1. Introduction into optical scan

There are many different ways in which beam-steering can be achieved such as using Galvanometer scanning mirror, piezoelectric scanning mirrors, electro-optic deflector and acousto-optic deflector/modulator. The beam steering process is done through the housing of a scan head. The beam steering system has a couple of direct applications on laser technology machines (laser engraving, annealing, marking, cutting, welding), optical communication systems for to stabilize laser beam over large distances, adaptive optics systems for tip and tilt distortions compensation, laser scanning and display devices, confocal microscopy system and optical tweezing applications.

a) Galvanometer Scanning Mirrors

Galvanometer is defined as a moving coil electric current detector. This detector works when a current is passed through a coil and generates a magnetic field (solenoid). This coil experiences a torque proportional to the current. If the coil's movement is opposed by a coil spring, then the amount of deflection of a needle attached to the coil may be proportional to the current passing through the coil. Such "meter movements" were at the heart of the moving coil meters such as voltmeters and ammeters until they were largely replaced with solid state meters.

The design of a mirror galvanometer comprises a coil of wire wound on a soft iron core suspended in the magnetic field of a permanent magnet. A small mirror is attached to the coil so that a beam of light reflected by this mirror will sweep through an angle which is proportional to the current passing through the coil.

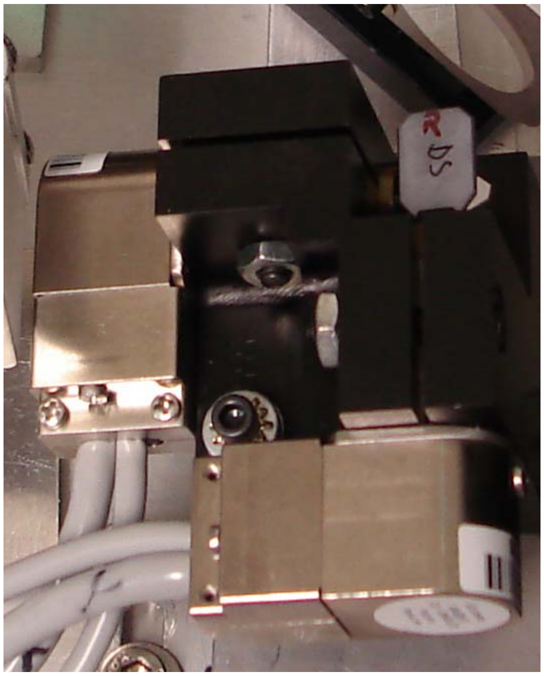


Figure.1 Above shows two orthogonal aligned Galvanometer scanning mirror

By incorporating of feedback, the galvanometer mirrors have better stability and precision. Current commercial systems operate at 1 ~ 2 kHz with step response times as short as 100 µs, and with 8 µrad repeatability. The comparatively slow temporal response limits their usefulness for fast-scanning applications, but their low insertion loss and large deflection angles make them a low-cost option for slow-scanning and feedback applications.

Recent advancement in feedback-stabilized piezoelectric (PZ) systems has resulted in the introduction of piezoelectric scanning mirrors. Piezoelectric systems have the advantage that they can scan much faster than galvanometer systems, reaching frequencies of 10^6 Hz. Piezoelectric (PZ) stage technolog has improved tremendously with the introduction of high-precision controllers and sensitive capacitive position sensing. Stable, linear, reproducible, ultra-fine positioning in three dimensions is now achievable with the latest generation of PZ stage. Previous problems of hysteresis and drift in PZ devices have been largely reduced through the use of capacitive position sensors in a feedback loop. With the feedback loop, a positional accuracy of 1 nm has been achieved commercially. Despite these advantages, PZ stages are not without drawbacks. They are comparatively expensive: a 3D stage with capacitive feedback position sensing plus a digital controller costs roughly $25,000.

b) Electro-optic Deflectors

An electro-optic deflector (EOD) consists of a crystal in which the refractive index can be changed through the application of an external electric field. A gradient in refractive index is established in one plane along the crystal, which deflects the input light through an angle $\theta \propto lV / w^2$, where V is the applied voltage, l is the length crystal, and w is the aperture diameter. Deflections in the order of 20 mrad can be achieved with a switching time as short as 100 ns, sufficient for some optical trapping applications.In contrast to acousto-optic deflectors (AODs), the un-deflected beam goes straight through the device, making optical alignment straightforward. The optical throughput can be as high as 90% and is limited only by small reflection, absorption and scattering losses. The EOD switching time is ~100 ns (limited mainly by the capacitive load), much faster than galvanometer mirrors, and even beyond most AODs. Despite low-insertion loss (~1%) and straightforward alignment, EODs have not been widely used in optical trapping systems partly due to the high cost and limited deflection range (~2 mrad), which may be inadequate for most applications. Wavefront distortion caused by crystal imperfection can also be a problem.

