Laser Beam Pointing Deviation under Environmental Stresses

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by

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Introduction and Motivation

Laser systems that require precise alignment almost constantly need readjustment. This is due to a number of things, among which are mechanical processes that throw off the laser beam pointing. It was the purpose of this project to study some of the mechanical effects on laser pointing and to better understand them. With an understanding of how laser pointing can be affected, sensitive systems can be better engineered and managed.

The main focus of this project was on mirrors and their mounts. These are an integral and ubiquitous part to any laser system and thus deserve attention. It has been noted that beams tend to drift after an adjustment has been made to a mirror. It has been further speculated that the amount of drift might be related to the amount of adjustment. This suspicion was investigated herein. Also, experiments were preformed to ascertain any difference between various mirror mounts relating to beam pointing.

The other main focus of this project was to study the effect of temperature on beam pointing. Thermal expansion affects every part of the system and at different rates. The net effect of temperature fluctuations can be significant. An understanding of these effects can lead to a better understanding of the behavior of laser systems, and can help to minimize their occurrence.

Position Sensing

Quadrant Photodiode

When initially faced with the task of studying beam pointing and tracking, the first idea that came to mind was to use a quadrant photodiode. This is a two-by-two array

of individual photodiodes separated by a gap. Light incident on the photodiodes is translated to a current. This is then converted linearly to a voltage, which is fed into an analog circuit that sums up the voltages. In this way, it is possible to convert incident light to an x- and y-coordinate, and thus track beam position. The advantages of such a device include a sub-millisecond time resolution, good spatial resolution, and high bandwidth. However, a number of problems also exist. One issue is that they can be quite expensive. Another is in getting the analog signal into a suitable computer environment. This could be done, but requires even more expensive hardware. Also, the beam size and shape would have to have been taken into consideration with many restrictions placed on them. Lastly, the beam could only be tracked through a relatively small area. Once it left one hemisphere, two-dimensional tracking would be lost [1, 2, 3].

Lateral Photodiode

We also briefly considered the lateral photodiode. This is a PiN photodiode with many embedded metallic contacts. A beam incident on the photodiode creates a current, and each contact would carry a fraction of that current. The current carried by a contact a certain distance from a beam of light is given by

$$I = I_t \left\{ \frac{sinh\alpha(L - x)}{sinh\alpha L} \right\}$$

where I_t is the total current, L is the distance between contacts, a is a constant dependant on the material used in the photodiode, and x is the distance from the beam to the contact, [4]. By comparing the distances between the various contacts and the beam, and knowing the contact positions, the location of the beam can be ascertained. This method was rejected for many of the same reasons as the quadrant photodiode [3, 4].

Charge-Coupled Device (CCD)

In the end, a CCD camera was used to detect and track the laser beam. The laser beam passes through filters, lowering the intensity, and a lens directs the light to the photoactive region of the camera. A CCD is a 2D capacitor array, which builds an electric charge proportional to the amount of incident light. A control circuit periodically causes the capacitor array to discharge through an amplifier that converts the current into a voltage. This sequence of voltages is transferred to the video card on the computer, which is in turn fed to LabVIEW. LabVIEW is a technical graphical programming language, that here was used to form a picture, perform calculations, and store data [5, 6, 7].

The camera was chosen for a number of reasons. A primary factor was the fact that it was already in the lab. In fact, throughout the course of this investigation, only items already existing the lab were used; nothing was specifically purchased. Also, the interface between the camera and the computer was simple and easy to work with. While there was a sacrifice in terms of speed, this was made up for by a large sensitive surface area of 4.8 by 3.6 mm. The size and shape of the beam were no longer considerations, and the beam could be tracked over a wide range of deviations.

LabVIEW

LabVIEW was the framework of choice for this project due to a number of reasons. First, it is a widely used language, and gaining experience with it would be helpful. Second, it has many built in features and capabilities that other languages do not

natively have. Finally, there were already some programs created by a graduate student that interfaced with the camera and computed the beam's center.

After studying the preexisting code, and understanding its workings, modifications were made to more suit the program to the specifics of this project. The center of the beam was made to be explicitly displayed, tracked over time in a graph, and saved to a specifiable location. The display of the program was also modified to contain only information useful to beam tracking. The result is a program that is easy to understand and use. Figure 1 shows the front panel of the program, and Figure 2 focuses on the graphs that track the center of the beam over time.
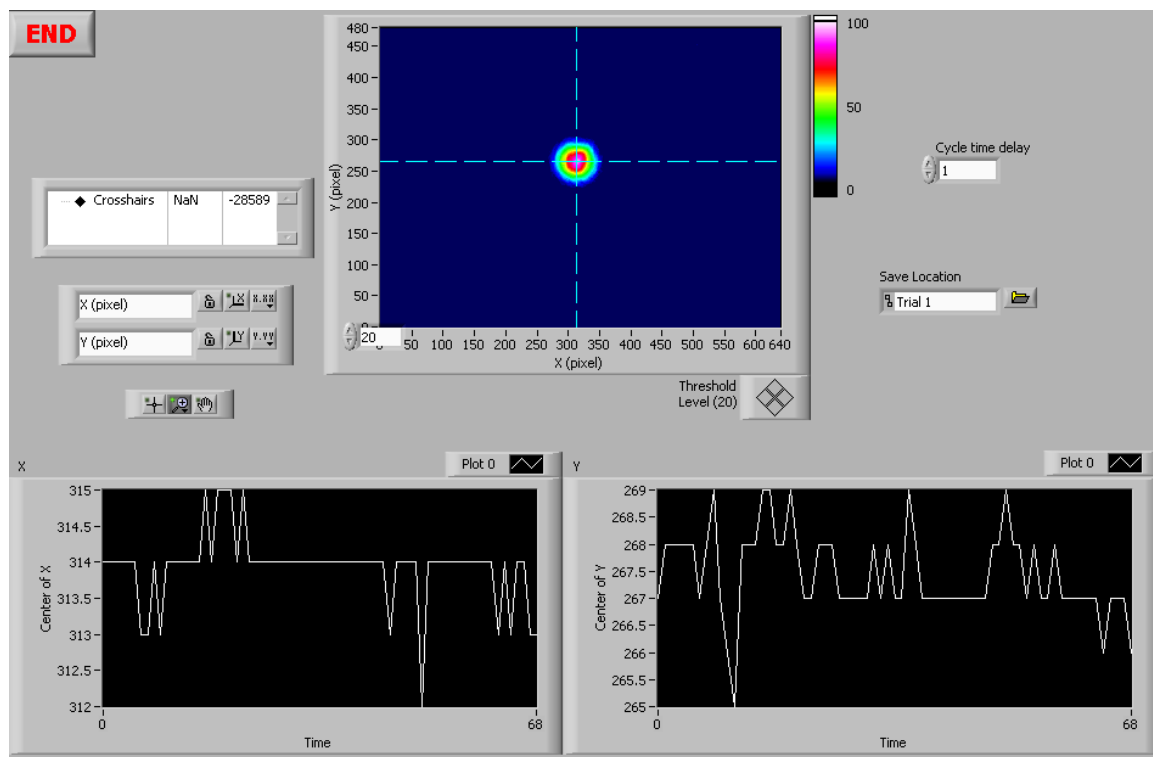
Figure 1: The front panel of the VI. The top screen displays the beam, with cross hairs on the center of the beam. The bottom two graphs track the x- and y-coordinates of the center of the beam over time. To the right are fields where the save location and the time delay can be specified.
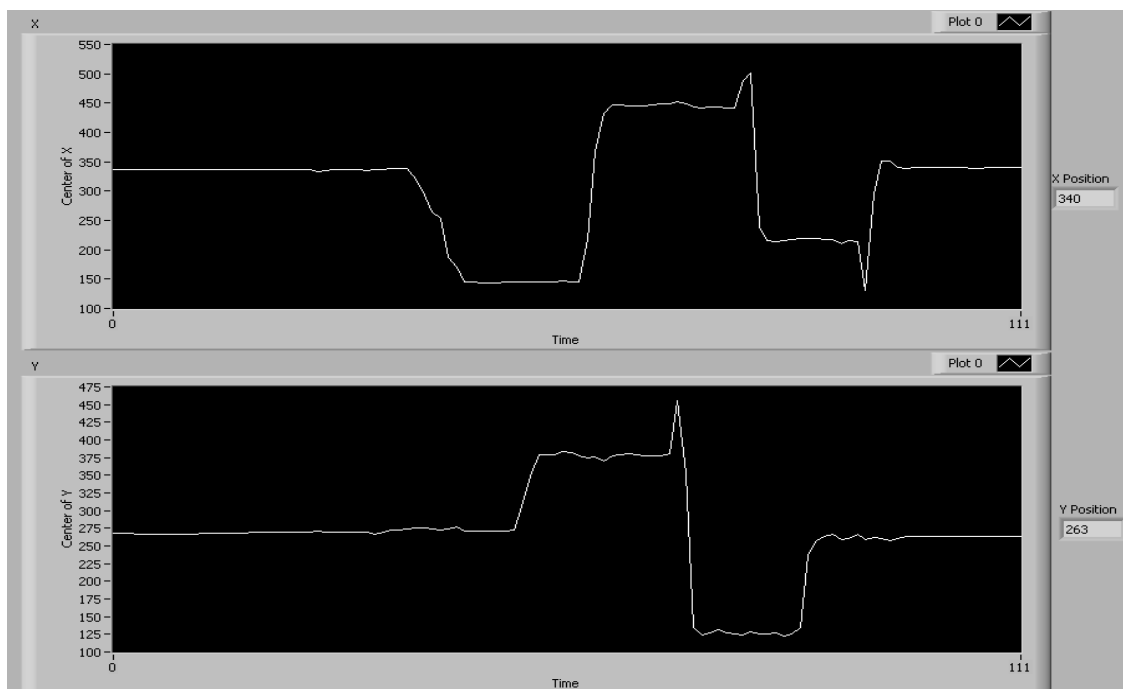
Figure 2: Line graphs showing the position of the calculated center of the beam, tracked over time.

