Optical Trapping of Micro Targets

Imperial College London

Kai Anson, Sohum Panda

Plasma Physics Group

Supervisor: Prof. Roland Smith

BACKGROUND

Optical trapping uses the radiation pressure of light from an upwards propagating laser beam to balance the force of gravity and hold a particle in position.

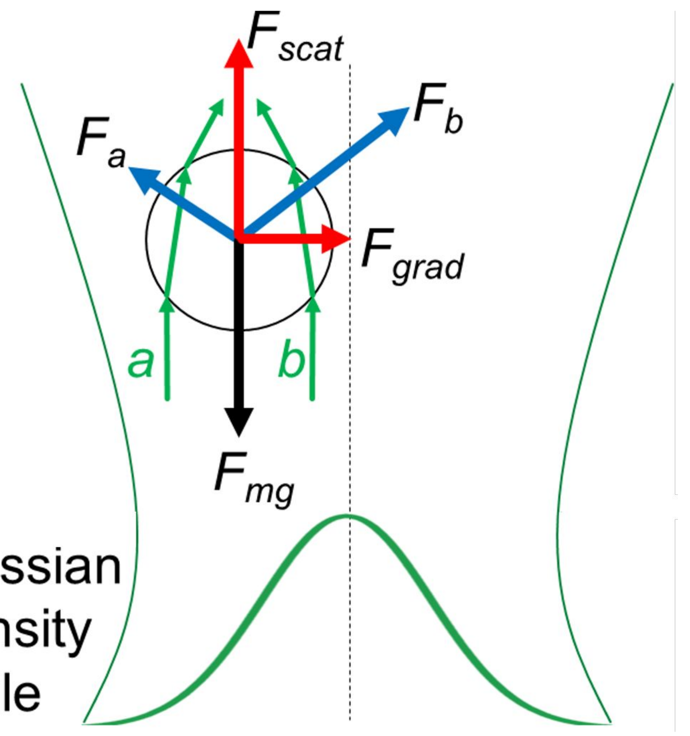


Figure 1: Diagram showing the forces on a particle in an optical trap.

- The refraction of ray *b* exerts a greater force than *a* since the beam is more intense nearer the centre
- The resultant force pushes the particle "downstream" and into the beam centre
- Particle becomes trapped at an equilibrium position, with small displacements causing a resultant restoring force [1]

- Can be used to trap micron scale targets for high intensity laser interactions
- Trapping enhances the electric field produced by the laser at the target surface and prevents electromagnetic pulses damaging electronics [2]
- These targets act as strong X-ray and particle sources [3, 4]
- Potential applications in fields such as medical imaging and treatment

Aims and Objectives

- Tracking the trapped particle's position and holding it stable against fluctuations is important to ensure that all laser shots hit the target
- Our project aims to characterise the properties of an optical trap and oil droplet targets, and implement a closed loop feedback control system to adjust the trapping laser power in response to the particle's motion

METHOD

- **Trapping Laser:** Frequency doubled Nd:YaG, λ = 532 nm, continuous wave, TEM_{00} mode (Gaussian)
- Mist of micron scale silicone oil targets generated via ultrasonic atomizer

