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Use of Optical Tweezers Sensor in Communication

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ABSTRACT

The use of optical tweezers sensors in communication has become a topic of research that attracts attention, because optical tweezers sensors are the latest thing that appears in today's technological and sophisticated era. Optical tweezers are a means of manipulating objects with light. The application of optical tweezers sensors in communication is by way of manipulation of small light particles that can be used in optical sensor technology. Optical sensors in communication are applied to the use of optical tweezers sensors that are used to monitor and control particles or impurities contained in optical fibers to transmit optical signals. Optical tweezers consist of a laser beam focused on a group of particles with a refractive index exceeding the surrounding medium. The working principle of optical tweezers in communication is through a laser beam passing through an object, so that it deflects and changes direction and changes its momentum focused on a high-quality microscope object to a point in its field.

Keywords: ***Communication, Use, Sensors, Optical Tweezers.***

1 Introduction

The use of optical tweezers is an optical system used to trap and regulate particles. In optical tweezer communication, optical tweezer research launched in 1986 is currently rapidly developing and applied in various fields of science. Simply put, optical tweezers consist of a laser beam focused on a group of particles with a refractive index exceeding the surrounding medium. The length of the applied leser wave is adjusted to the size and type of particles to be captured (A. Ashkin et.al, 1986). Half of the 2018 Nobel Prize in Physics awarded to Arthur Ashkin is someone who knows about the application of optical tweezers in biological systems (Ashkin et al., 1986) (Xin et al., 2020).

This discovery allows for precise control and manipulation of particulate objects, including: Cells and natural colloids. One possible application of optical tweezer sensors in communication is the manipulation of small light particles that can be used in optical sensor technology. A light sensor is a sensor that converts the amount of light into a certain amount of electricity. The output produced by the optical sensor changes as the light falls on the sensor surface. (Pesce et al., 2020).

Optical sensors have a variety of functions, including measuring light intensity, color, and detecting objects. In general, the components of optical sensors are divided into two parts, photovoltaic and photoconductive, solar power generates a voltage that fluctuates depending on the amount of light it receives. With further developments, optical tweezers sensors can become the most important tool to support technological advances in the field of optical communication in the future. Optical tweezers rely on the optical force that arises when the focused laser beam interacts with microscopic particles: the scattering force, pushing the particles along the direction of the beam, and the gradient force, which pulls them towards the high-intensity focal point. Optical tweezers are innovative instruments for manipulating microscopic biological objects that are great and are very suitable for use (Zhu & Avsievich, 2020).

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Optical tweezers are devices that use laser light to manipulate microscopic particles. It uses optical principles to capture and move small particles such as cells and molecules with high precision. The use of optical tweezer sensors is widespread in various research fields including biology, physics, and chemistry. In biology, this tool is often used to study the properties of living cells such as cell movement, cell interactions, and cell structure. In physics, optical tweezer sensors can be used to study the properties of materials at the nano and micro scales. The advantage of optical tweezer sensors is that particles can be moved with high precision without damaging the particle structure. In addition, this tool can also be used to measure the forces acting on these particles. Thus, the use of optical tweezers sensors has great potential to expand our understanding of various microscopic phenomena and can make an important contribution to the development of new technologies in various fields of science. In fact, the style, optics can also be applied to atoms and molecules to limit and move them. (Pesce et al., 2020a)

Communication is not only done face-to-face but can be done remotely. How can we communicate over long distances? Long-distance communication can be done because of increasingly sophisticated technology, of course, long-distance communication can be done if there is a signal. The use of signals in communication devices uses optical tweezers sensors, so communication can take place because of the optical tweezers sensor. This article aims to analyze the use of optical tweezers sensors in communication and their working principles and includes a discussion of the meaning of optical tweezers sensors.