There was, however, an issue with the timing of the program. It was found that the beam's center was calculated about three times per second. The program was composed of a large number of nested loops, only some of which are directly used in finding and tracking the beam center. The extraneous code was excised, and the overall program streamlined as much as possible. This resulted in data being collected at nearly twice the rate it originally was. While this was an improvement, it was still too slow to gather some high frequency vibration data. However, this slow speed cannot be cured through LabVIEW, as it is an inherent limitation in the video card. This was an acceptable drawback of using a video camera. However, timing was successfully adjusted in the other direction. Taking three data points a second was considered too many, and so the code was modified to wait a desired amount of time per loop. Thus it is

possible to specify any length of time between samplings, and take meaningful data over long periods of time.

In the end, the main program used in all the experiments works as follows. It consists of three frames, executed once sequentially. The first frame creates a window handle, and creates the necessary information. The second frame contains a large nested *while* loop. The window handle gets the image data from the camera. This comes in the form of an intensity graph, with an intensity value assigned to a spatial coordinate. The program sums up the intensities along the x and y values, and divides by the total output to compute the arithmetic mean. This information is sent to a graph on the front of the VI, and also as numeric values to a file. It is in this *while* loop that the saving function was implemented, by exporting the center values to a constantly appended spreadsheet file. Also, the timing feature was implemented here as well, by pausing the loop in its execution. Once the *while* loop is ended by clicking *end* on the front of the VI, the last frame is executed, killing the window handler and shutting down all necessary functions. This allows the program to be run many times concurrently. If the program is simply stopped mid operation, LabVIEW would crash.
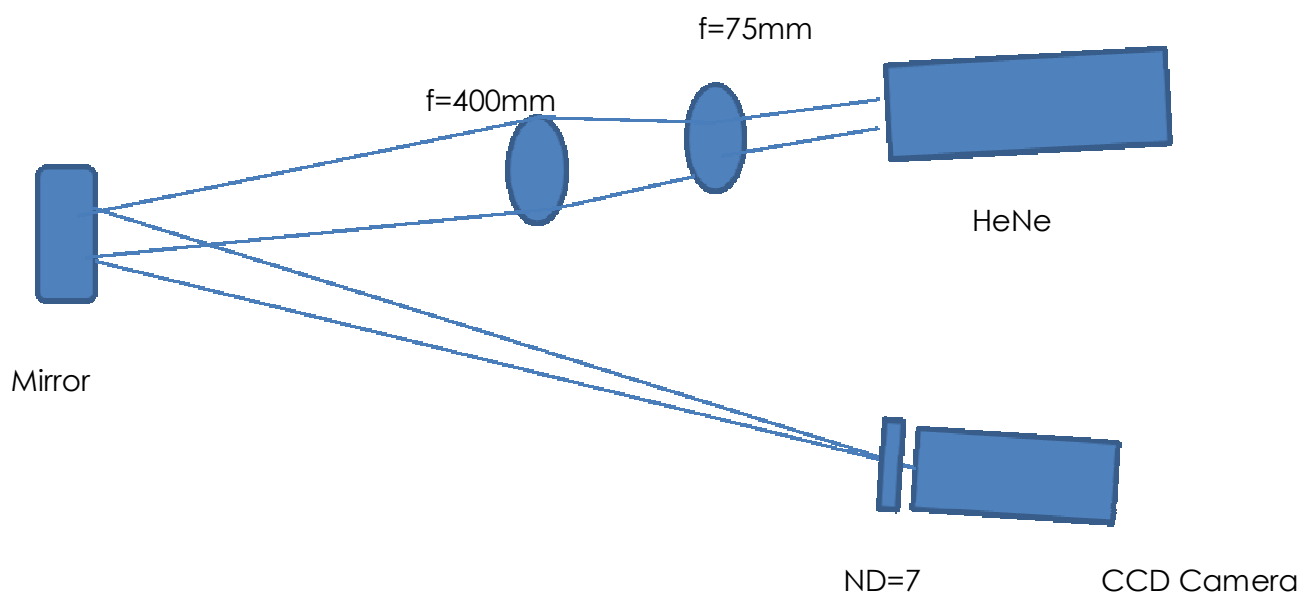
Setup

The majority of the experiments were conducted using the following setup. A 7mW 18 inch linearly polarized HeNe laser at 632.8nm wavelength with a 1.02mm beam was mounted at one end of the table. The beam passes first through a negative lens with a focal length of -75mm, and then a positive lens with a focal length of 400mm, so that it comes to a loose focus at the camera. The beam reflects off a mirror placed at the other

end of the table, and hits the camera, placed next to the laser. The three mirror mounts

used in this investigation were all from Thor Labs. The model numbers for the so called

good, *medium*, and *bad* mirror mounts, shown in Figure 3, are VM1, KM100, and KMS

respectively. The camera, a Sony SSCM183, is fitted with neutral density filters (ND=7)

so that the laser does not saturate the CCD signal. The intensity of the beam, with the

filters fitted, is completely within the intensity range of LabVIEW. This setup is shown

in Figure 4. The camera is connected to a TV, allowing for easy visual tracking of the

beam. From there it is connected to a PC. LabVIEW8, installed on the PC, handles the

rest.

Figure 3: From left to right, the good, medium, and bad mirror mounts. All mounts are from Thor labs, and their model numbers are, from left to right, VM1, KM100, and KMS.

f=75mm

f=400mm

HeNe

Mirror

ND=7   CCD Camera

Figure 4: The basic setup for all experiments. The HeNe laser shines a beam first through a negative lens, and then a positive lens, creating a loose focus on the camera. The beam reflects off the mirror and travels through neutral density filters before reaching the CCD camera.

Distances

The good mirror mount is said by the manufacturer to move .25 degrees per

revolution of the adjustment knob. The knob has 50 divisions per revolution, so:

.25 degrees/revolution * 1/50 revolutions/division = .005 degrees/division

I then tested to see what how much tilt would produce what response. I recorded the

position of the center of the beam, then adjusted the mirror by approximately .025

degrees (5 divisions on the knob), and then recorded the position of the center. Using the

standard formula for distance:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

I then calculated the distance the center moved as told by the program. The

results are as follows. All position and distance values are in pixels.

Table 1: Distance moved with a .025 degree vertical tilt

X	Y	Distance	Average Distance
296	203		79
291	131	72	
288	45	86	
291	123	78	
295	203	80	

Table 2: Distance moved with a .025 degree horizontal tilt

X	Y	Distance	Average Distance
295	203		89
207	201	92	
122	202	79	
200	202	80	
298	205	93	

Table 3: Distance moved with a .005 degree vertical tilt

X	Y	Distance	Average Distance
298	205		14
296.5	194	11	
296	179	15	
295.5	166	13	
296	149	17	

Table 4: Distance moved with a .005 degree horizontal tilt

X	Y	Distance	Average Distance
295.5	149		20
312	147	17	
331	147	19	
351	147	20	
374	148	23	

With a vertical tilt of .025 degrees the beam shifted about 79 pixels (on average), thus it is to be expected that with a .005 degree tilt, the beam should only move about 15 pixels. With a horizontal tilt of .005 degrees, the beam should move 18 pixels. I tested this.

The distance from the mirror to the detector was measured to be approximately 94.80cm. Going by the manufacturer's specifications, rotating the knob by one division is tilting the mirror by .005 degrees. Using trigonometry, the distance moved on the camera is about 0.001mm.

$$94.8cm \times \tan(.005) \approx .00828cm$$

The average distance moved with a .005 degree tilt is 17 pixels. From this, one pixel is on the order of 0.0012cm, or 0.012mm. This checks out, as the manufacturer says that there are 510 pixels in the space of 4.8mm, so one would expect each pixel to be about 0.01mm. All results that are given in pixels can be multiplied by 0.001 to get the rough distance in centimeters. Also, one pixel corresponds to roughly .0006 degrees of rotation by the mirror.

Adjustment and Relaxing

Motivation

This experiment was done to investigate the "myth" that the amount of mirror relaxation, and hence the pointing drift, is somehow related to the amount that the mirror was adjusted. The commonly held belief is that the more one adjusts the mirror, the more the drift. When initially setting up any optical system, gross adjustments to the mirrors

are often needed. After everything has a chance to relax, there will, according to this belief, be a large amount of drift. However, each subsequent adjustment will be on a smaller scale, resulting in less drift. Eventually, hopefully, one would not have to adjust at all. Sadly, temperature fluctuations overrule any mirror relaxing, so this would never actually happen without precise temperature control.

Procedure

This experiment was conducted using the standard set up. The mirror mount being tested was fit into place, and the beam centered on the camera, about 12 hours before measurements were taken. Mirror relaxing, regardless of the degree, is done on a timescale of a couple hours at most. Thus, after 12 hours, the mirror will be at a completely relaxed state.

The mirror was then adjusted by turning the knobs a set number of rotations in one direction, and then quickly back to their original positions. This was done in a matter of, at most, 10 seconds. Once the beam was back near the center of the screen, as checked on the television, recording was started. Data was taken over the course of an hour at 5 or 10 second intervals, to eliminate some of the noise, and provide a workable amount of data. This also gave the mirror enough time to relax, while keeping temperature effects to a minimum.

This was done with two different mirror mounts. The data was compared within each mount to see if there was any correlation between adjustment and relaxation, and also to study aspects of the relaxation. The different mounts were also compared to each other, to see the more expensive mounts had less relaxing drift that the cheap ones.

