EPJ Web of Conferences **266**, 13025 (2022)
EOSAM 2022
https://doi.org/10.1051/epjconf/202226613025

Automation strategies and machine learning algorithms towards real-time identification of optically trapped particles

João Oliveira[1,2,*], *Vicente* Rocha[1,2,], *Nuno* A. Silva[1,2,], and *Pedro* A. S. Jorge[1,2,]

[1]Faculdade de Ciências da Universidade do Porto, Rua do Campo Alegre 687, 4169-007 Porto, Portugal
[2]INESC TEC, Centre of Applied Photonics, Rua do Campo Alegre 687, 4169-007 Porto, Portugal

Abstract.
To automatically trap, manipulate and probe physical properties of micron-sized particles is a step of paramount importance for the development of intelligent and integrated optomicrofluidic devices. In this work, we aim at implementing an automatic classifier of micro-particles immersed in a fluid based on the concept of optical tweezers. We describe the automation steps of an experimental setup together with the implemented classification models using the forward scattered signal. The results show satisfactory accuracy around 80% for the identification of the type and size of particles using signals of 250 milliseconds of duration, which paves the path for future improvements towards real-time analysis of the trapped specimens.

1 Introduction

Ever since its introduction in 1970, the optical tweezers setup (OT) has proven itself to be a reliable tool to manipulate micron-sized particles, which eventually earned Arthur Ashkin, the Nobel Prize in Physics in 2018. More recently, OT has been integrated into microfluidic devices not only for flux control but also for the interrogation of dynamical properties of the trapped particle through dynamic light scattering[2], allowing to perform in depth analysis of a target specimen at individual level. However, despite the aiming at autonomous and intelligent opto-microfluidic devices, fully automated approaches to OT are still scarce in the literature.

In this manuscript we report our efforts in the development of a versatile and full stack approach to the automation of an optical tweezers experimental setup, integrating all the features and control within a single computational toolkit. Furthermore, introducing a strategy for identification of particles based on their dynamical properties via the analysis the forward scattered signal, we also pave the path towards intelligent devices capable of performing classification tasks at rates close to real-time.

2 Experimental System and automation strategies

The optical tweezers system used in this work consists of a conventional inverted microscope configuration for which a schematic is provided in Figure 1. The trapping laser is a fiber-coupled laser diode (Lumentum s27-7602-460) working at wavelength around 976 *nm*. Using a 100× oil immersion objective, the laser is focused to a spot size of approximately 1.1 μm, creating an optical trap. Live control of the trapping procedure is possible using a standard 1280×1024 pixel color CMOS camera.

For the analysis of the dynamical properties of the particle, the forward scattered signal of the trapping beam is collimated with a 10x condenser lens and subsequently directed towards a quadrant photodetector (PDQ80A-Thorlabs) placed at a conjugate back focal plane of the condenser. The detector responds in the range of 400-1050 *nm*, and the signal is acquired using a DAQ at a rate of 10KHz. After the acquisition of the signal, a set of the three signals (X, Y, SUM) is related with the transverse x and y position of the particle, while SUM corresponds to a total integral of what reaches the detector.

For a complete automation of the setup, we implemented a full-stack approach using Python, which allows us to control the system as well as perform the acquisition and analysis of the signal in a single computational tool and in real-time. For the hardware part, including laser, stages and camera, we adapted existent driver libraries and developed new ones. Then a series of routines that support typical OT experiments were created in intermediate scripts, before implementing a graphical user interface on top of these libraries using PyQt5. The implementation follows a ladder structure that covers distinct levels of expertise with distinct degrees of versatility: i) a driver layer, directed towards advanced users and developers; ii) a script layer, where an advanced user can program specific instructions for particular purposes; and iii) a graphical user interface layer, to be used by a regular user at beginner or intermediate expertise level. Furthermore, the modular approach to the organization of the code eases future scheduled improvements, such as the development of

