Pivot-Point Beam Steerer

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Abstract. A simplified beam-steering mount for a mirror or beam splitter can be adjusted quickly with three degrees of freedom, pivoting about the single point in space where the chief ray of the light beam strikes the reflecting surface, before being locked in place by tightening a single screw. The design goal is demonstrated by multiple superimposed images taken with different positions of the mount.

Keywords: optomechanical design, optical fabrication, alignment, reflection, mirrors, beam splitters.

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1 Introduction

Rotation around x, y, and z axes in a single system (three degrees of freedom) has been achieved by various techniques. One approach is to provide three pivots, one for each axis. Angular alignment of optical components such as mirrors and beam splitters is often constrained by having to rotate them about a fixed point in space, the point where the chief ray of the light beam strikes the reflecting surface, to avoid changes in optical path length or sideways displacement of the light beam. This can be accomplished if the pivots for the various degrees of freedom of the optical mount can be arranged to intersect at the point where the chief ray of the light beam strikes the reflecting surface.

Goniometers were originally invented to measure angles and adjust the tilt of objects.[1] Goniometer designs later evolved into optical mounts and beam steerers of various designs including the modern day expensive electromechanical goniometric stages marketed by optical equipment companies.[2,3]

Another device frequently used for beam steering (in more than one plane) is the gimbal mount, which also has applications in the inertial stabilization of optical assemblies.[4] The various forms of gimbals available operate on the same principle. Rotation can occur about two or three axes, usually intersecting and perpendicular to each other to allow independent rotation for each degree of freedom.[5]

Our "Pivot-Point Beam Steerer" pivots about a single point in space with three degrees of freedom. The principle of action has been used before in other apparatus such as in a "Self leveling weld fixture" described in United States Patent 6,083,333 by Beers et al.[6] Other devices related to our present design include an "Optical element mount comprising an optical element holding frame,"[7] an "Inertial pendulum optical stabilizer,"[8] an "Optical mount pivotable about a single point,"[9] and "Selectively positioning a workpiece."[10]

2 The Mount

Our beam steering mount (Fig. 1) is based on the principle that the center of a sphere stays at the same point in space for all kinds of spin unless and until a translational movement is performed. The mount consists of an optical-component-holding piece and a platform (Fig. 1). The optical-component holding piece (which is 3D printed) consists of a convex, truncated spherical base and a frame extending above from the planar face (upper face) of the base. The platform consists of a flat plate with a cylindrical hole in it. The convex spherical base of the optical-component-holding piece rests in this cylindrical hole, and thus the optical-component-holding piece can be rotated in this hole with the pivot point of rotation being the center of the virtual sphere defined by the radius and x/y/z position in space of the spherical base (Fig. 1.). The plane of the reflecting surface of the optical component is designed to be in the same plane as the pivot point of the optical-component-holding piece. This ensures that the chief ray of the light beam strikes the reflecting surface exactly at the only point of the reflecting surface that remains stationary during the 3D rotational adjustment of the mirror or beam splitter.