Test Run

I first did a test to see if there was anything to the myth at all. I took each mirror in turn, and put the mounts through their full range of rotation. Then I took data at an interval of 5 minutes per mark. Figure 5 shows the resulting data.
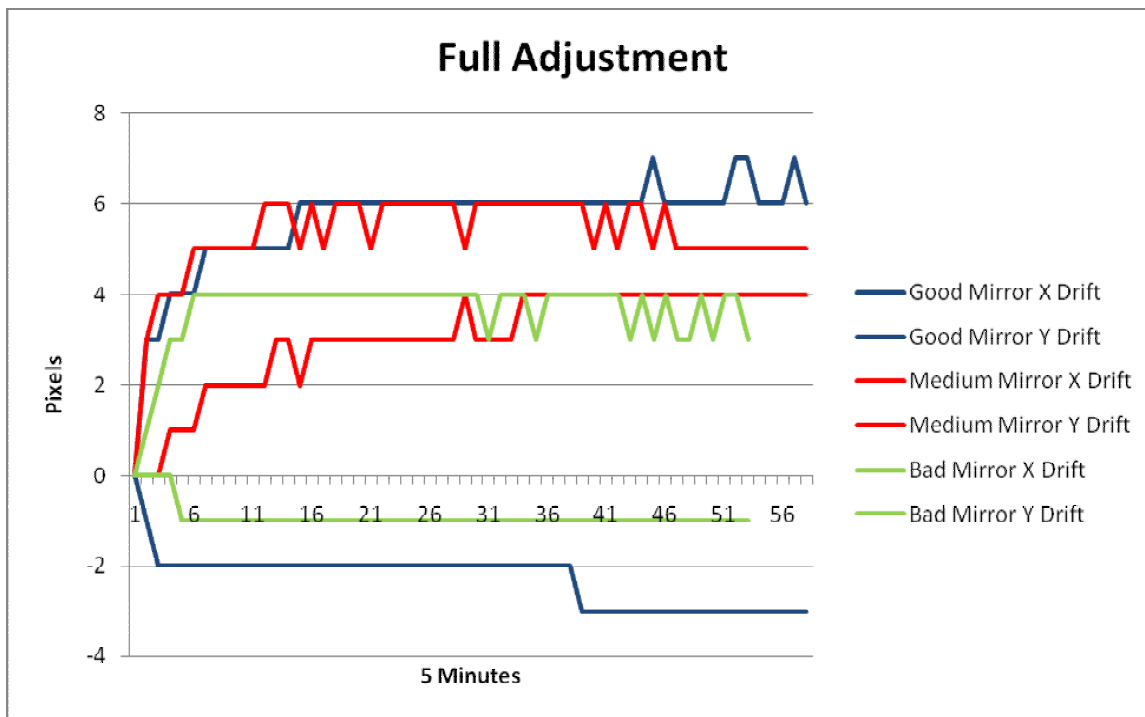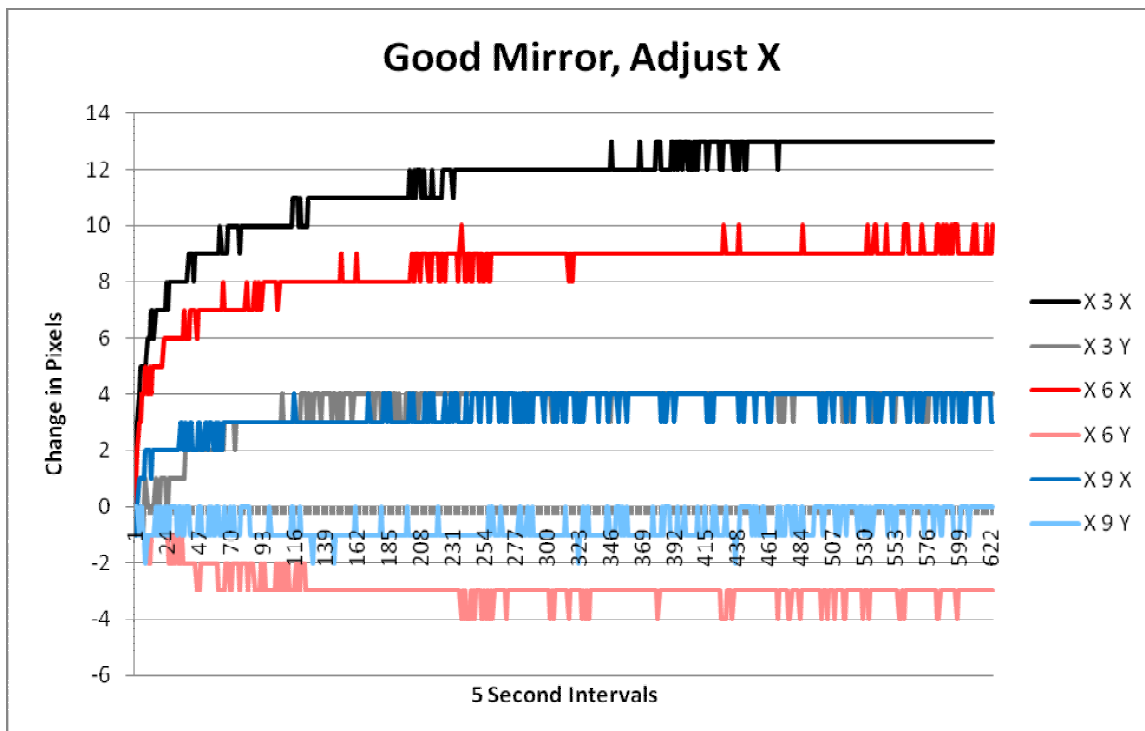
Figure 5: The X and Y coordinates of the center of the beam, taken at five minute intervals, of all three mirror mounts after adjusting them through their full range of motion.

From Figure 5, results looked good enough to proceed. There seemed to be an exponential change in position in most cases, with an evening out after about an hour. At most the change was only seven pixels, and at least one. While the change was not drastic, it was detectable for large adjustments at least.

<u>Adjustment and Drift</u>

From that point, data was then collected over the same mirror, varying the amount

of adjustment. The data was slightly manipulated before it was graphed. Since it was the

change in position that mattered, and not actual position, each data point was subtracted

from the starting value. This resulting point was graphed.

Figure 6: The X and Y coordinates of the center of the beam, taken at five
second intervals, using the good mirror. X 3 X denotes the X value of the center
of the beam when the horizontal knob is turned three revolutions, X 3 Y denotes
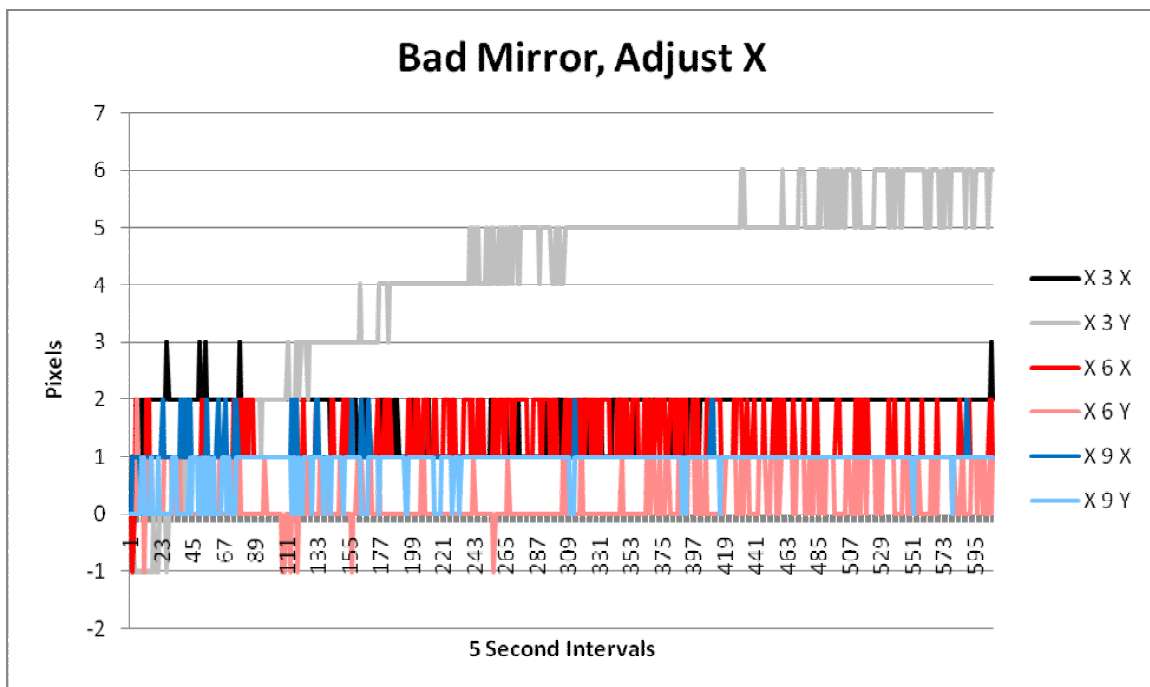the Y value.
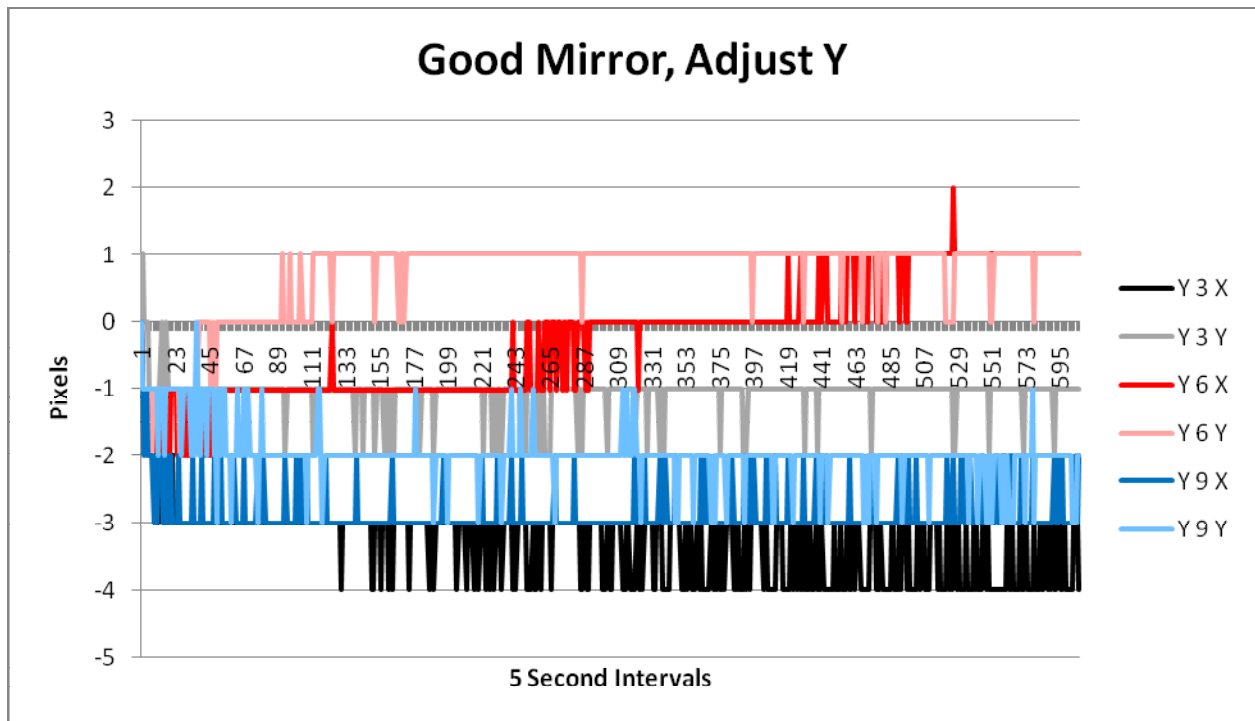
Figure 7: The X and Y coordinates of the center of the beam, taken at five second intervals, using the good mirror. Y 3 X denotes the X value of the center of the beam when the vertical knob is turned three revolutions, Y 3 Y denotes the Y value.

