Automated Laser-Beam Steering

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Abstract

To accomplish automated laser beam steering, a beam positioning algorithm has been derived to calculate the appropriate movement of two motors on a beam positioning mirror mount. This mirror is fixed on a stage that can rotate the mirror to any angle in order to simulate non-collinear positioning axes. The algorithm is implemented in a computer program capable of steering a laser beam to a specific position on a target image camera. The program accounts for non-collinear axis orientation between the mirror movement and the camera, scaling between mirror movement and camera beam position, beam centroid fluctuation, and the precision with which the user requires the beam to be from the specified target position. The program is then capable of moving the motorized mirror in order to steer the beam to any specified position on the target image camera.

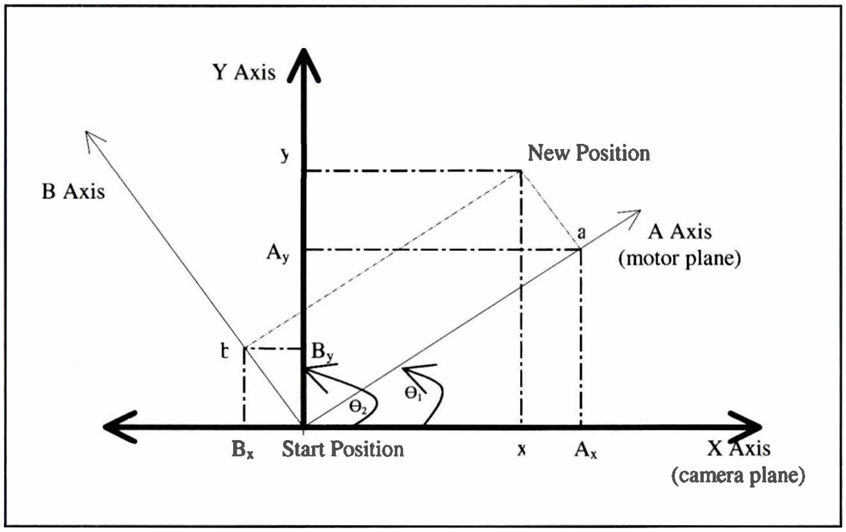
Background

Currently, the University of Rochester's Laboratory for Laser Energetics (LLE) OMEGA laser system requires human interaction to steer the laser beams in a manual fashion. This process can be quite time consuming and is subject to human error. Researchers have proposed a solution to this problem: an automated beam steering system. An effective system or program had not been developed at LLE. An important piece of an automated beam steering program is a way to find the centroid of the beam. This is very difficult to implement in the LLE OMEGA laser system because each beam is constantly contorting and changing shape resulting from beam turbulence.

There are two factors that affect the alignment of a beam, centering and pointing. Centering, which was the focus of this project, is steering the beam to be inside the circular reticule of a target, or in essence steering a beam to a specific position. Pointing is changing the angle of incidence to the target. A system that is to accommodate pointing, as well as centering, needs to have two positioning mirrors. Moving one mirror requires a compensating move in the other mirror. If the beam is not perfectly pointed or centered there is no way to tell which mirror is misaligned without the proper optical equipment. In order to be able to both point and center a beam, additional optical equipment is needed and is considered out of the scope of this project.

The goal of this project was to derive an algorithm to calculate the appropriate amount of movement of two orthogonal motors on a mirror in order to steer a beam to a specific position on a target image camera. The restricting factors were the rotation of the mirror and the beam noise. The mirror was mounted on a rotating stage in order to be able to arbitrarily change the angular orientation between the mirror axis and the camera axis. With a difference in axis orientation, the beam movement resulting from mirror repositioning is not parallel to the camera axis. Therefore, the algorithm must account for the need to move the mirror's positioning motors interactively. The geometry used to support the derivation of the algorithms is shown in Figure 1.