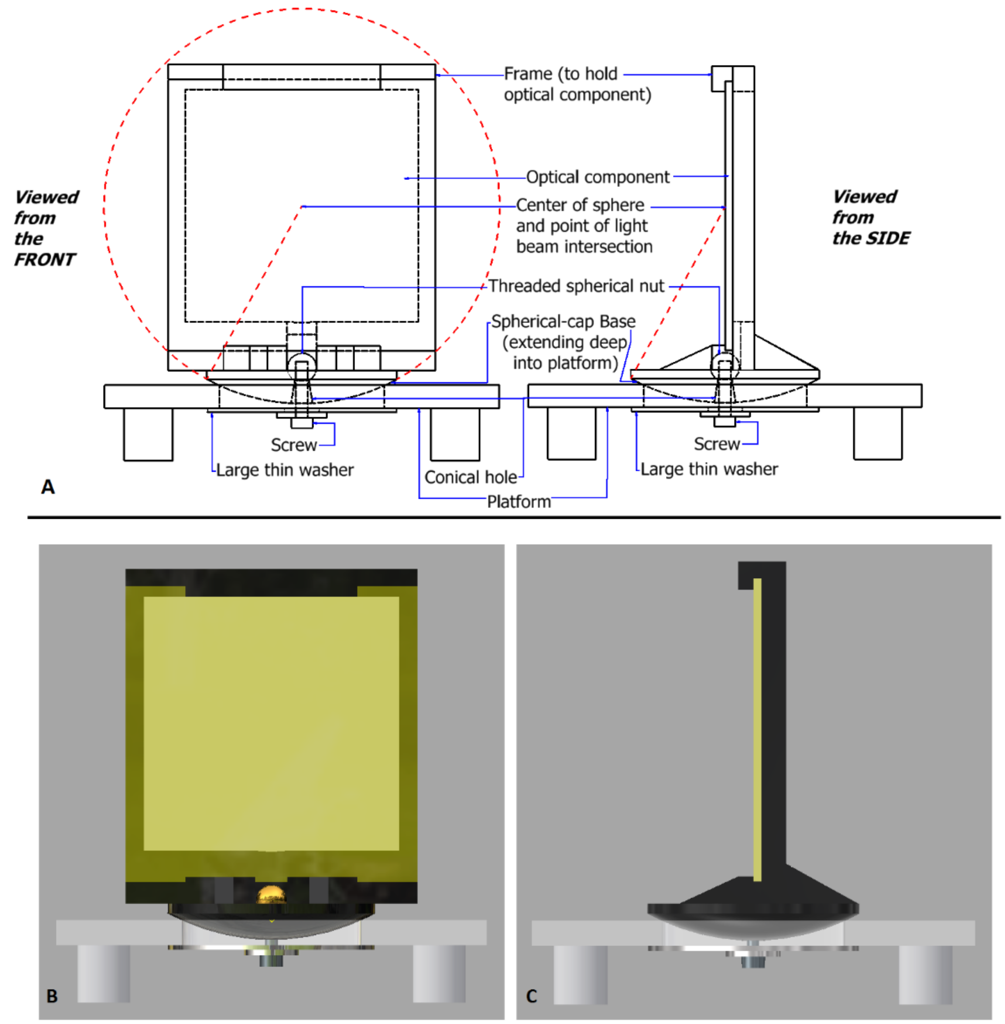

Fig. 1 The mount. The upper part of the figure shows labeled drawings, while the lower parts show 3D-rendered representations.

The spherical base of the optical-component-holding piece itself has an upper semispherical hole continuous with a lower conical hole (base down). When the base is sitting on the platform, a screw passes upwards, with a large diameter thin washer between the screw head and platform (Figs. 1, 2). The screw inserts above into a threaded metal sphere (a threaded ball similar to one in Ref. 11) which lies in the hemispherical hole in the spherical base. After the optical-component-holding piece is tapped or levered into place to produce the desired angle of beam steering, the mount is held downward by a pointed object such as a Phillips-head screwdriver to clamp it against the cylindrical hole in the platform, and the screw is tightened against its washer, and the large thin washer, which bridges the bottom of the cylindrical hole in the platform, clamps the spherical base against the platform. Experience has shown that this act of tightening has no tendency to alter the position of the spherical base of the mount.