When the good mirror mount was adjusted using the horizontal knob, a pretty picture emerged, as shown in Figure 6. The position changed with roughly the same curve, albeit to different extents. What struck me as strange was the fact that the deviation with three revolutions was greater than that with six, which was greater than nine. This is the opposite of what was expected. More in line with expectations was that the horizontal component drifted more than the vertical. The range of the X drift was 13 to four pixels, whereas the Y drift was from 4 to virtually no change. Also, the horizontal drift was all in a positive direction, or to the right of the camera. There was no clear pattern in the vertical drift.

With the adjustments done to the vertical knob, shown in Figure 7, a different picture emerged. There was no logical hierarchy to relative deviations. There was also no clear curve, as with the horizontal adjustments. The level of drift was also smaller, with the greatest deviation being only 4 pixels. The difference between adjusting the X and Y knobs can be attributed to different mechanics involved in the mirror. However, there seems to be no obvious logic behind the behaviour of the Y drifting.

Figure 8: The X and Y coordinates of the center of the beam, taken at five second intervals, using the bad mirror. X 3 X denotes the X value of the center of the beam when the horizontal knob is turned three revolutions, X 3 Y denotes the Y value.
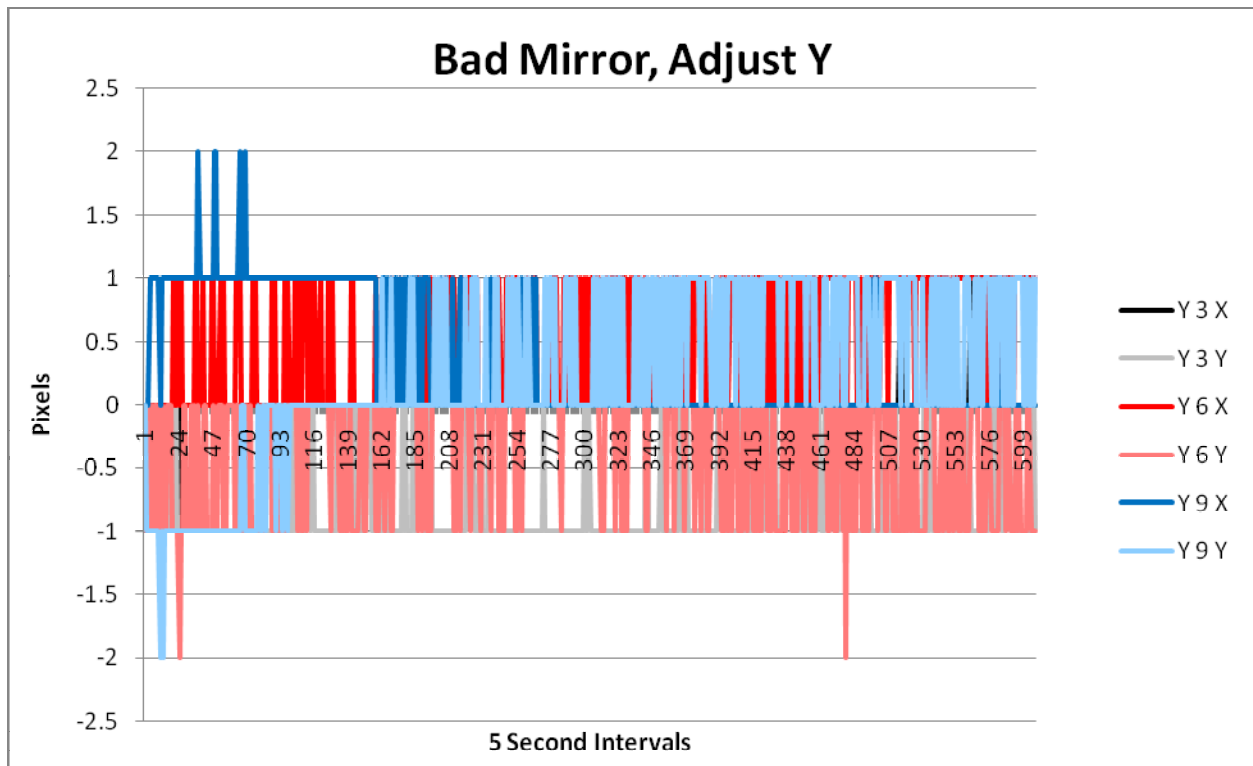
Figure 9: The X and Y coordinates of the center of the beam, taken at five second intervals, using the good mirror. Y 3 X denotes the X value of the center of the beam when the vertical knob is turned three revolutions, Y 3 Y denotes the Y value.

Figures 8 and 9 show the behavior of the bad mirror. The bad mirror, besides one random spike, does not show really any drift. There is also no strong correlation between the number of rotations and the drift. With the horizontal adjustments, all of the changes in position seemed to be in the same direction, but this is not the case with the vertical adjustments. It seems that the bad mirror is not very affected by adjustments, especially on the vertical knob.

Conclusion

The hypothesis that the amount of deviation was proportional to the amount of adjustment proved to be false. Also, in terms of drift after adjustment, the good and bad

mirrors are not aptly named. The bad mirror was more resistant to adjustment drift than the good. Adjustment drift behavior apparently depends on the type and construction of the mirror. I was hoping that there would be some general trends across mirrors, but this is not the case. The initial test data ended up differing from the subsequent data. This was probably because with the initial data set, the mirrors were mounted immediately prior to the experiment taking place. Thus, the observed drift was due not to the adjustment, but to the mirrors settling into their mounts. This phenomenon can explain where the hypothesis came from. The mirrors relaxing in the mounts coincide with the gross adjustments, and the cause of the drift was relegated to the wrong action. Relaxation drift mostly comes from mirror mount, and not any internal workings of the mirrors themselves.

Temperature

<u>Motivation</u>

Besides mirror relaxing, another culprit behind pointing drift is temperature change. Laser systems frequently require many components aligned precisely. Even if mirror relaxing and other mechanical problems are taken care of, there is still a problem with temperature changes throwing off alignment. When a material heats or cools, it expands or contracts. As the many components used are made up of many different materials, this expansion or contraction is done at different rates and to different degrees. Thus, the laser will drift when there is a temperature change. Various experiments were

conducted in an attempt to understand the effects of temperature changes on laser systems.

It is very expensive to house laser systems in labs with complete temperature control. Most labs, including the one these experiments were done in, have a very simple heating system. The air temperature is detected at some point, and when it differs from a target value, appropriately hot or cool air is pumped into the room until the correct temperature is detected. This system allows for a lot of leeway in terms of the temperature of the equipment. The whole heating/cooling system is very slow to respond. By the time corrective air reaches the equipment, pointing may have been thrown off considerably. Thus, this is a matter that affects many systems, and deserves looking into.

One of the first questions posed was whether a system, once heated, will return to its original alignment when it returns to its original temperature. Looking at the simple setup, it was decided to focus on the mirror and mount to test this. The reasoning behind this being that the table everything sits on is specially designed not to vary with temperature by much. Also, unless the heating or cooling is very specific, it will expand or contract at a uniform rate, leading to a small contribution to pointing instability. The laser and the camera are both rather large and solid, and thus will also affect pointing in an insignificant way. The mirror is small, composed of many parts, and is the most likely candidate through which temperature can affect a laser system.

Hair Dryer

To test the return position of the mirror after spot heating, a hairdryer was used. The mirror was positioned so that the laser spot was centered on the camera well before

hand, so that there was no drift due to mechanical relaxation. The experiment was conducted during the day so that there was no change in ambient temperature that would contaminate the results. The mirror sat at the opposite end of the table from the laser and the camera, isolated so that it would be the only thing getting heated. The hairdryer was applied to the back of the mirror, heating until there was a noticeable and significant drift. Then the hairdryer was turned off. The mirror then cooled down, which made the point drift back. The final pointing was noted.

This experiment was first conducted using the bad mirror. The blow dryer was turned on for 30 seconds prior to it being pointed at the mirror, so that it would be warmed up. The blow dryer was then pointed at the back of the mirror for a period of about 30 seconds. Then it was turned off and removed. The data was recorded at a rate of approximately 3 points per second.
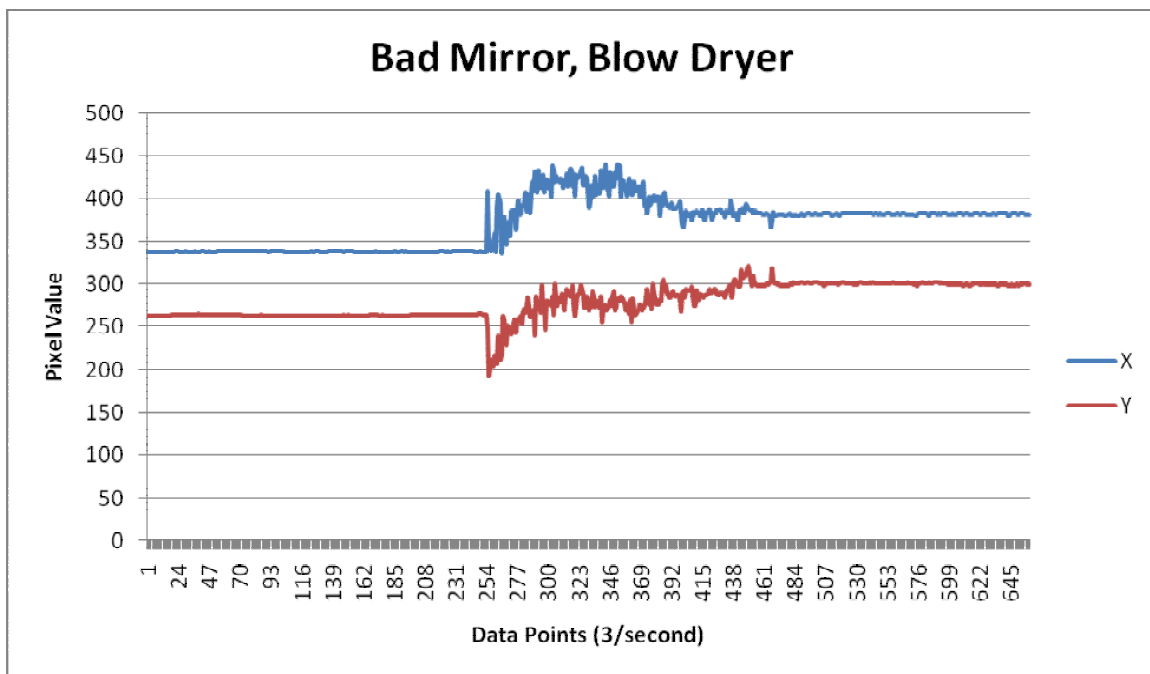
Figure 10: The X and Y coordinates of the center of the beam. The mirror was subject to a blow dryer for a short time from data points 250 to 370.

