Optical Tweezers: Lab Report

Ishaan Aggarwal

Submitted to: Dr. Paul Haljan
PHYS 332W
06-04-2023

1 Executive Summary

Since I missed a lot of lab days due to my absence, this report is going to focus on my work on the one full lab session conducted on April 4^{th}. The work in this lab is to explore optical tweezers and analyze the motion experienced during trapping. The lab followed the lab-script *Optical Tweezers: Instrumentation* posted on canvas, however it was modified after setup due to me missing lab sessions. The goals for this lab is to collect data for untrapped and trapped particles and use the data to analyze the different forces affecting the beads, while trying to complete as much of the analysis as possible, being able to produce figures which match the data collected during that lab session.

In the beginning of the lab session the main work was on the calibration of the trap. I was present for this step of the lab and set up the apparatus. The apparatus is setup according to fig 1. The work for this lab session is summarized in lab sessions 1 and 2 which are attached as a separate document to this assignment.

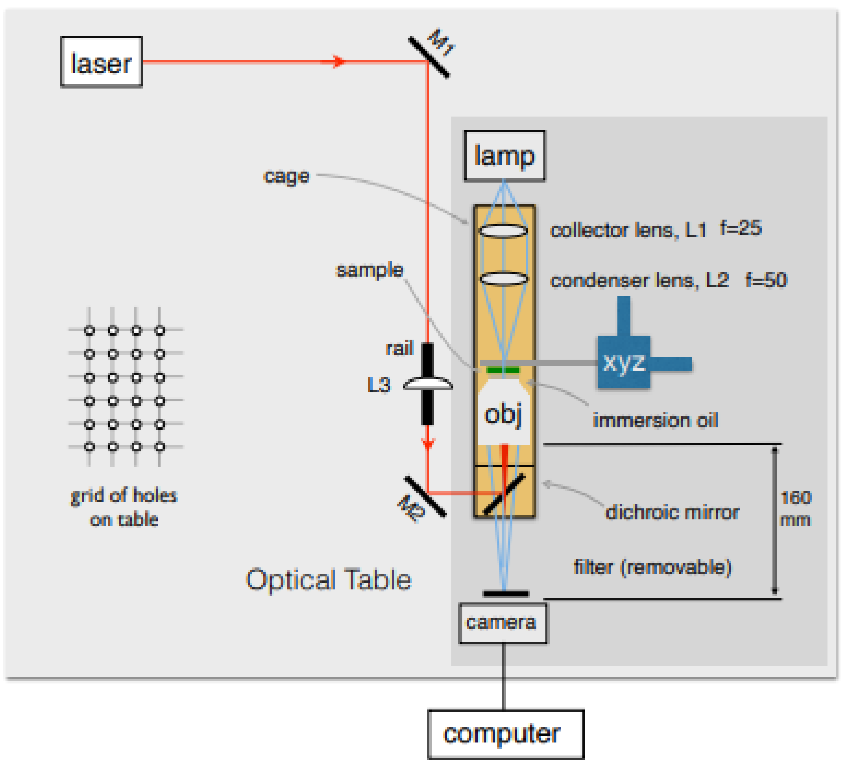


Figure 1: Schematic of the apparatus set up in the lab

The next part of the lab for me was trapping a bead and measuring the fluctuations of the bead when it was trapped vs when it was not trapped. The important distinction here was on two things. The reproducibility of the experiment, and the ability to use the untrapped bead's fluctuations to understand the motions of the bead over time. The main constrait faced here was lack of time in the lab.

Initially I decided to choose $80.6mW$ of laser intensity power. I did not choose a full laser power as I wanted the bead to be able to experience fluctuations under the trap. If the laser beam was on full power, which in this case for the laser is $0.210W$, then the bead would not fluctuate due to random motions, and this would not allow us to see the difference between the trapped and the untrapped bead. The main problem that I encountered during this time was the time under trapping of the bead. The bead over time would "jump" out of trapping and not stay trapped for the duration of the experiment. The real reason is unknown, and had I had more time I would definitely study it more but my preliminary reasoning for this is that the activation energy that the particle needed was overcome and the particle then fell out of the trap.