Figure 1. Motor and Camera Plane Geometry



$$x = A_x + B_x \tag{1}$$

$$y = A_y + B_y \tag{2}$$

The (X, Y) axes are in the camera plane and the (A, B) axes are in the motor plane. One of the mirror motors moves along the A axis, and the other moves along the B axis (motors A and B respectively). The motors, along with the (A, B) axes, can be rotated a complete 360° with respect to the camera or (X,Y) axes. x and y are the distances that the beam moves along the camera axes. a and b are the distances that the beam moves along the motor axes. A_x, A_y, B_x, and B_y are the distances that the beam moves on the camera plane as an effect of a move on the motor plane. A_x is equal to the distance the beam moved on the X axis as a result of an A axis move, B_x is the distance the beam moved on the X axis as a result of a B axis move, A_y is the distance the beam moved on the Y axis as a result of an A axis move, and B_y is the distance that the beam moved on the Y axis as a result of a B axis move. Using known incremental test moves along the A and B axes the four scaling constants can be determined. The relationships between mirror motor (a, b) movements and the movement of the beam on the camera (X, Y) axes are:

$$A_x = a\cos\theta_1 = n_a\alpha_{ax} \quad (3)$$

$$A_y = a\sin\theta_1 = n_a\alpha_{ay} \quad (4)$$

$$B_x = b\cos\theta_2 = n_b\alpha_{bx} \quad (5)$$

$$B_y = b\sin\theta_2 = n_b\alpha_{by} \quad (6)$$

In Equation (3) through (6), a and b are the beam position moves scaled to the camera axes. Factors, n_a and n_b, are the actual number of mirror motor move iterations to produce A_x, A_y, B_x and B_y. The test moves provide the 4 scaling constants: α_{ax}, α_{ay}, α_{bx}, α_{by}. Through substitution into Equations (1) and (2) it can be concluded that:

$$x = n_a\alpha_{ax} + n_b\alpha_{bx} \quad (7)$$

$$y = n_a\alpha_{ay} + n_b\alpha_{by} \quad (8)$$

By applying the results from the program's test moves and the scaling constants, it can be concluded that the number of motor count iterations in a (n_a) and b (n_b) to move a distance x,y on the camera plane are given by Equations (9) and (10). These two equations are derived by simultaneously solving Equations (7) and (8) for n_a and n_b .

$$n_b = \frac{y\alpha_{ax} - x\alpha_{ay}}{\alpha_{ax}\alpha_{by} - \alpha_{ay}\alpha_{bx}} \quad (9)$$

$$n_a = \frac{x\alpha_{by} - y\alpha_{bx}}{\alpha_{ax}\alpha_{by} - \alpha_{ay}\alpha_{bx}} \quad (10)$$

Experimental Setup

The experimental setup for this program is shown in Figure 2.

