector, the light passes through the system with appropriate optics, and the beam gets deflected through a lens arrangement.

There is going to be a sample through which it gets the illumination. This is a kind of motor stage that exhibits, and through a deflector, there will be a lens that will be integrated into it. So in this particular system, it has two lasers. One is called a probe laser, and the other is called a fiber laser. It passes through an acousto-optical deflector, and then, when it passes through an objective lens via the motorized stage, we can see a kind of illumination.

So ideally it can be used as a structure something like this; these structures can be oriented by such a system. So, by the movement of this acoustic optical deflector, it will develop such an orientation. This is a kind of simple system; it has the capability to generate

multiple laser spots with time sharing, and it can enable a form of dexterous manipulation for optical micro robots that is used by conventional systems. Now let us discuss the next configuration, which is called holographic optical. As for these holographic optical tweezers, they can generate multiple laser spots and are used for manipulating a micro robot in the required plane.

The overall construction includes a visible light source, a mirror, and a sample. This is fed to a mirror that is integrated with the CMOS camera. There are two dichroic mirrors. One dichroic mirror is like this, and the other dichroic mirror is like this. There is going to be a kind of spatial modulator from the sample through the spatial modulator, which we call SLM. The IR laser is there. This is going to be a kind of CMOS camera. In this particular case, we have a kind of SLM called a spatial light modulator. It is a kind of time-sharing with spatial position control using optical tweezers in a straightforward manner, and several micro objects can be trapped. For instance, let's have particle 1, particle 2, and particle 3. These particles can be easily trapped using this particular system, and they can be transported to the target areas.

So, trapping multiple parts of a structure via different focal points has been used to control the planar rotation of a micro robot. However, the out-of-face orientation control is difficult to implement since the focal points of the optical laser traps are constrained in the same focal plane with a special design of a micro robot, which is required to achieve a kind of out-of-plane manipulation. Let us discuss the overall system configuration of this kind of optical tweezers. So that is like a different process that is deployed with reference to the automation of this particular system. The key components involved in automating this optical tweezers are concerned; let us consider this as an optical tweezer.

One of the key inputs for this optical tweezer is the real-time motion control, where a laser beam focal point and velocities are integrated. It has a working image where the perception, which is an image processing, is deployed in the workspace image. From the perception, one of the aspects goes to the manipulation and the other one goes to the path planning. From the manipulation, the system design modeling is being fed into this path planning process, and from the path planning process, it is fed into the real-time system. The feedback from this optical tweezers is for an efficient operation aimed at understanding the influence of different operational parameters.

Appropriately, the system design will take shape and model the system, and from the modeling, the inputs are fed into the path planning, and from the path planning, it is going to real-time motion control. This will help us have collision-free trajectories for the objects or cells to reach a particular position. Now, it has the operation, and then whatever objective constraints are there are being fed into this path planning. The estimated location and orientation of the cell are observed in this. The overall fundamentals of this system,

whenever we are trying to model them, include some key parameters that we may need to consider.

Let me just list the key parameters affecting the overall performance of optical species. One is the state's bead position and appropriate control inputs; the optical trap, which is nothing but the laser beam focus. The second one is linear, and the non-linear spring stiffness is the stiffness parameter for the axial and radial components. Third are the thermal forces, which are ideally modeled using a kind of Gaussian, and the fourth is the viscous drag; buoyancy and the inertial forces are considered appropriate. So, these are some of the key parameters that are affecting the performance of an optical tweezer.

So, whenever we are designing such optical tweezers for different manipulation-related applications, these are the parameters that need to be considered.