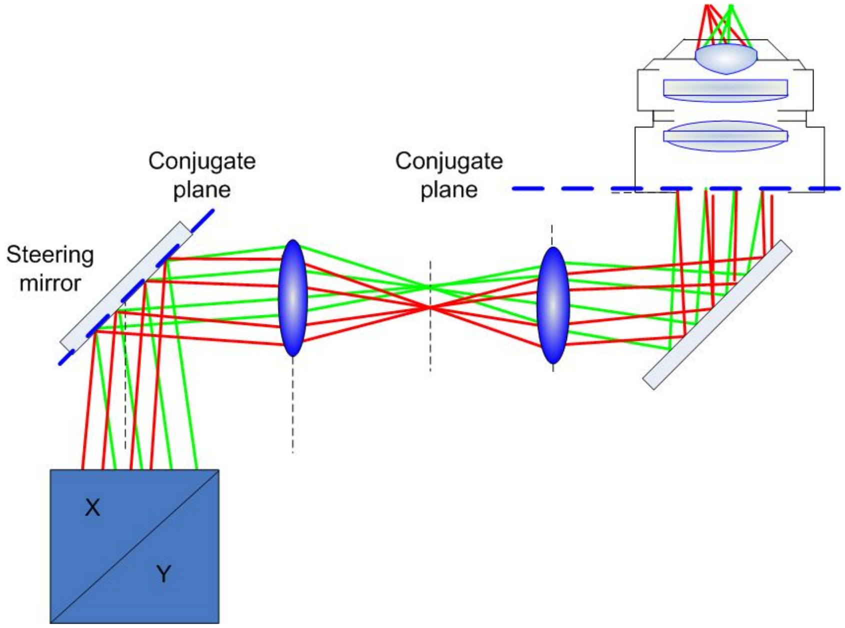
c) Acousto-optic Deflectors/Modulators

An acousto-optic deflector/modulator (AOD/AOM) consists of a transparent crystal inside which an optical diffraction grating is generated by the density changes associated with an acoustic travelling wave of ultrasound. The acousto-optic effect occurs when a light beam passes through a transparent material, such as glass, in which travelling acoustic waves are also present. Acoustic waves are generated in the glass by a piezoelectric transducer that is driven by a RF signal source. The spatially periodic density variations in the glass corresponding to compressions and rarefactions of the travelling acoustic wave are accompanied by corresponding changes in the index of refraction for propagation of light in the medium. These travelling waves of index of refraction variation diffract the incident light much as the atomic planes of a crystal diffract x-rays in Bragg scattering. For acoustic waves of sufficiently high power, most of the light incident on the acousto-optic modulator can be diffracted and therefore deflected from its incident direction. The grating period is given by the wavelength of the acoustic wave in the crystal, and the first-order diffracted light is deflected through an angle that depends on the acoustic frequency through $\Delta\theta = {}^{\lambda f}\!/_{v}$, where λ is the optical wavelength, and v and f are the velocity and frequency of the acoustic wave respectively (${}^{v}\!/_{f}$ is the ultrasound wavelength). The diffraction efficiency is proportional to the depth of the grating, and therefore to the amplitude of the acoustic wave that produced it. AODs are thereby able to control both the trap position (through deflection) and stiffness (through light level). A pair of AODs can be combined in an orthogonal configuration to provide both x and y deflections of the optical trap. Due to optical losses in AODs (an ~80% diffraction efficiency is typical), and the result of using two AODs in orthogonal configuration is a power loss of almost 40%. An additional drawback to AOD is that their diffraction efficiency tends to change over the acoustic bandwidth, hence transmitted light intensity (related to trap stiffness) can differ by as much as 10% ~ 15% for different deflections. In practice, every AOD needs to be characterized carefully before use for deflection-dependent changes in throughput.

2. Scan Head Design

In most multi-axis optical scan head, galvanometer scanning mirrors are one of the most common optical scan head arrangements. The orthogonal scan mirrors have low insertion loss and high flexibility in the design of the scan patterns.

a. Optics Path design



The key idea for the optical scanning mirror is to ensure that the collimated laser beam is channelled into the focusing lens through a relay lens, consist of a scan and tube len system. To ensure diffraction-limited performance of the optical system, the objective rear focal plane (entrance aperture) must constantly be uniformly filled by a planar wave (collimated beam) during scanning. This condition is vitally important to allow a high resolution scanning pattern. Hence, in the two orthogonal independent scan mirrors, the movement of the two mirrors can simultaneously produce a specific scan (2D vector) pattern or raster scan. The size and the distance of the scan mirrors need to be small relative, minimizing their inertia, and allowing rapid oscillation for fast frame rates, as well as enabling scan rotation. By making sure that the two scanning mirror are positioned as closely as possible, as such that a collimated input laser beam would