The first 200 or so data points of Figure 10 establish the resting position of the beam. When the blow dryer was applied, a smooth curve of some sort was expected. What was seen, however, was a lot of wiggling movement. The laser point jumped around in a seemingly random pattern. Looking at the gross movement of the beam, a curve is apparent. This suggests that the mirror is heating up, which creates a net movement of the mirror that changes the base from which the smaller deviations occur. The blow dryer was applied for about 30 seconds, and there is a change in the gross motion of the beam around 350, as expected. From there, the x value falls, and the y value continues to rise. Eventually, both coordinates settle as the mirror returns to room temperature. The point where the beam settles is different from the original resting place of the beam. From this I would have liked to conclude that there is some thermal memory to the mirror, and that a change in temperature leads to a change in position even after the original temperature is reestablished. However, the odd behavior of the pointing gave me pause.

The jumping around of the pointing meant to me that more was acting on the mirror than just heat. Since I had used the bad mirror initially, I though I would repeat the experiment, using the much bulkier good mirror. I hoped that it would cut down on the amount of pointing oscilation.
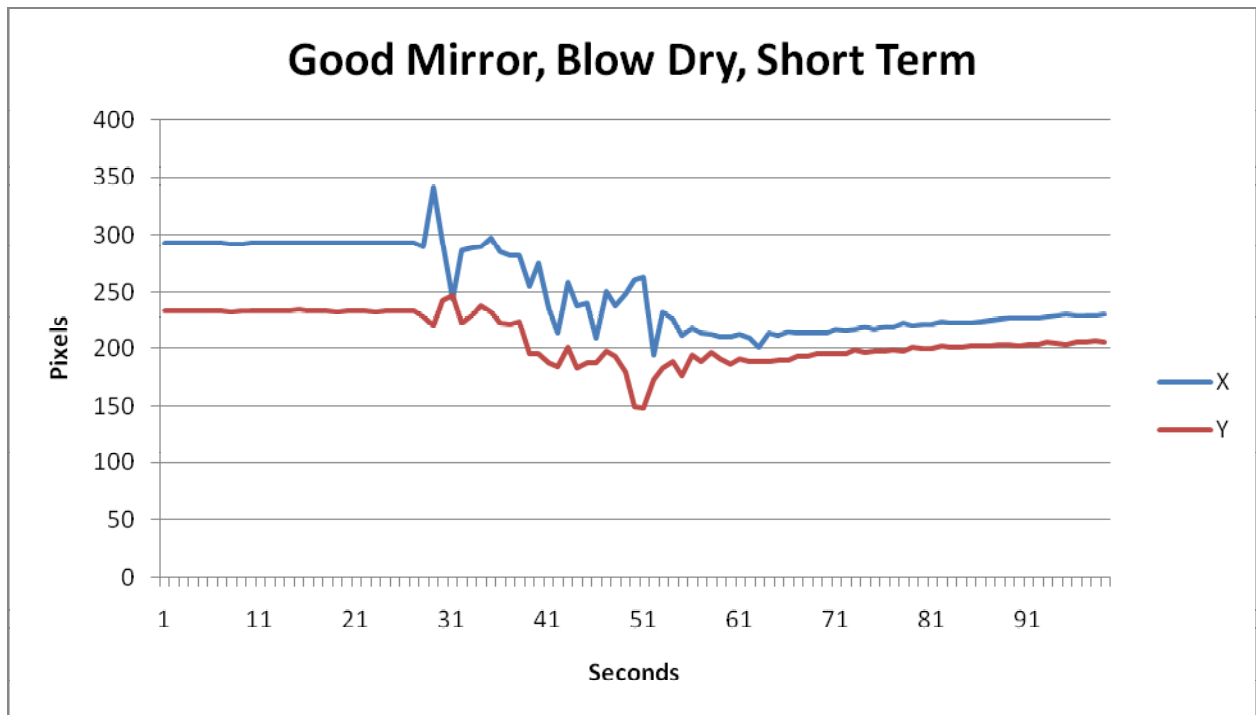
Figure 11: The X and Y coordinates of the center of the beam. The mirror was subject to a blow dryer for a short time, from t = 29 seconds to t = 52 seconds. The period of disturbance is highlighted.

This trial, shown in Figure 11, was run similarly to the first. The beam was left alone for the first 30 seconds, then the blow dryer was applied for 30 seconds, and then the beam was left alone for the remainder. The pointing behaves in this situation much as it did in the last. Once the blow dryer is applied around 29 seconds, the pointing jumps around. At t = 52, the blow dryer turns off, and still there is odd pointing behavior. However, eventually it calms down, and begins to rise again.
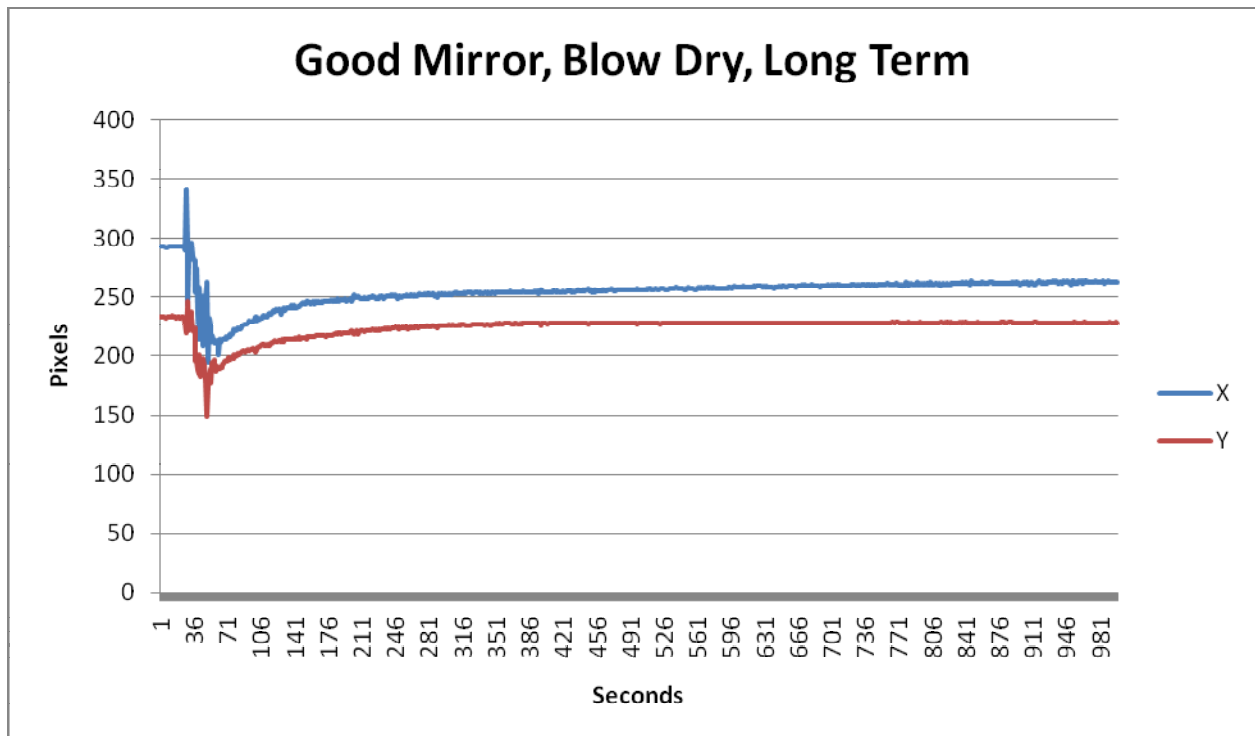
Figure 12: The X and Y coordinates of the center of the beam. The mirror was subject to a blow dryer for a short time, from t = 29 seconds to t = 52 seconds. This shows the behavior of the beam over a long period, letting the mirror mount cool.

Figure 12 shows a graph of the beam pointing in the long term. The pointing, after the heating rose quickly at first, then slowly tended back towards the original position. However, it never fully recovered to its starting place. Again, I would like to say that temperature changes result in a permanent deviation of pointing. First, some other new questions must be looked into.

Air Turbulance

The first mystery was the odd pointing action. Instead of a nice, smooth curve when warming, there exists a jagged pattern. This is due apparently to the air motion

inherent to a blow dryer. Although heat was the only desired output, wind was produced as well. I then tried to find what effect, if any, the wind had on the system.