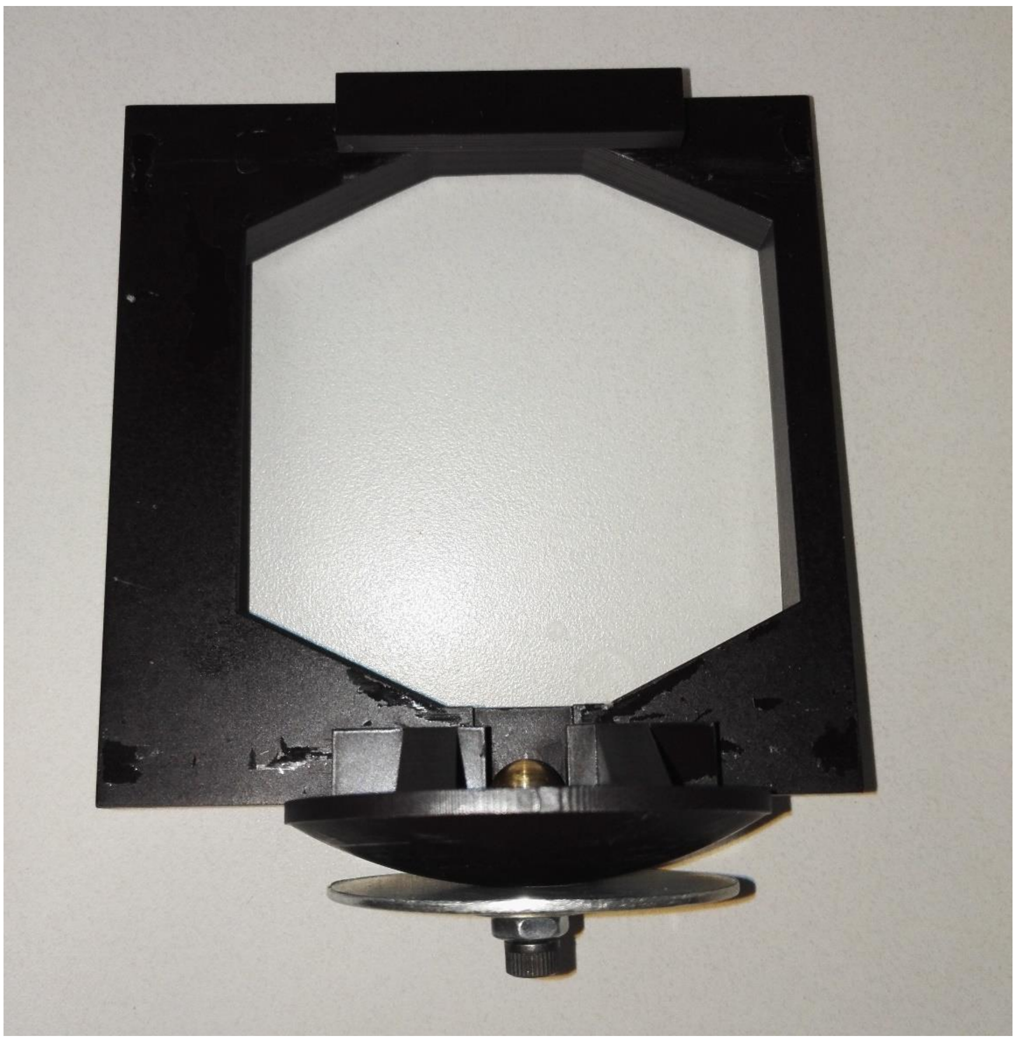

Fig. 2 The mount. The optical-component-holding piece without the platform in between the washer and the spherical base.

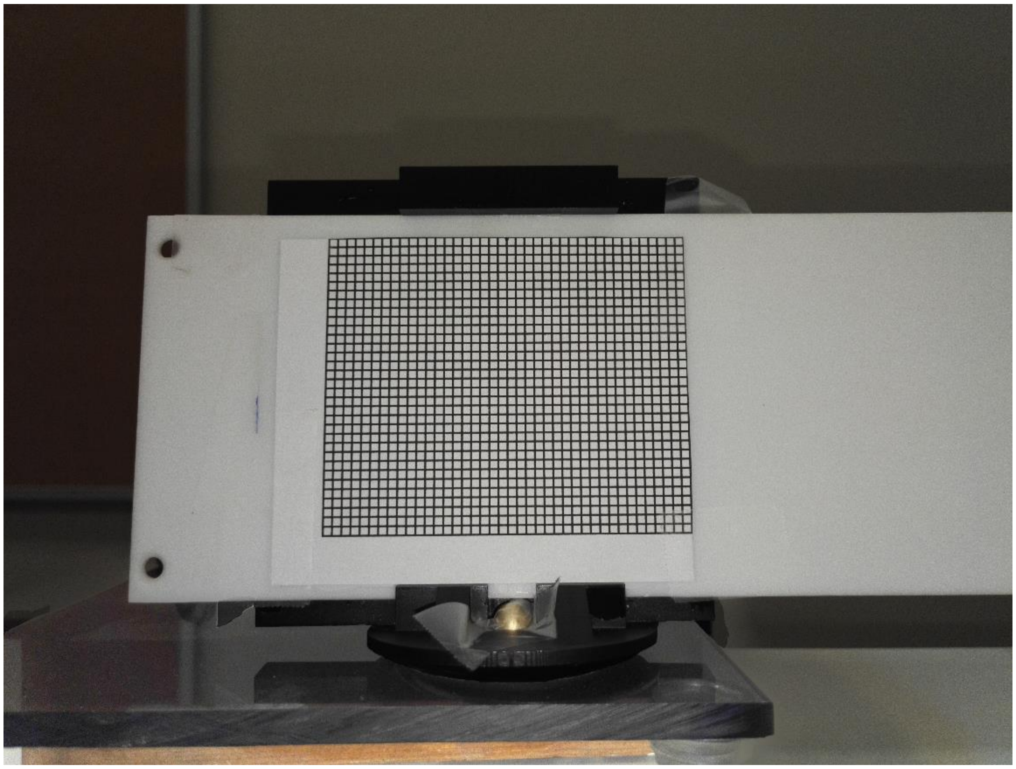

Fig. 3 The mount prepared for the proof-of-concept experiment. The optical-component-holding piece with its spherical base rests in the cylindrical hole in the platform. In place of an optical component, a white plastic plate is used with a 2 mm grid glued onto it.