To combat this problem to be able to collect enough data points for the analysis, I chose a slightly higher power intensity of the laser at $125mW$. When I did some practice runs with this intensity I found that the bead was able to stay in the trap for 5 minutes which is the time I needed for gathering the experimental data.

The analysis for this lab took a longer time than expected due to the graphing of the different models and fitting functions to them. The main packages used were the matplotlib, numpy and scipy packages of python. The hurdle was learning to fit functions onto histogram which is well documented but a new learning experience for me. The results are shown in the results section of the document. The main result as we can see from figures 2 and 7, is the difference between the two fluctuations. This is due to the difference in thermal fluctuations felt by the trapped particle as opposed to the untrapped particle.

In the future, or if I had more time, I would like to explore why the beads were leaving the trap after some time. It will be an interesting problem to document about and explore.

2 Prelab Theory

The theory which is important to what I am focusing on today is the movement of a trapped bead vs an untrapped bead and comparison of the fluctuations of an untrapped bead which provides a control signal to be able to remove noise from the system.

The untrapped bead is subjected to the same intense light but is not trapped, as the laser is not directly on the bead. The important forces which could provide fluctuations in this bead are: Electrostatic forces: If the free-floating particle is charged, it may experience electrostatic forces due to the presence of other charged particles in the fluid. Hydrodynamic drag: The free-floating particle may experience drag forces from the surrounding fluid, which can influence its motion and behavior. The magnitude of this force depends on the viscosity of the fluid and the size and shape of the particle. Most importantly (the most dominant force observed) is motion due to thermal fluctuations. This is not due to the laser but because the system is not observed at absolute zero the free floating particle is subject to thermal forces due to containing some energy.

The trapped particle is then experiencing forces due to the optical trap. The forces on the trapped particle is a balance of 3 forces: Radiation pressure force: The primary force that holds the trapped particle in the optical trap is the radiation pressure force. When the laser beam is focused on the particle, the photons in the beam scatter off the particle and impart a small amount of momentum to it. This momentum transfer creates a net force that pushes the particle towards the center of the trap, where the intensity of the laser beam is highest. Gradient force: The gradient force arises due to the variation in the intensity of the laser beam along the direction of propagation. This force acts to pull the particle towards regions of higher intensity, and it is particularly strong near the edges of the trap. Scattering force: The scattering force is similar to the radiation pressure force but acts in the opposite direction. It arises due to the scattering of light by the particle and acts to push the particle away from the center of the trap.

3 Documentation

The goals for this lab is to collect data for untrapped and trapped particles and use the data to analyze the different forces affecting the beads, while trying to complete as much of the analysis as possible, being able to produce figures as outlined in *optical tweezers: instrumentation* lab script which is posted on Canvas.

2:00 - beginning of the lab is now going to be to check calibration data of the beads. I am going to try and trap beads and check how well the trap works and how the data looks under analysis.

2:30 - trap check is complete, as the trap is functioning as it should. I am choosing to use a power on the laser of $80.5mW$, as this will allow for a trap to be set but not so stiff as to block the movement of the bead under the laser.

3:30 - There is some problem in the trap where the bead is being trapped for a little bit of time and then becoming untrapped. I am qualitatively observing the bead, and around the 2 minute mark the bead seems to become untrapped. This could be due to the misalignment of the laser with the bead, and not being at the right distance to be trapped.