Figure 2. Experimental Setup

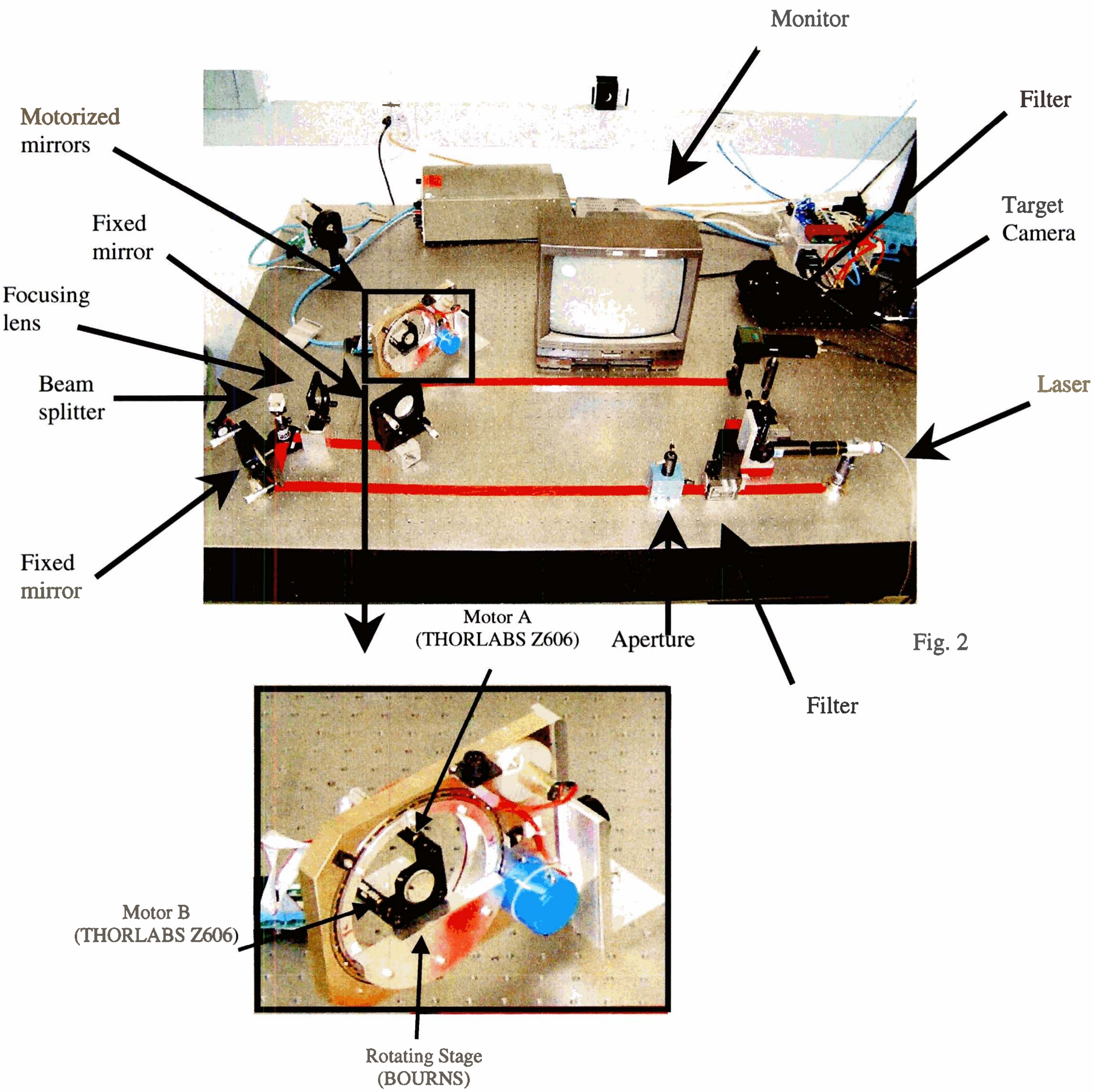