*e-mail: jmfoliveira110@gmail.com

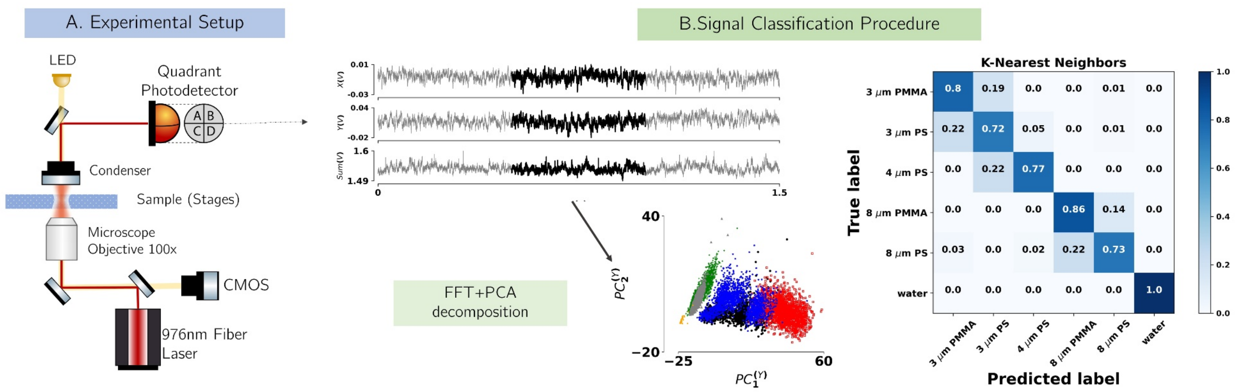

Figure 1. A. Visual summary of the Optical Tweezer system and signal classification procedure as described in the main text. B. Visual summary of the classification procedure and confusion matrix results for the particle dataset described in the main text.

an image analysis library and the addition of a spectrometer to collect the Raman spectrum of the trapped specimen.

3 Classification of particles using PCA decomposition

Being sensitive to the displacement of the trapped particle in the transverse directions, the acquired signal from the quadrant photodetector allows to probe the Brownian motion of the trapped beads which contains information regarding the physical properties of the particle[1]. In the recent years, our team explored a few strategies for single particle/cell classification using optical trapping systems and scattered radiation, both using the back-scattered[2] and forward scattered signal[3]. Focusing on the latter for the purpose of this work, we reported the classification of trapped particles by introducing an algorithm that consists on performing a dimensional reduction with Principal Component Analysis performed in the Fourier space before the application of common classification strategies such as K-nearest neighbors.

To test the classification capabilities of the system, we implemented a classification mode into the software solution described before. For the training procedure, we acquire distinct signals of 30 seconds of total duration at an acquisition rate of 10kHz for each particle type. The signals are then divided in segments of 1 second each in order to increase the dataset size, and employed to train a classification algorithm, which can then be tested in unseen particles.

The results obtained for a dataset of 5 types of particles (total of 45 particles tested, 40 used for training phase and 10 used for test) is presented in Figure 1. As observed, the overall accuracy around 80% suggests that this implementation was able to distinguish and classify accurately the solutions prepared.

4 Concluding remarks

Automation strategies are a crucial step for a seamless integration of optical tweezers (OT) tools in future intelligent optomicrofluidic solutions. In this work we presented an ab-initio approach to the automation of an experimental OT setup, developing a modular structure that allows for future improvements and addition of specialized hardware. Furthermore, by investigating the possibility of classification in living cells, we are researching the capabilities of the setup as a biomedical diagnosis tool, that performs accurately and is cheap to manufacture, which is of natural importance in the current state of medicine.

Overall, the findings enclosed pave the way for a diversity of technological solutions of OT from micro to nanoscale, establishing an integrated and acessible tool for label-free and reagentless biosensing, single cell diagnostic amongst many other applications.

References

[1] Gieseler, Jan *et. al.*, Optical tweezers — from calibration to applications: a tutorial, Advances in Optics and Photonics **13**, pp.74-241 (2021)

[2] Paiva, J. S. and Jorge, P. A. S. and Ribeiro, R. S. R. and Balmaña, M. and Campos, D. and Mereiter, S. and Jin, C. and Karlsson, N. G. and Sampaio, P. and Reis, C. A. and et al. *iLoF: An intelligent Lab on Fiber Approach for Human Cancer Single-Cell Type Identification*, Scientific Reports,10,1, 2020

[3] Carvalho, Inês Alves and Silva, Nuno Azevedo and Rosa, Carla C and Coelho, Luís CC and Jorge, Pedro AS, Sensors **21**, 6181 (2021)