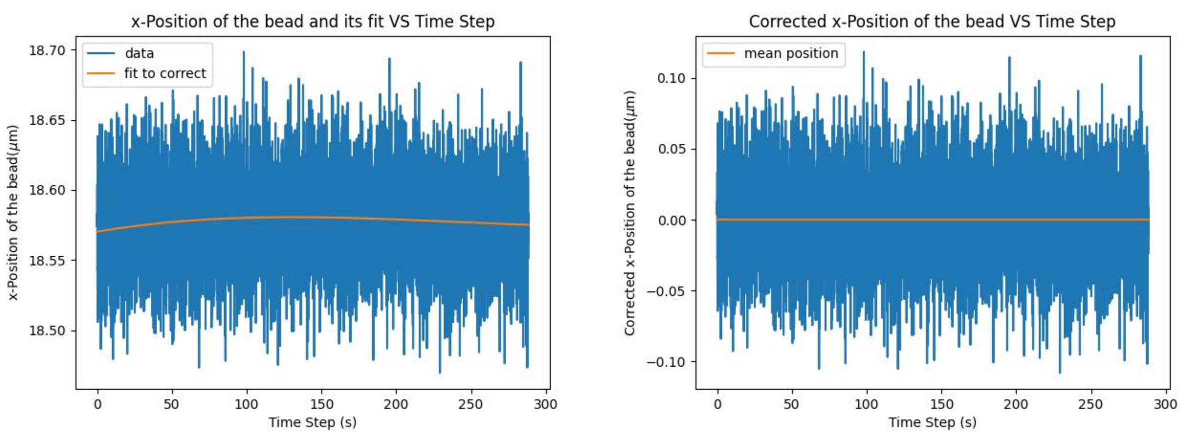
4:10 - The problem is still occurring. Thinking about the problem in greater detail, I think that the problem could be due to randomization of energy. I think that the way to combat this due to low time in the lab is to up the trap intensity and see if that makes a difference. This should increase the trap strength and should be able to trap the bead for a longer period of time.

4:25 - I have now put in laser intensity of $125mW$. Now the trap is holding for the duration of the trap. I have a low amount of time but if I did have more time I would like to explore the behaviour that I saw.

5:30 - I was able to collect all of the data needed and will be conducting the analysis. The analysis work is described under analysis section. For the analysis of this lab, there is a lot of work to correct the data. Since I have so many runs collected I will be working with a lot of different data and trying to use the best data amongst them. The code is designed so that I can showcase 4 things in the data collected: The time series of Brownian motion, auto-correlation function, histogram of the position + fit + residuals, and the plot of potential energy as a function of position.

4 Results

The following are the results for the untrapped bead. The fluctuation in the motion as you can see from 2 is quite minimal. This is as expected from the motion as there is minimal Brownian motion within the system. Figure 5, showcases the histogram of the untrapped bead which we can see has a large concentration at the mean position of the bead itself. Figure 4, shows the auto-correlation of the untrapped bead. As expected in this case we see the data as an decay equation type graph which means that the auto-correlation is close to being perfect. Figure 6 shows the temporal correlation of the x and y positioning of the bead. Since the graph shape resembles a disk we can say that there is no bias in the system of a drift or randomization. There are however lots of outlier points due to the random occurrences which can happen at the table and surroundings of the lab setting.