2 Research Methodology

Communication is the process of exchanging and understanding information between two or more parties. Communication is not only done in person but can also be done remotely (virtually). Communication can involve the sender of the message, the recipient of the message, and the communication channel. Sending messages online can be done when it has a high enough signal level. And the application or use of optical tweezers sensors is very beneficial because optical tweezers sensors used to monitor and control particles or impurities contained in optical fibers to transmit optical signals. Optical tweezers have become the method of choice in single-molecule manipulation studies. In this primer, it is first of all the matter that reviews the physical principles of optical tweezers and the characteristics that make them a powerful tool for investigating single molecules (Bustamante et al., 2021).

Optical tweezers are a means of manipulating objects with light. With this technique, microscopic small objects can be held and steered, allowing for accurate measurements of the forces applied to these objects. (Malinowska et al., 2024). Meanwhile, optical fiber is a channel that has a glass size even smaller than a hair. (Salsabilla, 2023). Standard optical tweezers rely on a punched optical force When the focused laser beam interacts with the miscroscopic particles: scattering force, pushing the particles along the direction of the beam, and gradient style, pulling it towards a high-intensity focal point. Importantly, the incoming laser beam is not affected by the position of the particles because the particles are outside the laser cavity.(Kalantarifard et al., 2019).

Optically trapped particles can be used as highly sensitive microscopic force transducers that can exert and measure forces ranging from hundreds of piconnewtons to several femtonewtons. Given that it is only one dimensional, for a small displacement from the equilibrium position, the force acting on the colloidal particles located at x in a trap centered on x_{eq}

$$F_{ot} = -K_x(x - x_{eq})$$

Where is the stiffness of the trap along the x-direction. The resulting trap potential is harmonious K_x

$$U(x) = \frac{1}{2}K_x(x - x_{eq})$$

Since the particle is in a harmonic trap potential, the distribution of its position is Gaussian:

$$\rho(x) = \left[\frac{\rho_0 \exp\ k_x(x - x_{eq})^2}{2k_B T}\right]$$

The radiation force that light exerts on matter comes from the conservation of electromagnetic momentum during the scattering process. Historically, optical power was generally understood in strong estimates based on size constraints. In fact, when the particle size is much larger, the optical beam regime. In addition, in optical trap experiments, complex objects from tens of nanometers to tens of micrometers are manipulated, and cells, biological structures, metal structures, dielectrics, or hybrids are often far from two extreme regimes or from spherical shapes. Therefore, in many cases, complete electromagnetic calculations need to be used to obtain correct predictions about the behavior of optical traps. At each scattering event, the change in the momentum of the beam creates a reaction force at the center of mass of the particle. Taking into account these various reflection and refraction events, the optical force can be calculated directly as follows:

$$F_{fray} = \frac{n_m P_i}{c}\hat{r}_i - \frac{n_m P_i}{c}\hat{r}_{r,0} - \sum_{j=1}^{+\infty}\frac{n_m P_{t,j}}{c}\hat{r}_{t,j}$$

Where $\hat{r}_i \hat{r}_{r,j}\ and\ \hat{r}_{t,j}$ is a unit vector representing the direction of the incoming ray and the reflected beam and the i-beam beam, respectively, calculated using the Fresnel reflection and transmission coefficients. In general, most of the momentum transferred from beam to particle is caused by only the first two scattering events, especially for small angles of encounter. And Fiber Optics is an important telecommunications infrastructure for broadband networks around the world. The transmission width of bandwidth signals with low delay is a key requirement in today's applications (Yanuary & Lidyawati, 2018).

Optical tweezers are tools used to manipulate microscopic particles using laser light. In the context of fiber optics in communication, its contribution is through several aspects , namely optical tweezers sensors can be used to move small particles that may be trapped or clogged in fiber optic systems. In optical sensors, tweezers apply several principles of physics to capture and manipulate microscopic particles:

1. Light Momentum:

Light has momentum, which can be used to push small particles. The momentum of light is given by the equation:

$$p = \frac{hv}{c}$$

2. Diffraction of Light

Light diffracted by small particles can be used to determine its position with high precision. This technique is called optical interferometry.