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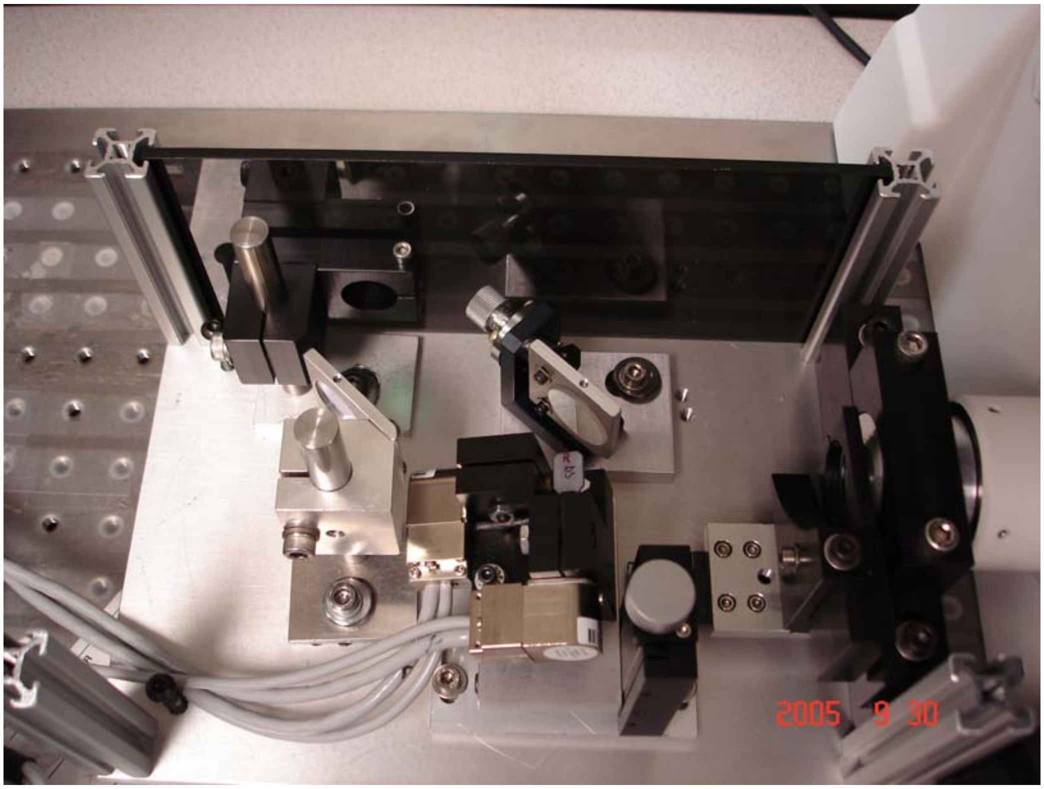
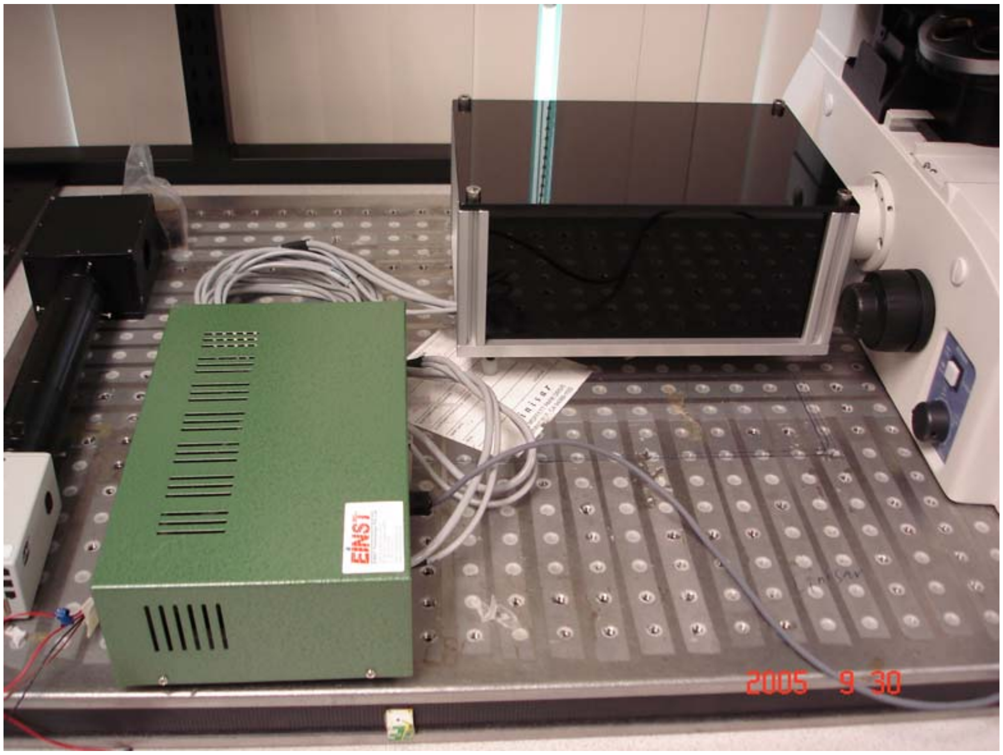
deviate minimal to its output laser beam. The figure above shows the collimation system of optical scanning system.





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