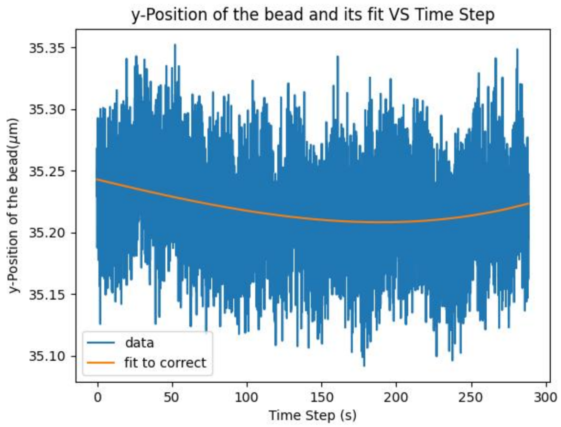


(a) Subfigure 1a

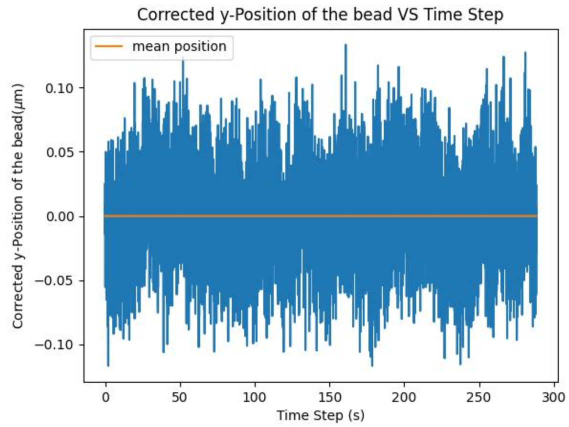
(b) Subfigure 1b

Figure 2: This figure showcases the uncorrected (raw) motion which is shown in sub-figure 1a, and the corrected motion with the mean positioning of the bead in sub-figure 1b. This motion for the x positing of the bead.

The following are the results for the trapped bead. The fluctuation in the motion as you can see from 7 is quite minimal. This is as expected from the motion as there is minimal Brownian motion within the system. Figure ‘ 10, showcases the histogram of the trapped bead which we can see has a large concentration at the mean position of the bead itself. Figure 9, shows the auto-correlation of the trapped bead. As expected in this case we see the data as an decay equation type graph which means that the auto-correlation is close to being perfect. Figure 11 shows the potential energy function of the x and y positioning of the bead. Here the fit of the energy function is not optimal due to the high fluctuation of the positioning of the bead.

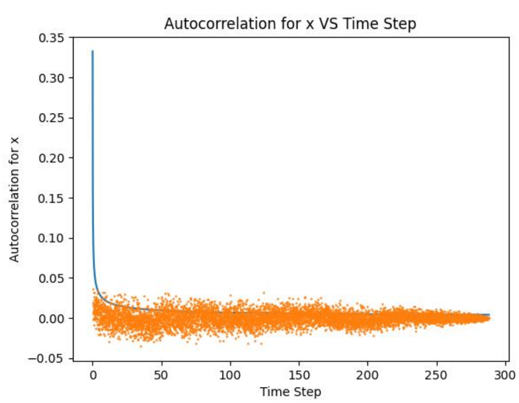


(a) Subfigure 2a

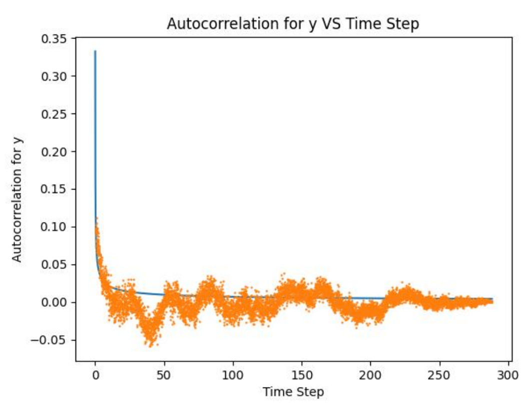


(b) Subfigure 2b

Figure 3: This figure showcases the uncorrected (raw) motion which is shown in sub-figure 1a, and the corrected motion with the mean positioning of the bead in sub-figure 1b. This motion for the y positing of the bead.