3. Light Pressure

Light also has pressure, which can be used to trap small particles. The light pressure is given by the equation:

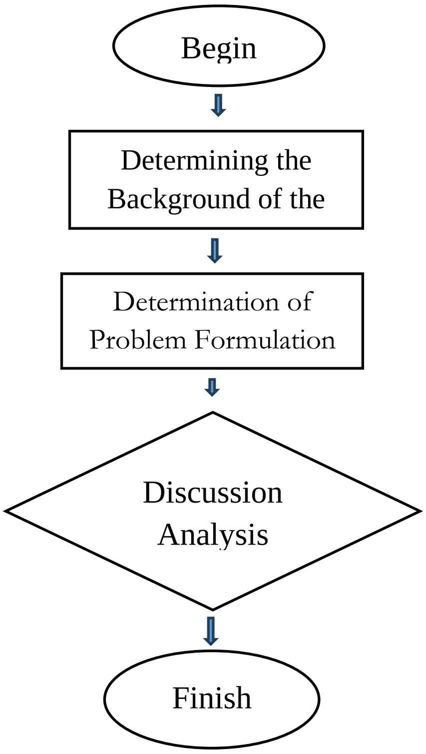
$$p = \frac{I}{c}$$

4. Raman Scattering

The light scattered by small particles can be used to identify their chemical composition. This technique is called Raman spectroscopy.

5. Fluorescence

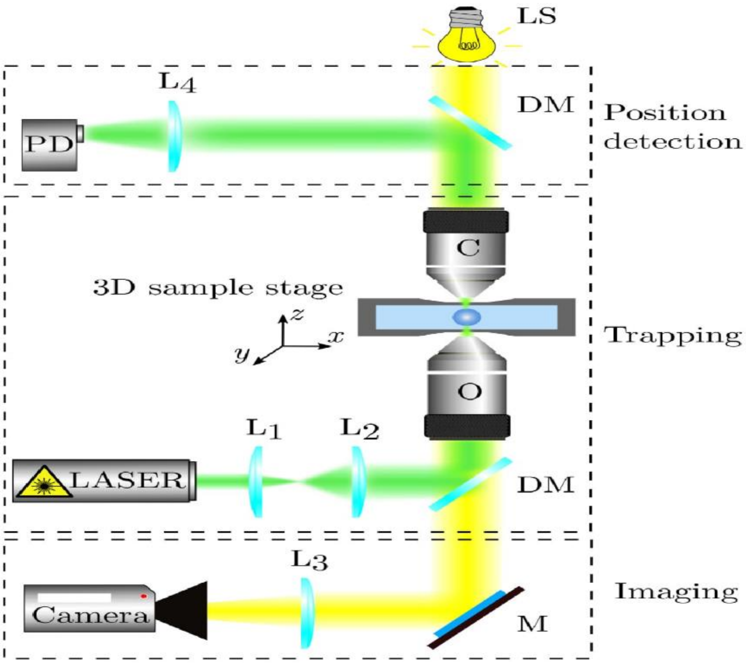
The light excited by small particles can be used to measure their optical properties. This technique is called fluorescence spectroscopy.