Before looking at the effect of the air stream on the mirror itself, I looked to see if the moving air had any effect on the beam alone. For the above experiment, I used the good and heavier mirror and a sample rate of one point per second. I took the blow dryer and directed the air stream through the path of the beam, in both directions, yet avoided all optics. The blow dryer only interferred with the air the beam traveled through. I took data for about 30 seconds to establish a resting position, and then applied the air stream for another 30 seconds, and then turned it off. The below graph shows the results.
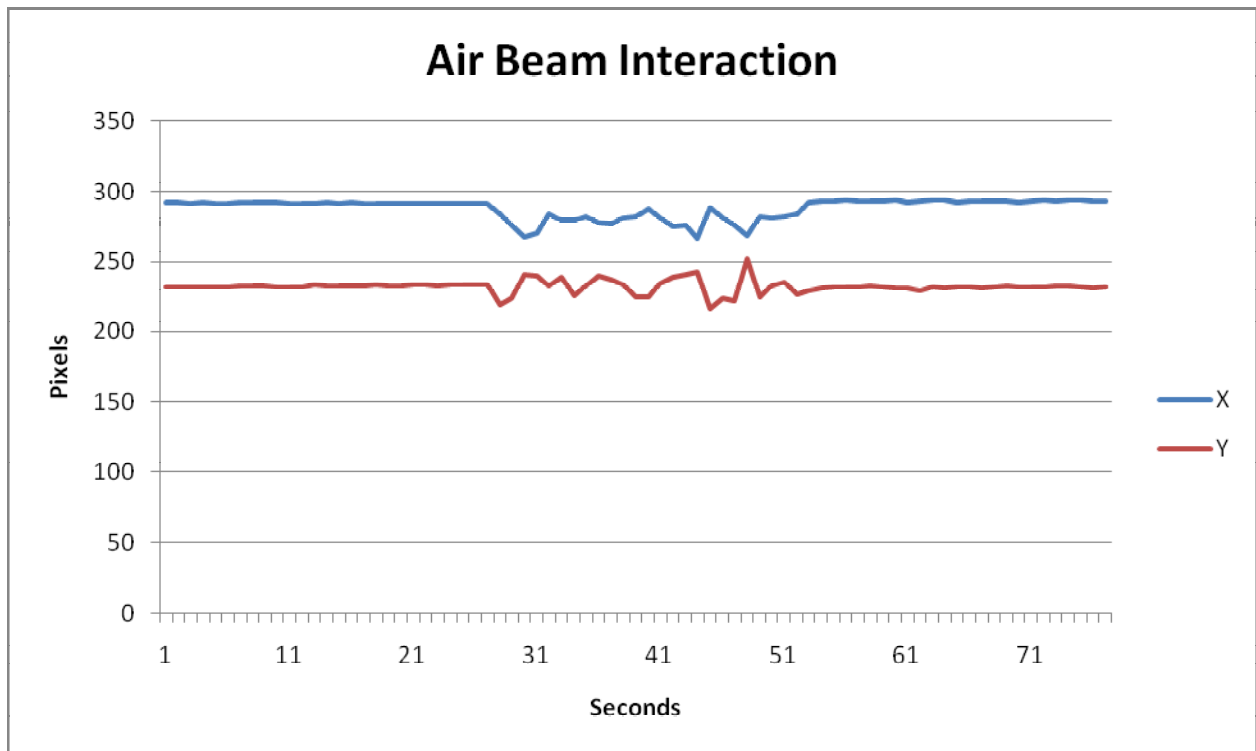
Figure 13: The X and Y coordinate of the center of the beam. A blow dryer was applied to the airspace of the beam between t = 25 and t = 53.

Figure 13 shows that simply disturbing the air through which the laser beam passes will create a noticable disturbance in the pointing. However, this effect is clearly temporary. After the air stream is removed, the pointing returns to its original value. This makes sense, as no element of the laser system was changed in any way.

Looking at the effect that a blow dryer had on the pointing, I wondered if the simple act of breathing in the area of the beam would create a noticible disturbance. To test this, I used the same setup as the blow dryer experiment, but using the streamlined version of the tracking program, and thus able to take 5 data points a second. I put my face about 5 inches from the beam, away from any equipment. For the space of 50 or so data points, I took resting data, then from 65-108 I breathed normally, then went away.
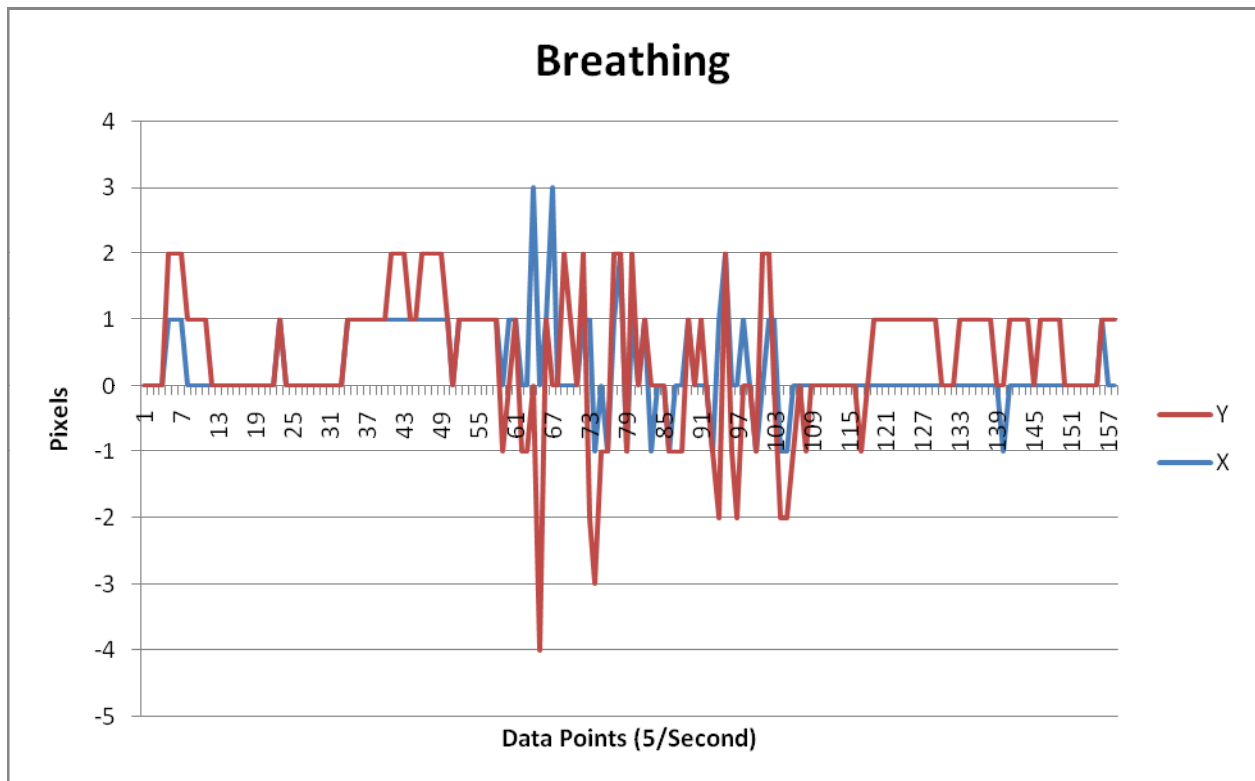
Figure 14: The X and Y coordinates of the center of the beam. The air turbulence produced by normal breathing was directed at the airspace of the beam between data points 65 and 108.

From Figure 14, it is rather clear that the simple act of breathing had an effect on beam pointing. Granted, it is not a large effect, producing deviations only twice as large as normal resting deviation. However, for an extremely sensative system, this could be an issue. I had not previously expected that disturbing the air in the vicinity of a laser beam would affect it. Looking at this data, I have to conclude that there is in fact a danger that air movement in the area of an experiment could affect said experiment. A laser system should be guarded against not only vibration and temperature, but from air movement as well. This is warning against yet another precaution needing to be taken to preserve laser system stability.

After it had been established that simply disturbing the air through which the beam travels affects pointing, I next tried to see what effect wind had when applied directly to the mirror. This would create a somewhat similar pattern to what was seen before, as the air is disturbed, but any additional drift might signify that there was a mechanical reason behind the previously observed drift, and not just a temperature related one. I tried to test this using the good mirror again, and the streamlined LabVIEW program with its 5 data points a second. For the first 50 points, I did nothing. From about 60 to 120, I blew on the back of the mirror, trying to simulate the blow dryer without the heat. I tried as much as possible to blow only cool air. From 120 on, I did nothing.
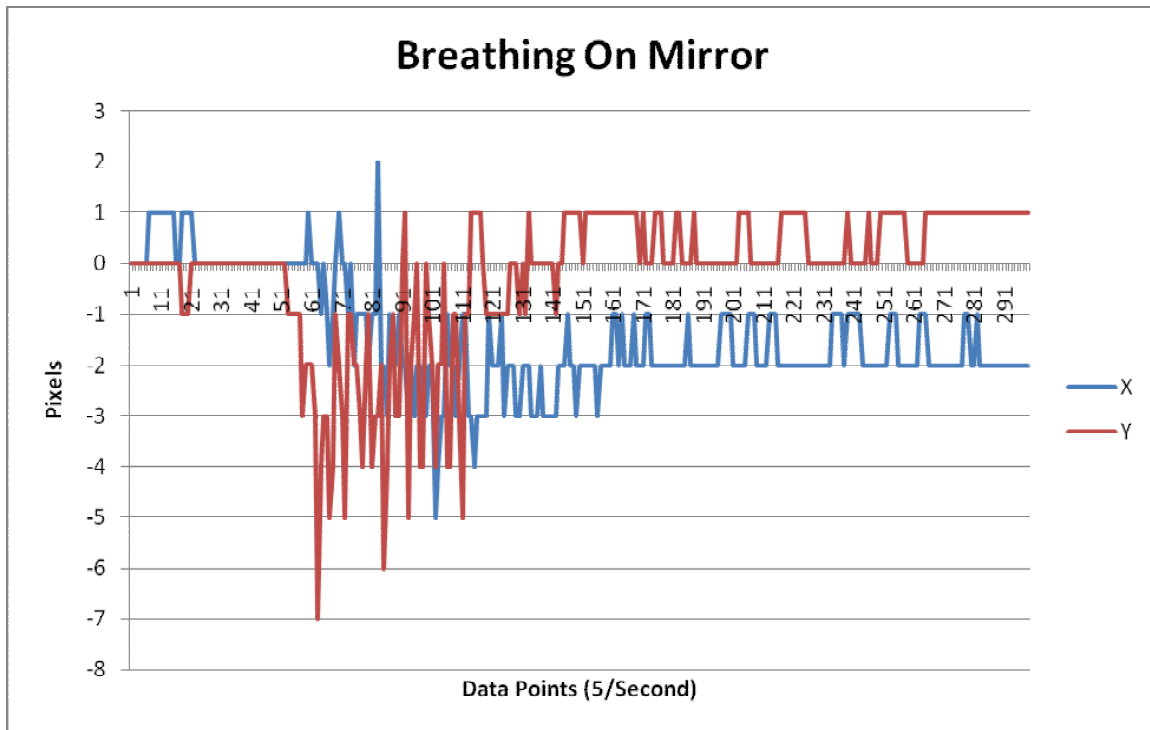
Figure 15: The X and Y coordinates of the center of the beam. The back of the good mirror was blown on between data points 60 and 120.