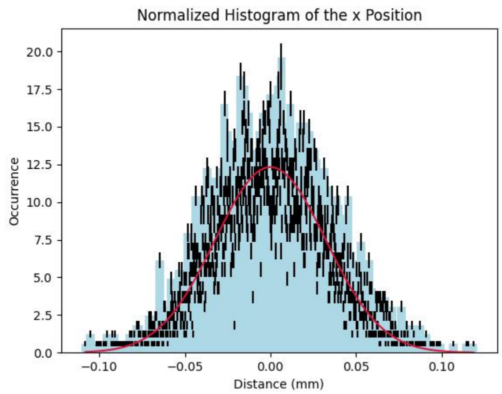


(a) Subfigure 1a

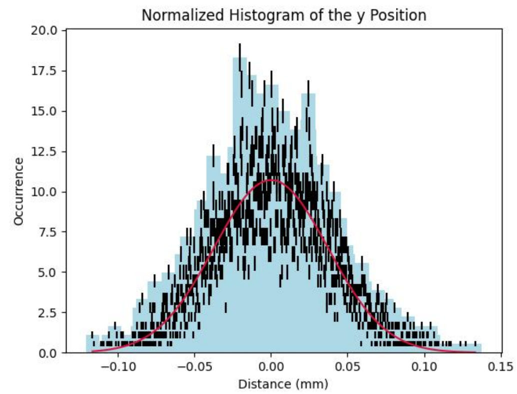


(b) Subfigure 1b

Figure 4: This figure shows the auto-correlation functions of both x and y positioning of the bead. Sub-figure a shows the auto-correlation of x positioning and sub-figure b shows the y positioning of the bead.

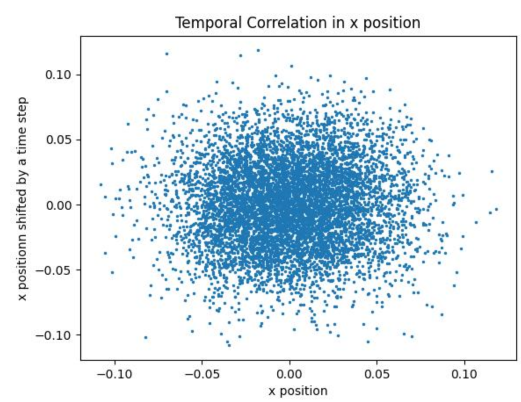


(a) Subfigure 2a

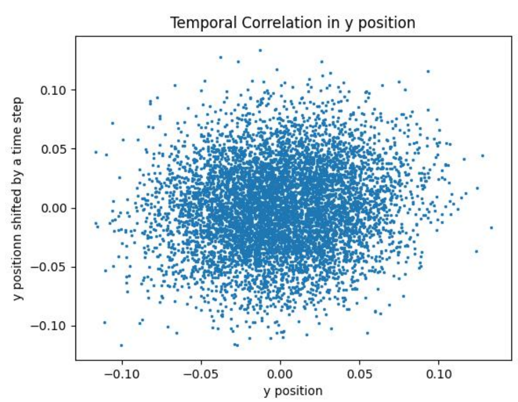


(b) Subfigure 2b

Figure 5: This figure shows the histogram with the fit of both the x and y positioning of the bead. Sub-figure a shows the histogram of x positioning and sub-figure b shows the y histogram of the bead.