Picture 1 Research Diagram

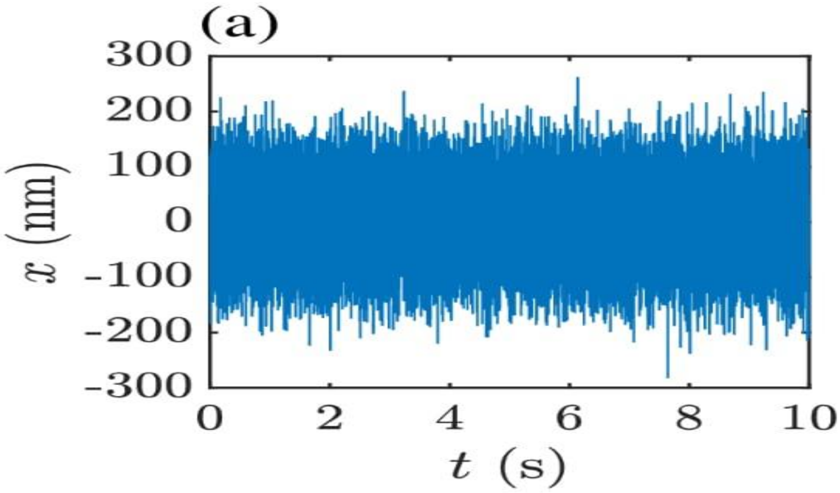
3 Results and Discussion

A sensor is an object or device that detects signals or signals from changes in energy such as electrical, physical, chemical, biological, mechanical and other energy sources (Yusro & Diamah, 2019). Optical Tweezers (Optical tweezers) are highly focused laser beams that can trap microscopic particles, in practice, optical tweezers can be made by focusing the laser beam through a microscope, either commercial or homemade.(Abbott et al., 2023). As illustrated in figure 1, the basic setup of optical tweezers consists of the following parts: trapping, imaging, and position detection. DM, dicroic mirror; M, mirror; O, the purpose of the microscope; C, condenser; , , $L_1 L_2 L_3$and L_4lens; LS, Light source

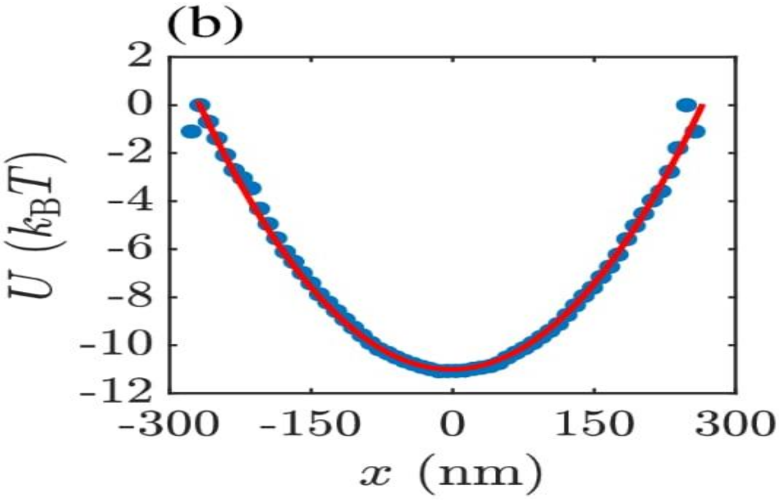


Picture 2 The basic setup of the Optical Tweezer consists of a *imaging, trapping, position detection*

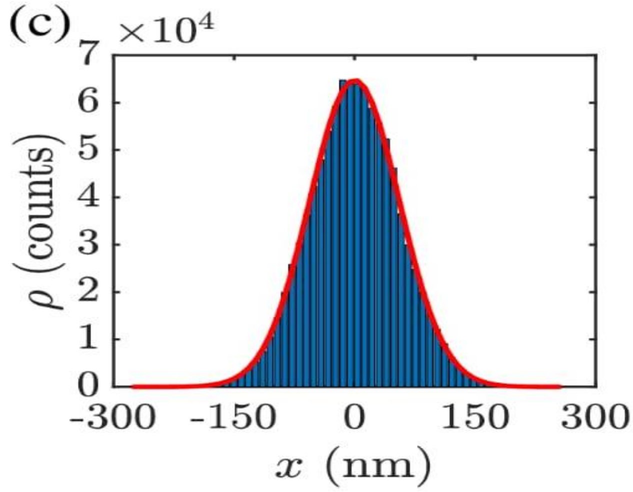
Single-beam laser traps for neutral particles that have a wide range of applications in physics and biology. The gradient trap force is applied by bringing the laser beam to the finite diffraction of the focal point through an objective large numerical aperture microscope (Maia Neto & Nussenzveig, 2000). Arthur Ashkin proved that plastic particles can be hidden by light (latex) by focusing a laser beam on a container containing the particles ("Optical Tweezers," 2018). Optically trapped particles are subjected to harmonic forces that tend to keep them close to a stable equilibrium position. Considering only one dimension, for displacement. The typical trajectory of optically trapped particles, can be seen from the figure:



Picture 3 Optically trapped Brown particle trajectories



Picture 4 Optical Potential



The particle continues to move due to Brown's fluctuations. Therefore, optically trapped particles are in a dynamic equilibrium between the thermal noise that constantly pushes them out of the trap and the optical force that pushes them towards an equilibrium position. In order for the particles to remain in the optical trap, the optical potential well must be deep enough. An optical trap is a device used to micro-manipulate microscopic objects using a focused laser beam within the field of view of an optical microscope (Kužela et al., 2024).

The working principle of these optical twezeers is that through a laser beam is focused by a high-quality microscope objective onto a point in the specimen field. This point creates an "optical trap" capable of holding small particles in the center. The force felt by these particles consists of light scattering force and gradient force due to the interaction of particles with light. Optical tweezers are made by modifying a standard optical microscope. These instruments have evolved from simple tools for manipulating micron-sized objects to sophisticated devices under computer control that can measure displacement and force with high precision and accuracy (Steven, 2020).

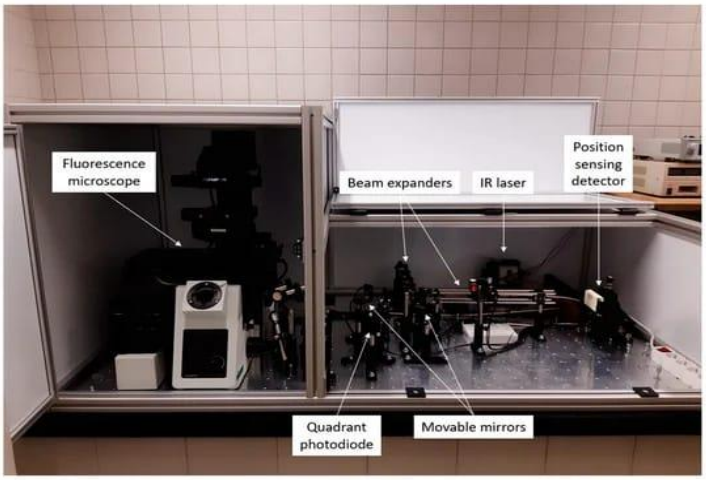
The basic principle behind optical tweezers is the transfer of momentum associated with the bending of light. Light carries momentum that is proportional to its energy and the direction of its propagation. Any change in the direction of light, either through reflection or refraction, will result in a change in the momentum of the light. If an object deflects light so that its momentum changes, the conservation of momentum requires that the object undergoes a change in momentum that is in the opposite direction and is equally large. This gives rise to the form of force acting on the object. (Steven, 2020).

3.1 Use of Optical Tweezer Sensors in Communication

Optical Tweezer sensors can be used to monitor and control particles or impurities contained in Optical fibers that are used to transmit Optical signals

Optical tweezers (OTs), also called optical traps, are a versatile tool for manipulating micro-objects ranging in size from micrometers to tens of nanometers, invented by Ashkin in 1970 (Ashkin et al., 1986). Creating an optical signal that involves a link or link and involves the use of a transmitter, usually from an electrical signal to a signal along the fiber, acknowledging that the signal is not too distorted and not too weak, obtaining the optical signal and converting it into an electrical signal (Idachaba et al., 2014). Optical fibers are used as sensors by removing the optical fiber layer.