From Figure 15, it is clear that blowing on the mirror had some effect on the pointing of the beam. Besides the temporary disturbance of the air, the long term pointing was changed, if only by a little. However, as the mirrors had already proven to be extermely sensative to heating, and it is impossible to not blow hot air, I did one more test.

To isolate the effect of airflow on the mirror, independent of temperature, I used a paper fan. This utilized the ambient air of the room, which should not cause a change in temperature of the mirror. The fan was applied between data points 50 and 110.
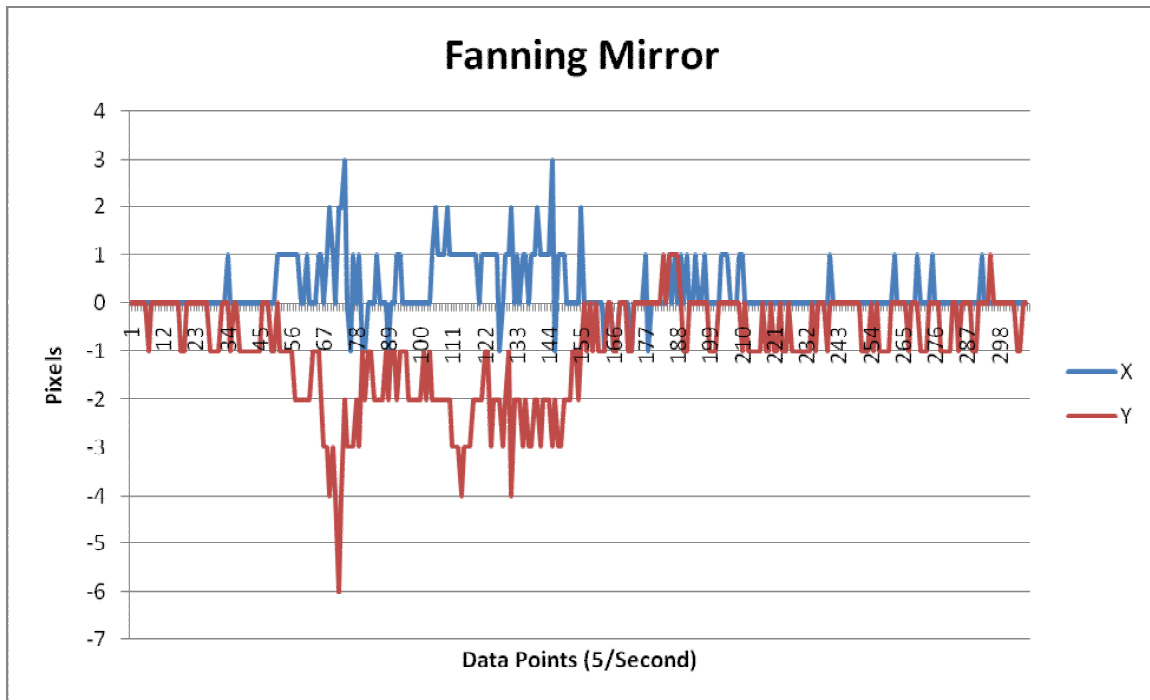
Figure 16: The X and Y coordinates of the center of the beam. A fan was applied to the back of the mirror between points 50 and 110.

From Figure 16, it appears that pure air turbulence does not permanently affect beam pointing. The deviation due to disturbance by fan was comparable to that of breathing. With the fan there was no pointing drift though. Thus, it can be concluded that the beam drift seen in the breathing experiment was due to temperature change. While a sufficiently strong wind can probably blow the mirror out of alignment, minimal airflow such as this can only temporarily cause fluctuations in the beam, while temperature cycling may have a permanent effect.

Heat Gun

While a little wind was seen to have no effect on permanent beam pointing, it would be best to not have to worry about wind at all. Also, since the focus of this investigation was on temperature, it would be best to isolate it as much as possible. So, it

was decided to deliver heat by convection. A heat gun was used to heat a piece of metal mounted on a stand to about 120 degrees Celsius. This was then placed behind the mirror. Heat would radiate off the piece of metal, and warm the mirror, without creating much air turbulence.

A starting temperature of the back of the mirror was taken using an IR temperature gun. The pointing was then recorded for a time, to get a resting position. Then, the heated piece of metal was placed behind the mirror for about 30 seconds. The metal was then removed, and data was taken until the mirror had regained its original temperature.
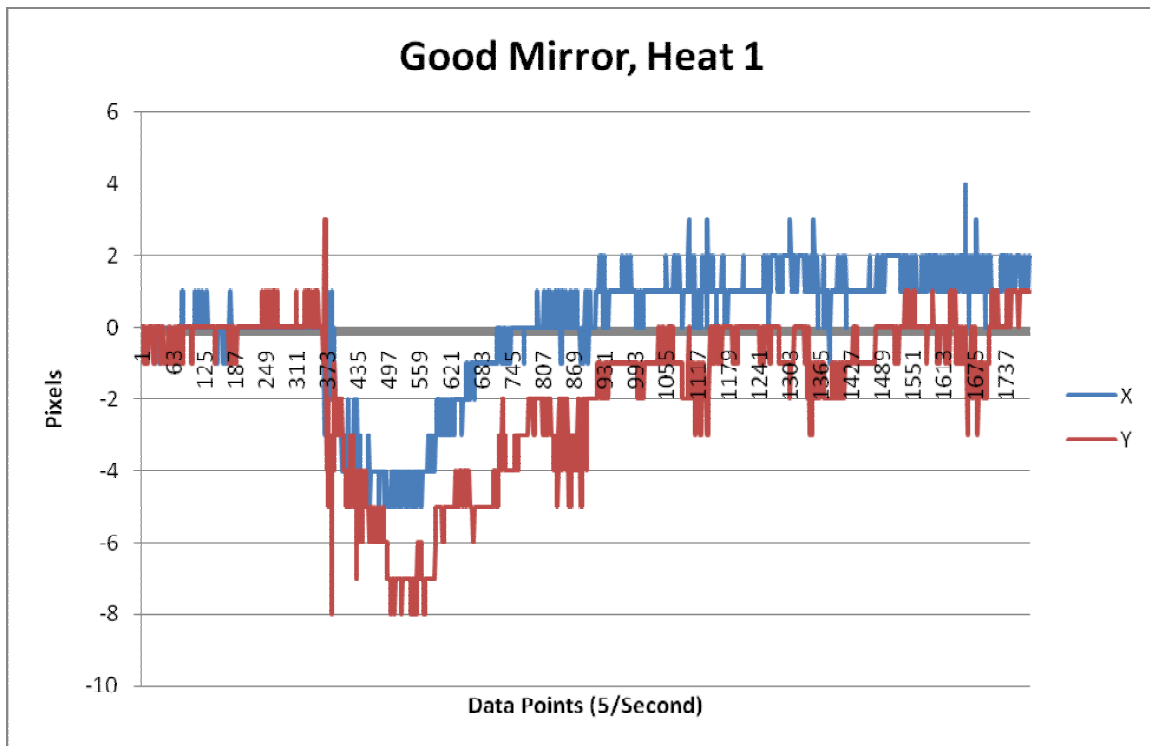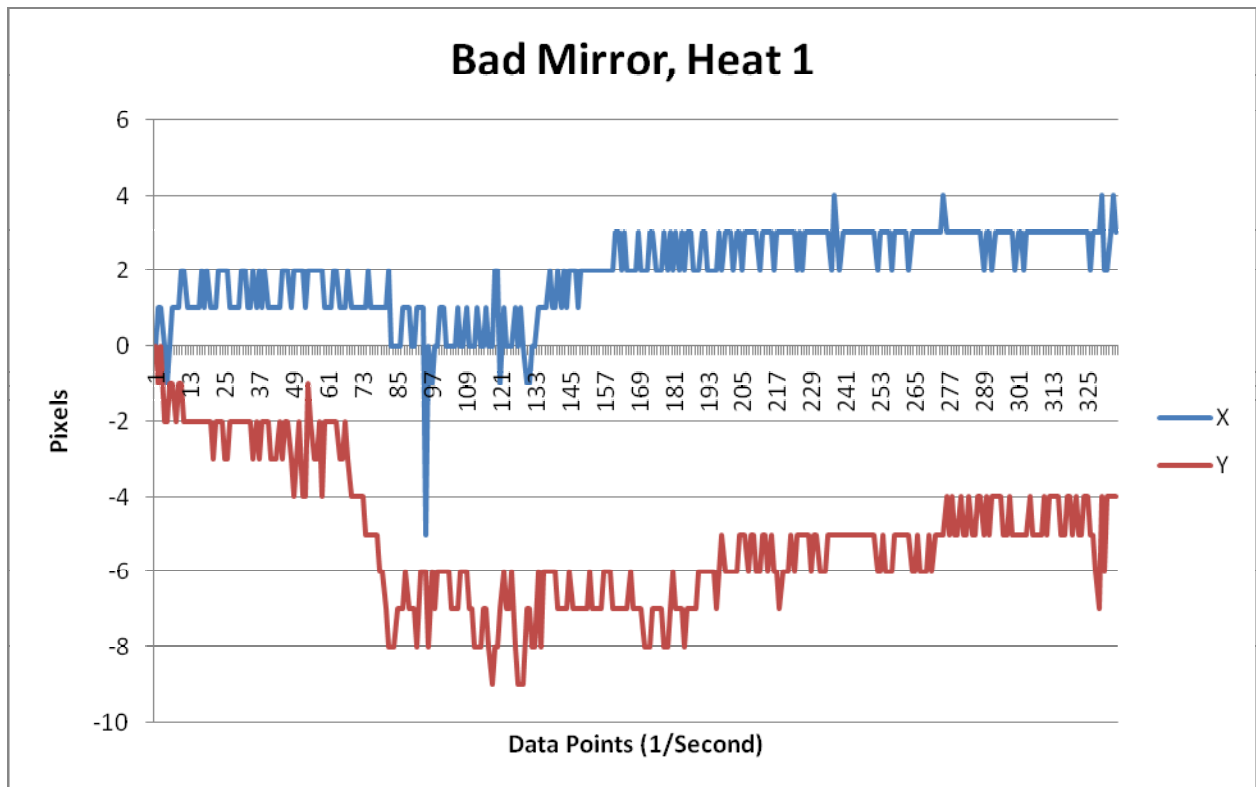
Figure 17: Heat was applied to the back of the good mirror via convection for a short period of time. The mirror was then allowed to cool to its original temperature.
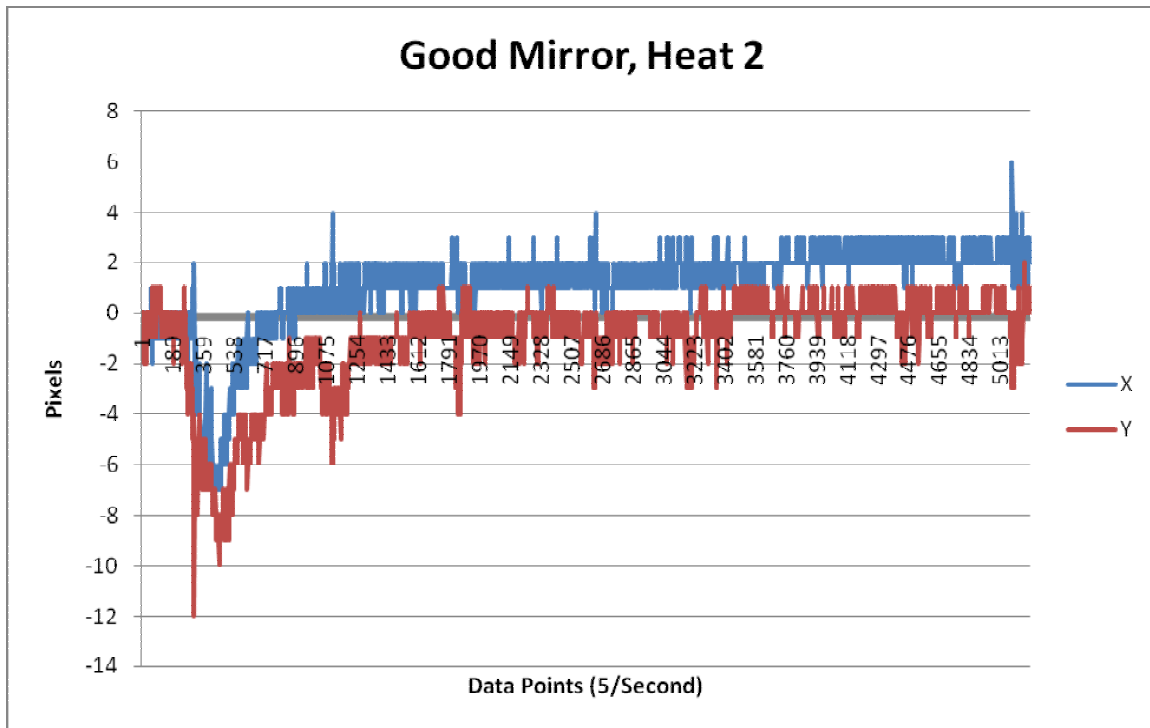
Figure 18: Heat was applied to the back of the good mirror via convection for a short period of time. The mirror was then allowed to cool to its original temperature.