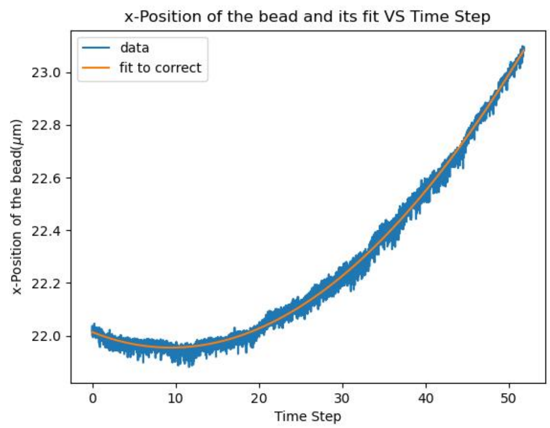


(a) Subfigure 1a

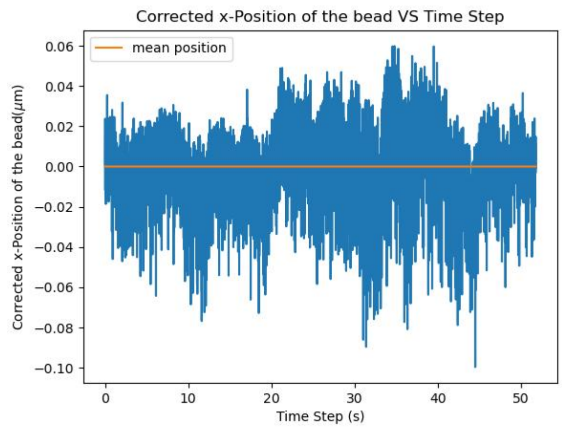


(b) Subfigure 1b

Figure 6: This figure shows the temporal correlation functions of both x and y positioning of the bead. Sub-figure a shows the temporal correlations of x positioning and sub-figure b shows the y positioning of the bead.

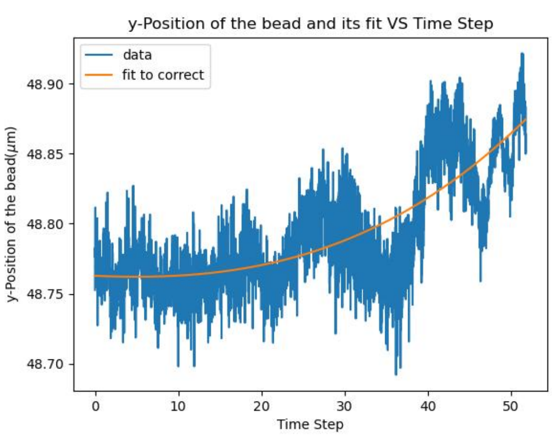


(a) Subfigure 1a

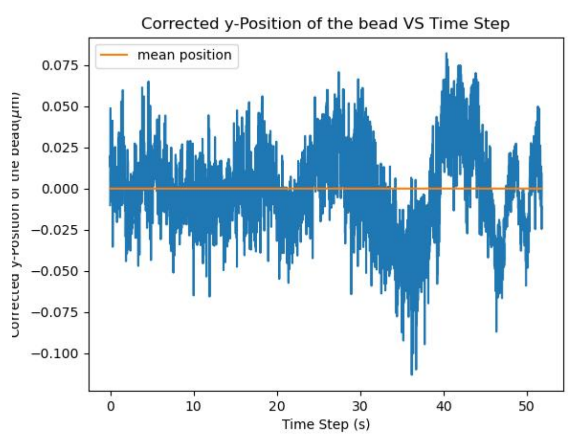


(b) Subfigure 1b

Figure 7: This figure showcases the uncorrected (raw) motion which is shown in sub-figure 1a, and the corrected motion with the mean positioning of the bead in sub-figure 1b. This motion for the x positing of the bead.

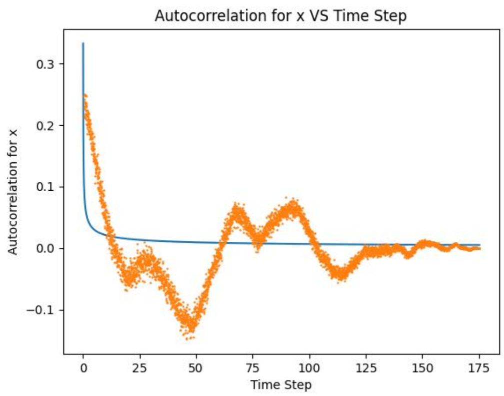


(a) Subfigure 2a

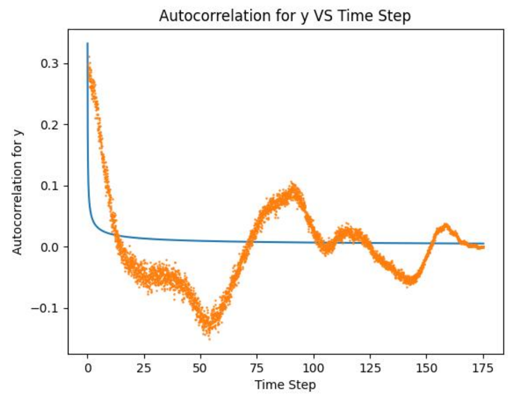


(b) Subfigure 2b

Figure 8: This figure showcases the uncorrected (raw) motion which is shown in sub-figure 1a, and the corrected motion with the mean positioning of the bead in sub-figure 1b. This motion for the y positing of the bead.