Fiber optics continue to play an important role as a data transmission medium, using light as a transmission source (Dee Unglaub Silverthorn, 2013). The dual optical tweezers equipment based on the Olympus IX-73 fluorescence microscope and the cost-effective IR trap diode laser with a wavelength of 808 nm and a power of 3200 W are made in our laboratory and come with an integrated software package. This allows the operator to control the instrument, calibrate, record the measured data and perform post-processing and visualization. All of the software's features are designed to be easy to use and integrated into an intuitive user interface. (Carvalho et al., 2021).



Picture 5 Experimental tool of optical tweezers based on fluorescence microscope and IR laser on an anti-vibration platform covered by a protective case

How optical tweezers sensors work to monitor and control particles or impurities in optical fibers:

1. Sensor Placement

   First of all, the optical tweezers sensor must be placed near the optical fiber to be monitored.
2. Particle Detection

   Optical tweezers will detect particles or impurities contained in optical fibers by monitoring changes in the intensity of light reflected or emitted by these particles. These sensors can use photodiode detectors or cameras to detect changes in light intensity.
3. Particle Capture

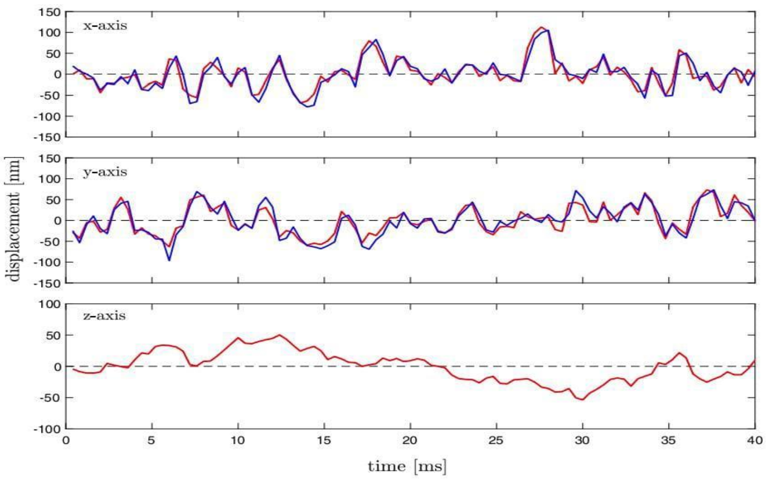
   Once a particle is detected, the optical tweezers sensor will use the optical field generated by the laser to capture the particle. This optical field will create a tensile force on the particle and hold it inside the optical field.

4. Fiber Optic Cleaning
   Once the particles are captured, optical tweezers sensors can be used to clean the optical fibers by moving the particles in the desired direction or removing them from the optical fibers. This can be done by changing the direction of the optical field or by moving the lenses or other optical components.
5. Monitoring and Control

Optical tweezers sensors will continuously monitor particles or impurities in optical fibers.

Digital Video Microscope Alternatives

An alternative to digital video microscopy is the use of interference patterns arising from interference between the input and scattered fields (Carvalho et al., 2021). The condenser collects such a pattern and the photodetector located in the rear focal plane of the condenser records the signal produced. So, by tracking the movement of the intensity distribution of the interference pattern, the position of the particles on the transverse xy plane can be measured. The majority of experiments can be performed with detection bandwidth in the range of facq~10103 Hz.



Picture 6 Optical Particle Tracking

The position of the particles can be tracked using a digital video microscope or interferometry. An excellent agreement between the position measured by two techniques on the xy plane: the blue line representing the coordinates of the particles measured using a digital video microscope overlaps with the red line representing the coordinates obtained from interferometry. (Pesce et al., 2020b) (Simmons et al., 1996).

4 Conclusion

The use of optical tweezers in optical fibers in communication works on the principle that utilizes laser light emitted through optical fibers to capture and move small particles, such as microcells or nanoplastic particles. The application of optical tweezers sensors shows that this technology can make a valuable contribution to the development of optical sensing technology and the understanding of optical phenomena related to communication activities. With further developments made, optical tweezers sensors can become the most important tool to support the continuation of life and technological advances in the field of optical communication in the future.

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