For both the above trials, shown in Figures 17 and 18, the mirror and mount started at 21 degrees Celcius. The metal plate was heated to about 120 degrees Celcius. After heating, the back of the mirror reached a temperature of 22.9. So, the mirror rose only 1 degree, which translated into a displacement of about 8 to 10 pixels at most. In both trials, the Y direction was affected more that the X. There was a relatively steep climb as the mirror heated, and a more gradual one as it cooled down. This is to be expected. What is interesting is that the beam moved in the same direction when the mirror was heated, down and left on the camera. The beam, although moving the most in the vertical direction, returned to tis original position. There was a net horizontal effect of about 2 pixels, however. This drift occurred in the opposite direction from the heating drift. It was like the mirror overcorrected itself.

Figure 19: Heat was applied to the back of the bad mirror via convection for a short period of time. The mirror was then allowed to cool to its original temperature.
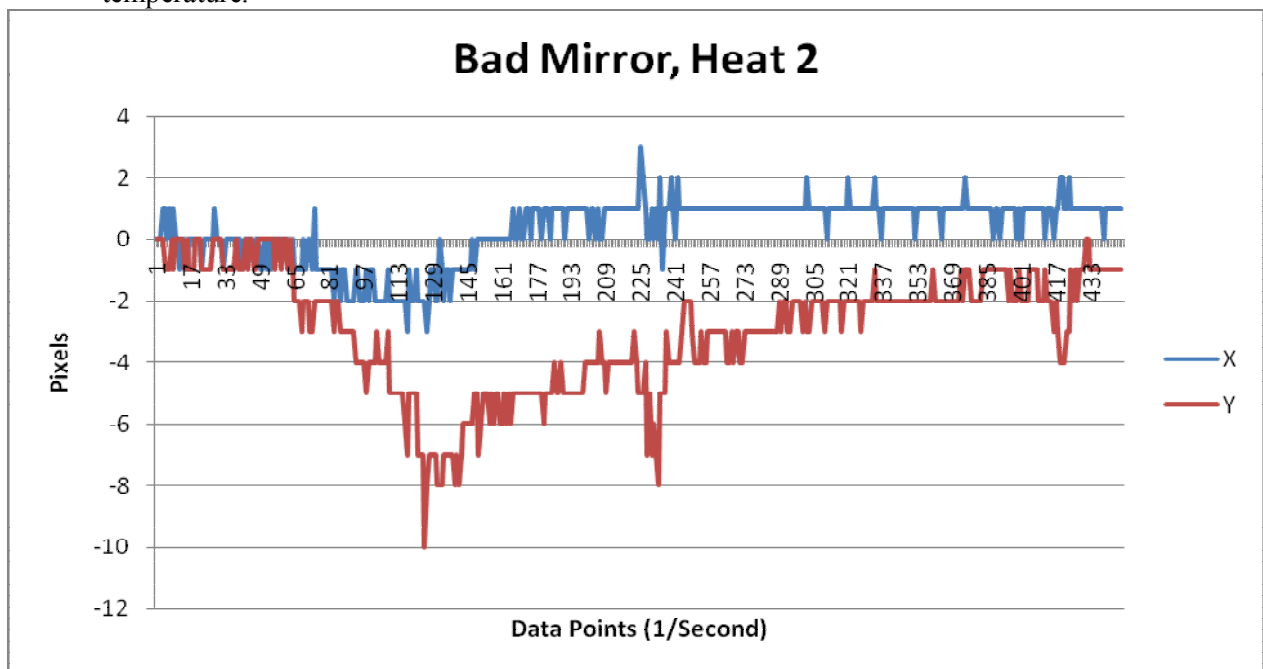
Figure 20: Heat was applied to the back of the bad mirror via convection for a short period of time. The mirror was then allowed to cool to its original temperature.

Figures 19 and 20 show the results of the bad mirror mount. The bad mount had a starting temperature of 21.6 degrees Celsius in both trials. The metal plate was heated to about 120, and the maximum temperature reached by the mount was about 22.6. Again, there was an increase of one degree Celsius on the back of the mount. However, the bad mirror behaved differently from the good mirror when heated. This can be understood, since their construction, materials, and mechanisms are different. These differences apparently contribute to different actions under temperature changes. There was a maximum vertical displacement of about 8 pixels in both cases, while the horizontal displacement was minimal. The trend of the beam to drift down and to the left continued from the good mirror mount. The vertical displacement also showed the relatively rapid ascent and slower descent curve, while the horizontal displacement was too small to show anything. The X value eventually ended up overcorrecting itself for a net gain of about one pixel. The Y value never fully recovered from its initial drop, and remained two to four pixels below starting.

In both mirrors, a one degree Celsius temperature change equated to a maximum pointing change of about 10 pixels in the good mirror, and 9 pixels in the bad. Overall, the good mirror is more susceptible to heat, with a greater permanent deviation. However, in both cases, a change in temperature resulted in a small permanent change in pointing. This means that heat cycles will change alignment. And since in both trials both mirror mounts changed in roughly the same direction, repeated heat cycling will result in greater deviations.

Conclusions

The purpose of this project was to track down and analyze laser beam pointing deviations. To that end, an accurate yet simple beam pointing tracking system was created and implemented. This system can be easily reproduced and used to answer any questions that might arise from a unique setup or different equipment. In regards to pointing deviation due to mechanical relaxation, it was concluded that adjustments made to the mirror via the knobs are not always a significant factor, and final pointing drift is not proportional to the amount of adjustment. Air turbulance can cause temporary disruption of beam pointing, and even a weak breeze can have an effect. The greatest source of beam deviation was temperature. The pointing could be disrupted by the slighest change in temperature of the mirror. A change of as little as one degree Celsius can permanently change the beam pointing. Also, as the changes tended to the same direction, repeated temperature changes can result in large deviations.

Thus, if a stable laser system is desired, it is our recommendation to do the following. Wait about an hour after a mirror is mounted before settling on a final pointing position. Be careful when adjusting the mirrors, as the one that is being used may be subject to drift. However, this is not a great concern. The money spent on mirror mounts reflect their precision when it comes to adjusting them, not their stability or sensitivity. Also, be wary of air currents during operation of the beam. The breeze coming through an open door, or the breath of someone near the path of the beam can be enough to interfere with the pointing. The biggest warning is to keep the temperature of the room and the mirror as constant as possible. If there is a change of even one degree,

be prepared to recalibrate the system, even if the temperature returns to its original value.

In terms of beam pointing, a laser system can be extremely sensitive to environmental

stresses.

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