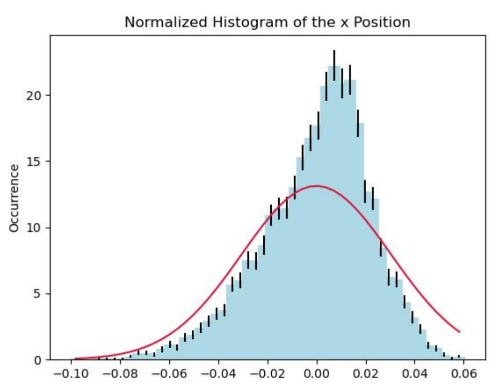


(a) Subfigure 1a

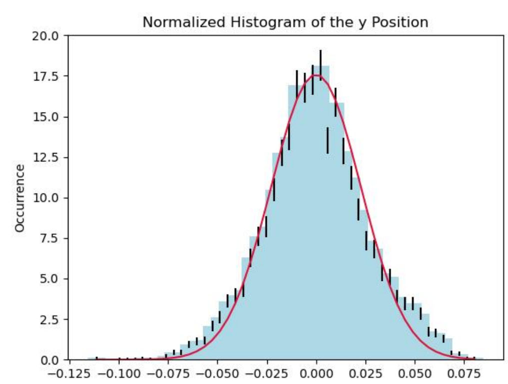


(b) Subfigure 1b

Figure 9: This figure shows the auto-correlation functions of both x and y positioning of the bead. Sub-figure a shows the auto-correlation of x positioning and sub-figure b shows the y positioning of the bead.

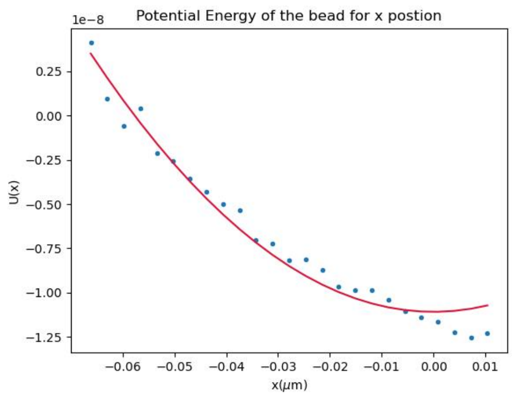


(a) Subfigure 2a

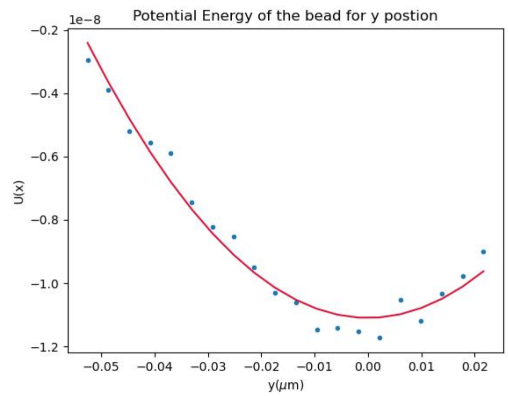


(b) Subfigure 2b

Figure 10: This figure shows the histogram with the fit of both the x and y positioning of the bead. Sub-figure a shows the histogram of x positioning and sub-figure b shows the y histogram of the bead.



(a) Subfigure 1a



(b) Subfigure 1b

Figure 11: This figure shows the potential energy functions of both x and y positioning of the bead. Sub-figure a shows the potential energy function of x positioning and sub-figure b shows the potential energy function y positioning of the bead.