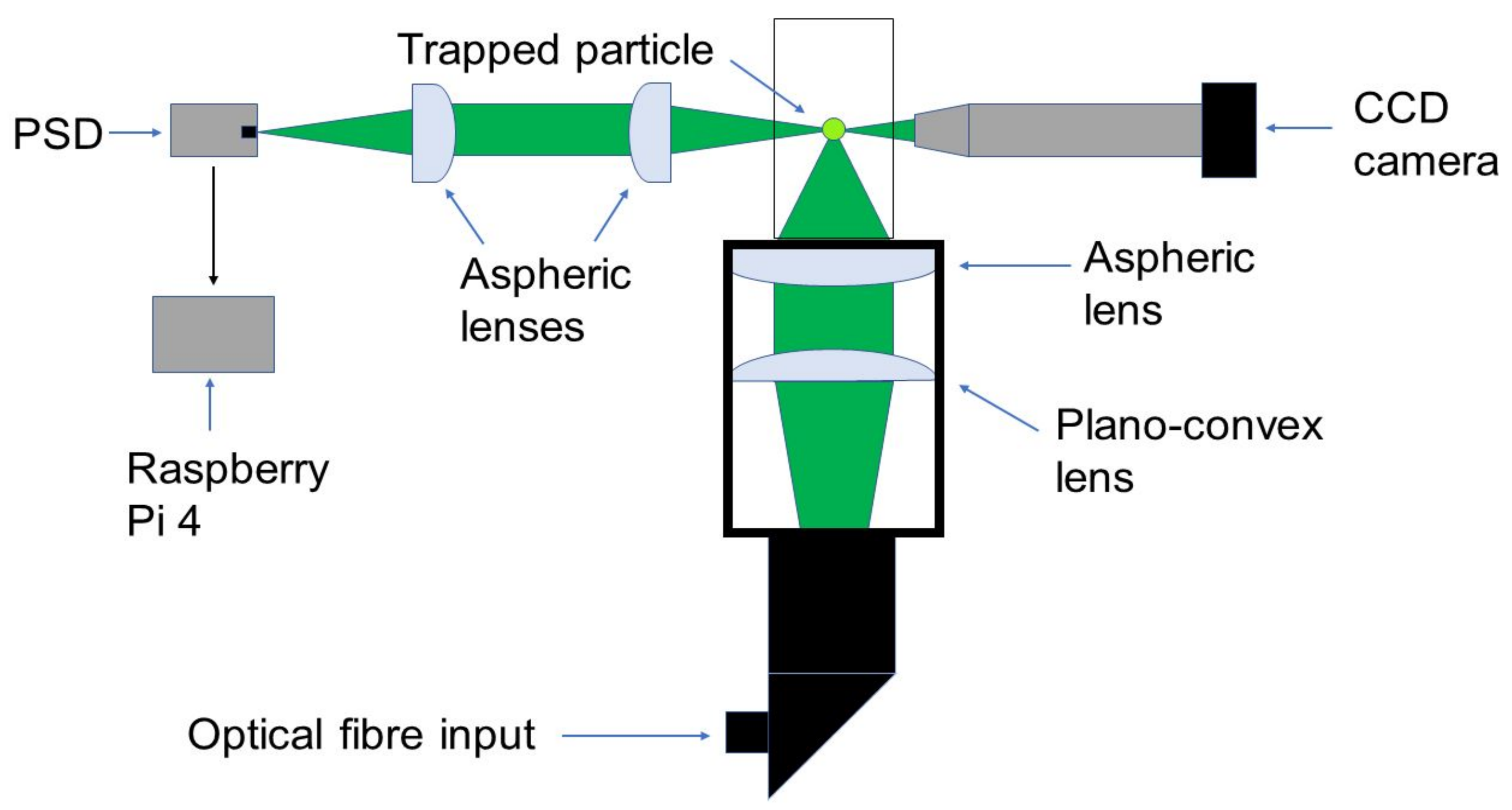


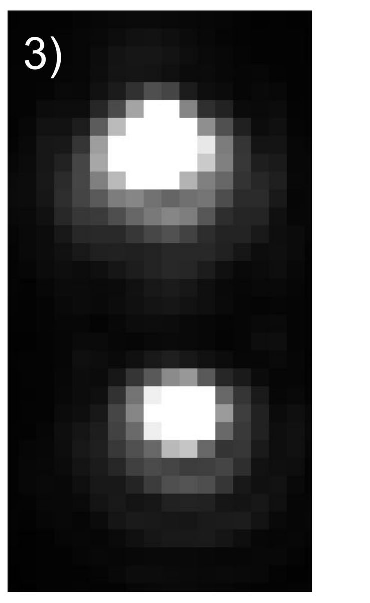
Figure 2: Diagram of the trapping system. Laser delivered via optical fibre through vertical rail system.

- Laser power output of ~1.25 W coupled at 35-40% into fibre
- Micro targets loaded from above laser through a draught collar
- CCD camera and position sensitive detector (PSD) used to detect trapped target from upper and lower scatter points
- Transimpedance amplifier used to convert current from PSD to voltage and fed to Raspberry Pi 4
- Pi used to analyze particle dynamics, sampling at ~10 kHz, and predict future particle motion
- The Pi will then be connected via voltage box to a Pockels cell
- The Pockels cell will allow for the modulation of the laser power delivered and can thus adjust the equilibrium height the particle traps at - **continuously counteracting the particle motion to stabilise its position**