3 Method

A 2-millimeter square grid printed on paper was fixed onto the front surface of a flat plastic plate (Fig. 3) which was used instead of an actual optical component for testing purposes. The mount was oriented by aiming it into various directions (Fig. 4), and an image was taken for each orientation with a smartphone camera fixed at an appropriate distance from the grid surface. These images were superimposed in Adobe Photoshop, after making the white parts of each grid image transparent for proper clarity of all layers equally, with the center of each camera image superimposed at the center of the combined image.

Fig. 4. Some of the orientations of the mount during the proof-of-concept experiment.

4 Results

The above method yielded a pattern of dark lines overlapping each other due to the different orientations of the grid that were imaged (Fig. 5.). This pattern demonstrated a small area of the grid that remained essentially stationary, indicating minimal change of position of this area of the grid with any orientation of the mount. This corresponded to the virtual center of the spherical base.

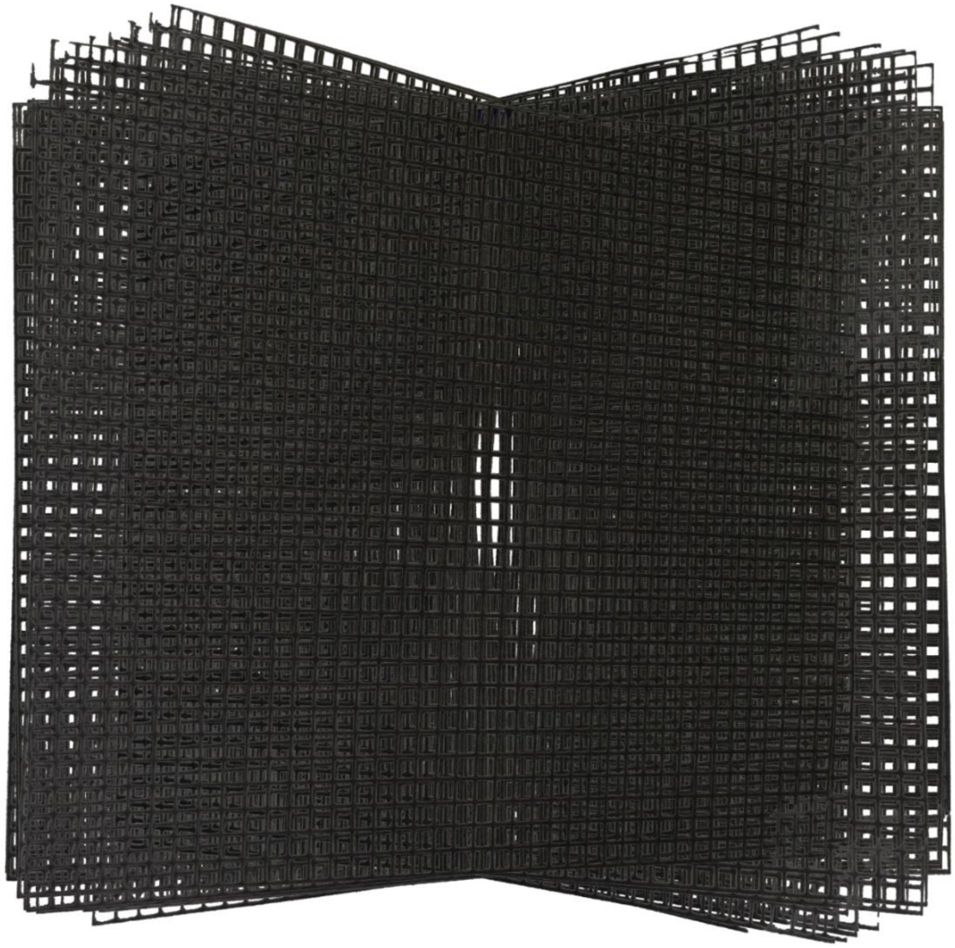

Fig. 5 Image obtained after superimposing all the images of the black lines of the grid in the different positions.