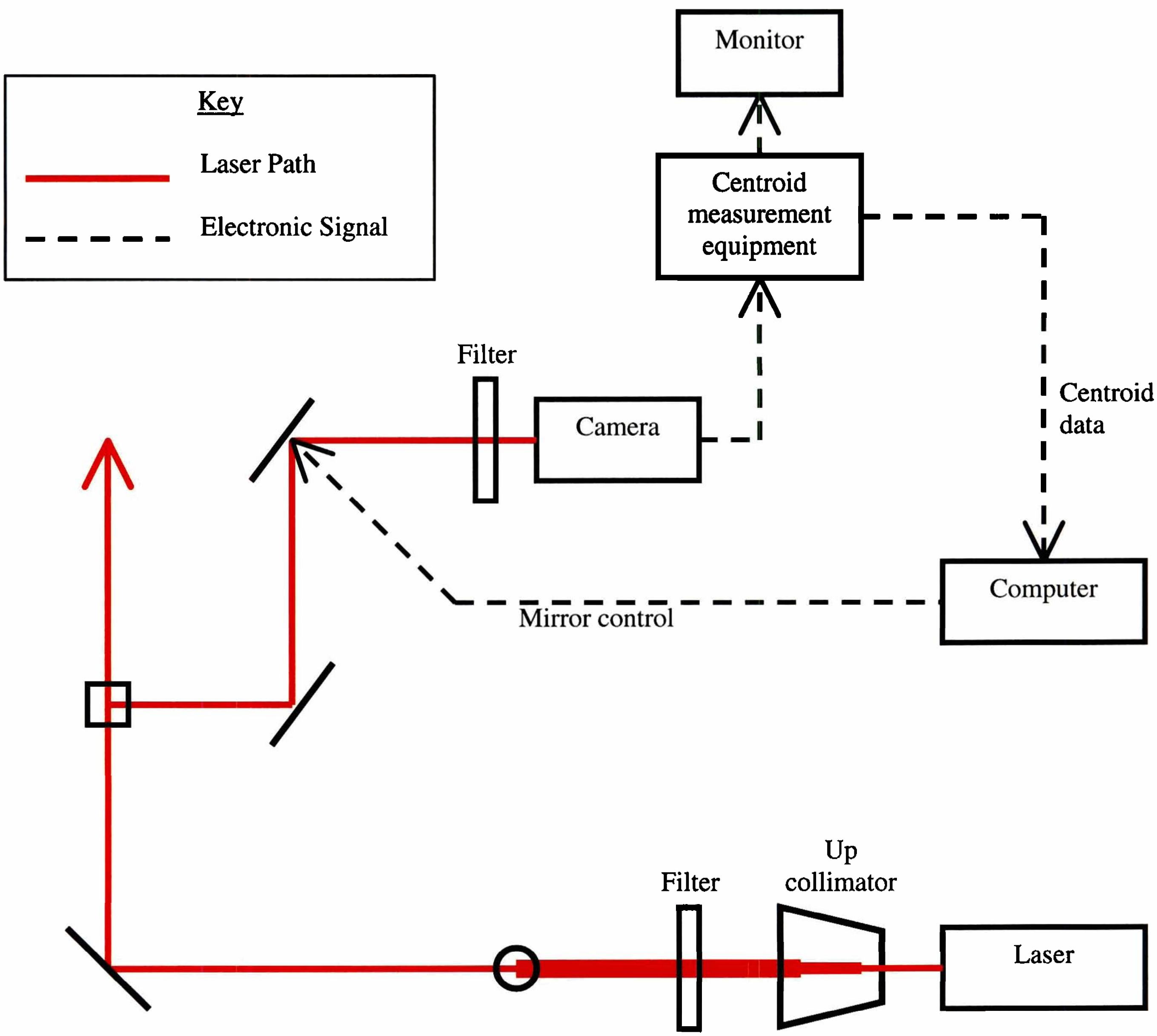