RESULTS

Particle Size Determination

Figure 3: Particle imaged by CCD, upper and lower scatter points seen



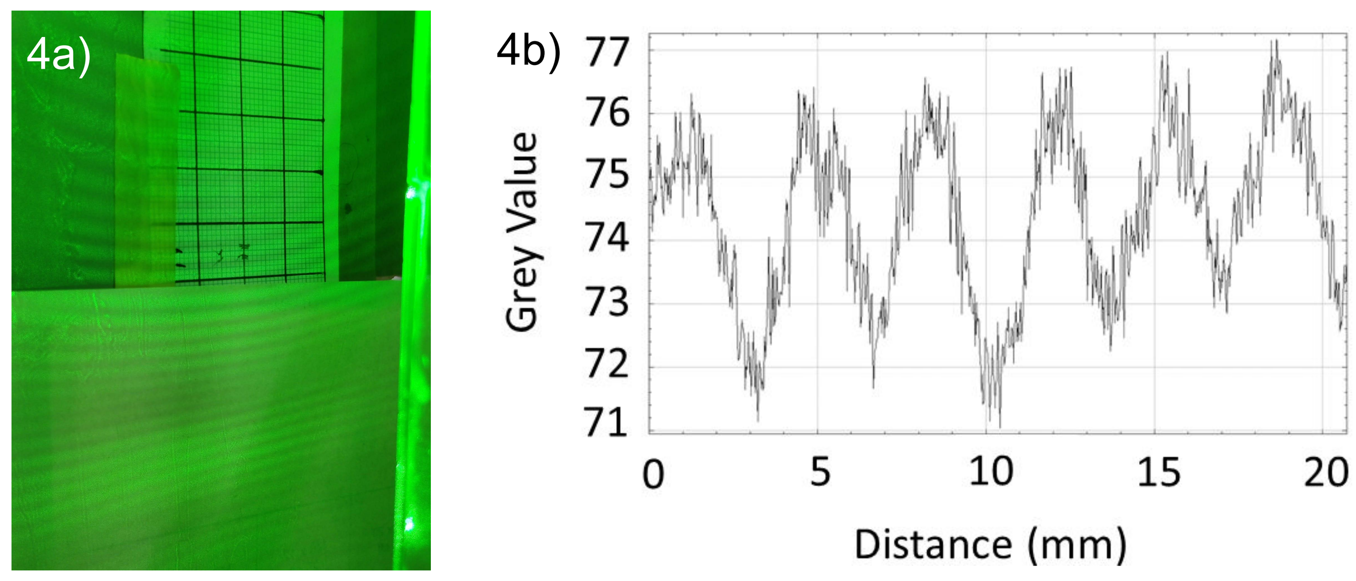
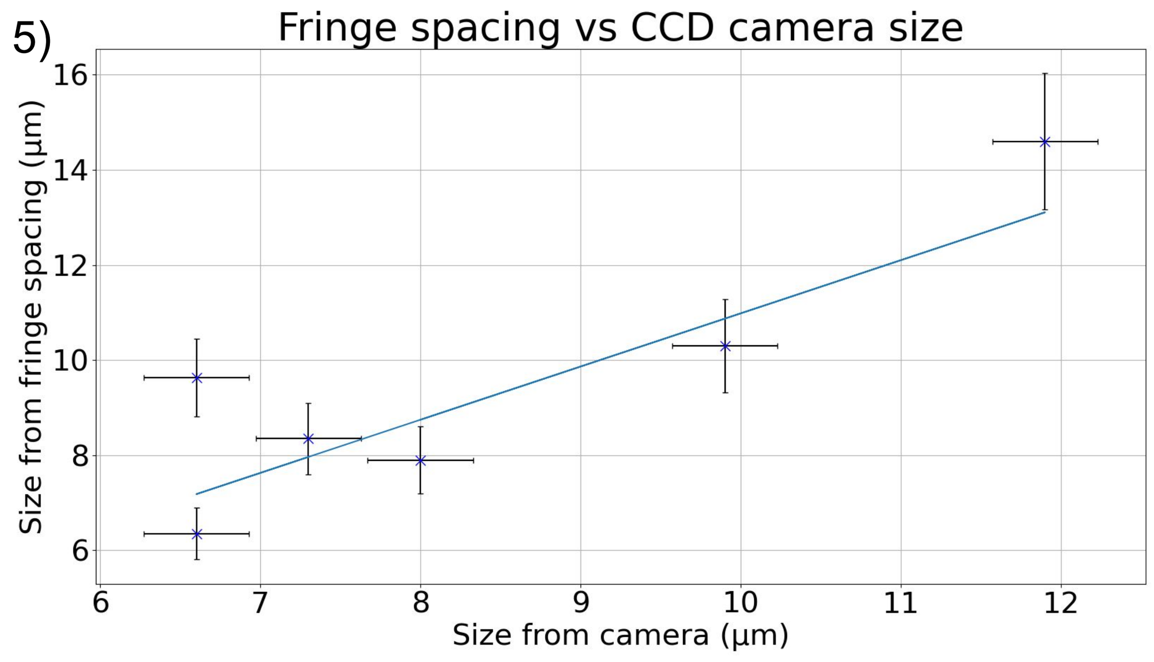