5 Discussion

This design is ideally suited for the initial alignment of a beam-steering optical element where the final position is fixed, not requiring frequent adjustment. This avoids the dedication of an expensive goniometer stage to remain in the set-up. If the beam steerer must be occasionally adjusted, making the large washer slightly flexible or adding a spring to the design (Fig. 6.) can facilitate such adjustment.

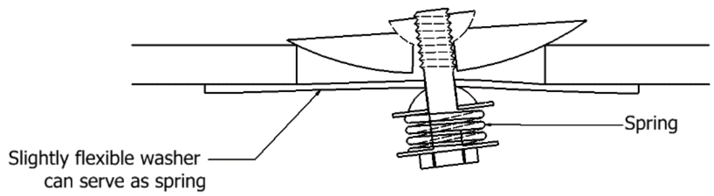

Fig. 6 An alternative design. It consists of a slightly flexible washer between the screw and the platform and/or a spring between the screw and the large washer. This can facilitate occasional readjustment of the beam steerer if and when necessary.

One way to improve the proof-of-concept experiment would be to use a grid of small black dots together with an appropriately higher resolution camera to localize the center of rotation of the base more accurately.

Various other designs for such a mount are possible, composed of a cylindrical hole in a platform and a spherical base in different arrangements such as illustrated in Figures 7 and 8.

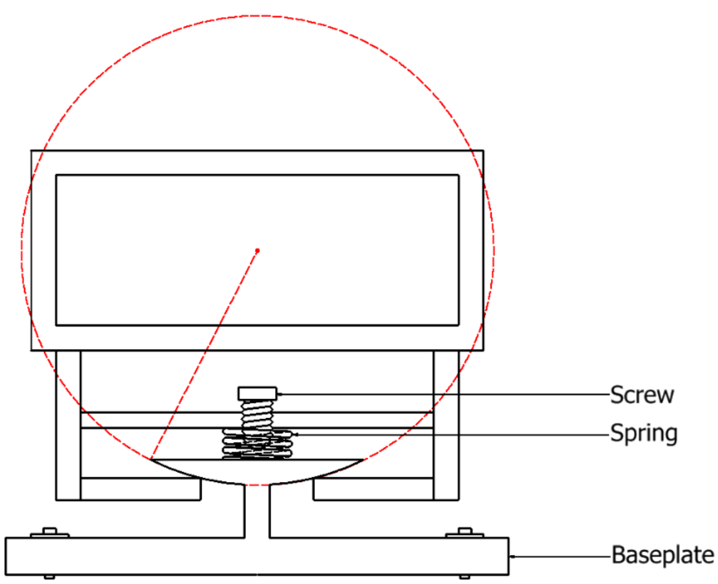

Fig. 7 An alternative design. This is the reverse of the design in Fig. 1.

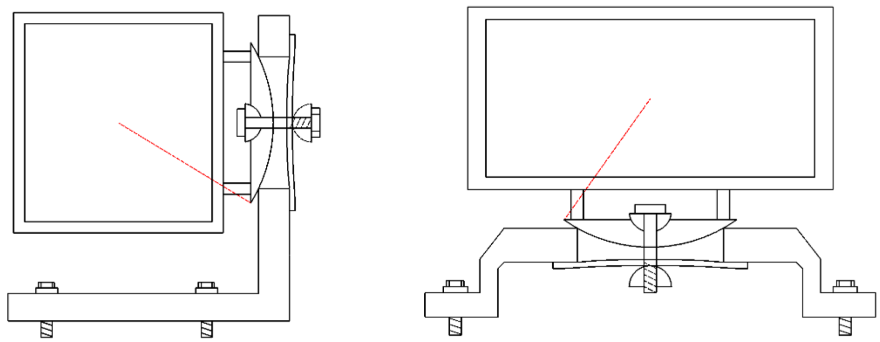

Fig. 8 Other possible arrangements of the mount.

6 Conclusion

There are various ways in which our simplified mount has advantages over conventional gimbals and goniometers, lacking only the ability to be adjusted very smoothly and precisely. The mount we used for experimentation is a 3D printed part. 3D printing such a piece is an easy task, with the product being light in weight and relatively economical.[12-14] Being economical, it can serve well for educational and initial experimentation purposes. Mounts of custom sizes can readily be produced as needed for a specific optical setup.

The goniometer stages that are commonly in use give a great degree of precision and accuracy but not 3 degrees of freedom in a single system.[2,3,5] Up to 6-axis complex systems can be obtained for specialized purposes but are prohibitively expensive.[15,16]

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