Figure 3. Schematic Layout of Experimental Setup



Schematic Layout

The schematic layout of this experiment is shown in Figure 3. The beam is produced by a low power visible class III A laser (Lasermax Inc. S/N – 711802). It is then spread by an up-collimator (CVI model: BXUV 40-5x-355 S/N: 980428-13) and is filtered to reduce its intensity. An aperture to decrease the diameter of the beam follows the filter. The beam then bounces off a fixed mirror at 45° (this mirror has a fan attached in order to simulate beam turbulence) and goes through a beam splitter that is in place in order to accommodate another experiment on the same optical bench. The beam is then focused by a focusing lens (not shown), and makes a 90° turn at another fixed mirror. The beam then hits the motorized mirror that is controlled by the automated beam steering program. This mirror has two motors (THORLABS Z606) that control it and it is mounted on a rotating stage (BOURNS). After the motorized mirror, the beam is filtered again and enters the target image camera (PULNiX TM-745).

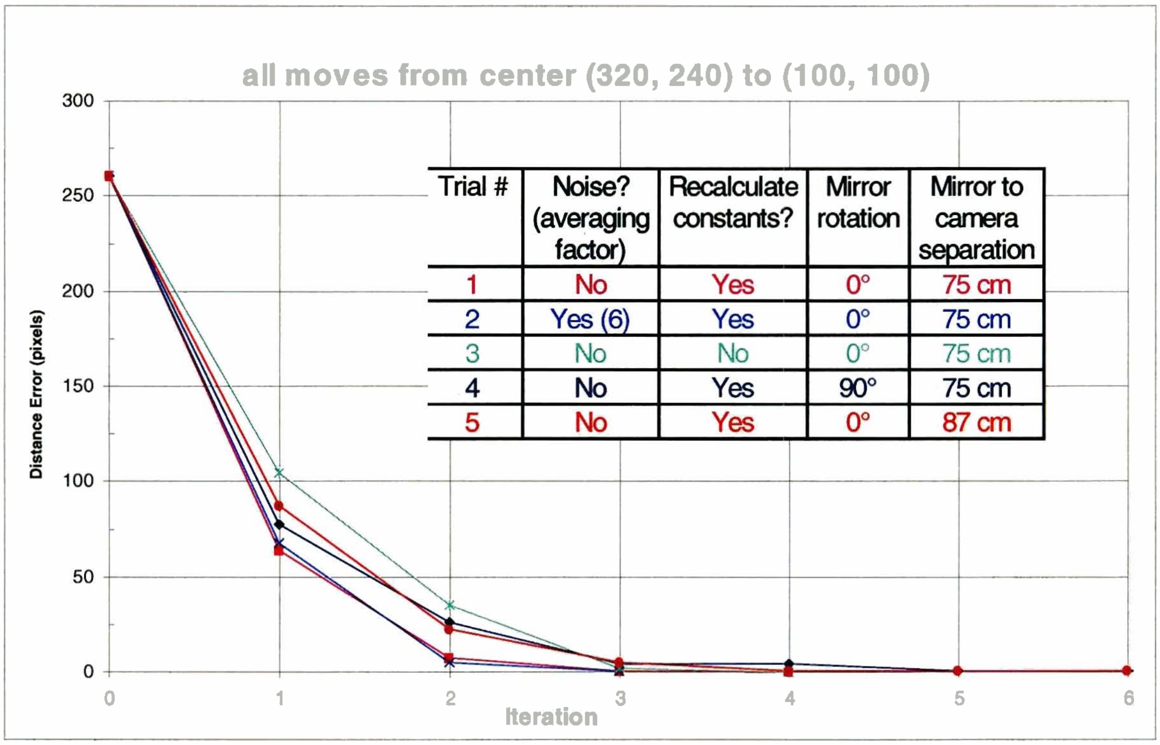
Program Procedure

The program not only accounts for the axis difference between the mirror and the camera, but also accounts for beam turbulence, or noise. The program reads the position of the beam the number of times supplied by the user-determined averaging factor to find the average position of the beam with turbulence. The program uses the averaging factor to overcome the beam centroid noise. There are other variables that can be changed by the user. The user can choose to calculate the move constants every iteration by doing small test moves at each new position to find the relationship between mirror motor counts and beam movement on the camera. The user can also supply the program with an arbitrary goal position or can tell it to steer the beam to the center of the screen.

Program Results

After several tests, it was concluded that the program accomplishes the goal. However, the completition of beam steering sometimes took more than one iteration. See Fig. 4 for a graph of results.

Figure 4. Experimental Results



Trial #	Noise? (averaging factor)	Recalculate constants?	Mirror rotation	Mirror to camera separation
1	No	Yes	0°	75 cm
2	Yes (6)	Yes	0°	75 cm
3	No	No	0°	75 cm
4	No	Yes	90°	75 cm
5	No	Yes	0°	87 cm

The first trial was the control trial. There was no noise, the constants were recalculated every iteration, the mirror was not rotated, and the mirror to camera seperation was 75 cm. For each trial, one variable was changed. The beam reached the goal position every trial within 6 iterations.

Future Developments

Currently, the automated beam steering program is only capable of centering the beam. In order to make the program able to point the beam, addditional optical equipment is needed. In addition to adding a pointing capability, the motor control needs to be more accurate in order to steer a multi-beam laser system. This could be accomplished by compensating for backlash in the mirror motors. There may also be nonlinearities in the camera and positioning motors producing positioning errors that need to be determined and compensated for. However, regardless of the known and unknown error-producing factors, the program still works; it steers a laser beam very accurately.

Acknowledgements

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