Figure 4a): 2 slit interference pattern produced by interference of light from particle's upper and lower scatter points. **b)** Fringe intensity plot from greyscale version of Fig 4a.

Figure 5: Graph of particle size calculated using fringe spacing vs using direct viewing from CCD camera. This data gives a relation of: **y = 1.124 x - 0.214**

With more data points, we expect to get closer to a 1:1 relation between the two methods of calculating particle size.



Power Spectrum

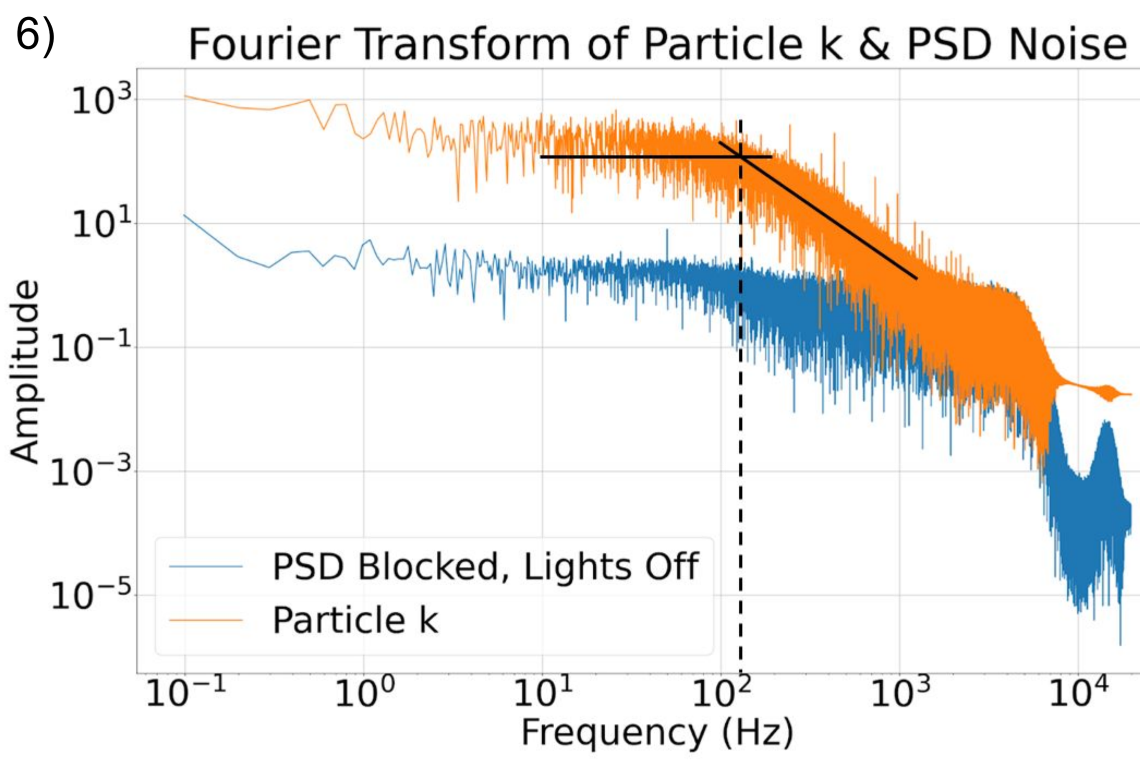


Figure 6: Log-log plot of the Fourier transform of PSD readings from a trapped particle, along with Fourier transform of PSD noise.

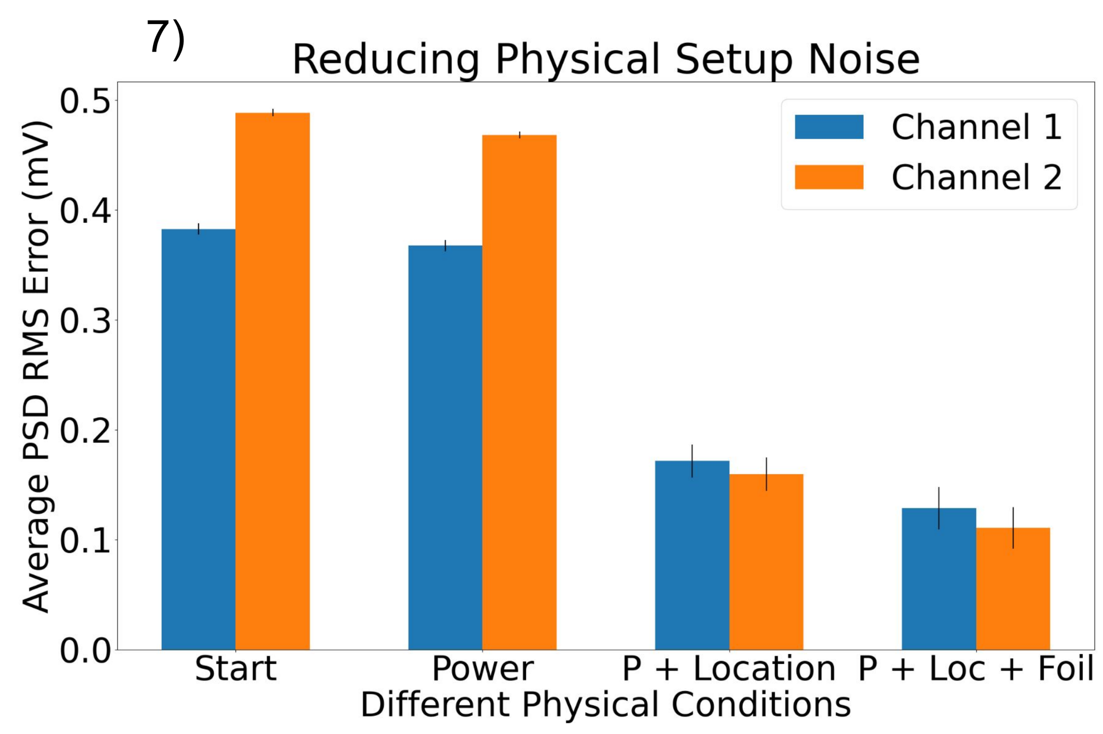
The intersection of two straight lines can be used to find the corner frequency f_c from which the spring constant κ of the trap can be calculated.

- **f_c = 120 ± 5 Hz** **Particle Diameter = 8 ± 0.7 µm** **κ = 1.0 ± 0.2 × 10^{-6} Nm^{-1}**

Noise Reduction

Figure 7: Bar chart showing the reduction in inherent PSD noise for both PSD channels.

By combining finding the best power supply, the best location to place the Pi and covering up wiring with foil, we were able to **reduce inherent noise on a sample of 100,000 points by over 66%.**



FURTHER WORK

- Connect Raspberry Pi to Pockels cell via voltage box to complete closed loop feedback system
- Adjust and measure particle position in real time through the completed feedback system. Aim for ± 1 µm vertical stability using system

REFERENCES

[1] Neuman KC, Block SM.Optical trapping.Review of scientific instruments.2004;75(9):2787–2809.
[2] Price C, Donnelly T, Giltrap S, Stuart N, Parker S, Patankar S, et al. An in-vacuo optical levitation trap for high-intensity laser interaction experiments with isolated microtargets. Review of Scientific Instruments. 2015;86(3):033502.
[3] Donnelly TD, Rust M, Weiner I, Allen M, Smith R, Steinke C, et al. Hard x-ray and hotelectron production from intense laser irradiation of wavelength-scale particles. Journal of Physics B: Atomic, Molecular and Optical Physics. 2001;34(10):L313.
[4] Symes D, Comley A, Smith R. Fast-ion production from short-pulse irradiation of ethanol microdroplets. Physical review letters. 2004;93(14):145004.