

MÁSTER EN NUEVAS TECNOLOGÍAS ELECTRÓNICAS Y FOTÓNICAS

TRABAJO DE FIN DE MÁSTER - CURSO 2026-2027

PROPUESTA

Título:	De la fotónica a la motilidad: microscopía avanzada y seguimiento celular basado en inteligencia artificial para relacionar las propiedades ópticas con la dinámica celular.
Título en inglés:	From Photonics to Motility: Advanced Microscopy and AI-Based Cell Tracking to Link Optical Properties with Cellular Dynamics
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Resumen:

Natural photonic structures are widespread throughout the biological world, where they perform a broad variety of optical functions including coloration, light harvesting, photoprotection, camouflage, communication, and environmental sensing. These systems have attracted considerable attention in recent years because they provide outstanding examples of biological materials capable of manipulating light through nanoscale structural organization rather than pigmentation alone. The study of such naturally occurring photonic architectures has not only expanded our understanding of biological adaptation but has also inspired the development of novel bioinspired optical [1] and quantum technologies[2].

Among photosynthetic microorganisms, *Euglena gracilis* represents a particularly intriguing model system due to its unique combination of motility, photosensitivity and structural complexity [3]. This unicellular flagellate possesses a flexible pellicle composed of helically arranged proteinaceous strips that confer remarkable mechanical adaptability while simultaneously generating periodic surface corrugations at submicrometric length scales. Recent studies have suggested that these surface architectures can give rise to photonic effects, including selective reflection and optical resonances, potentially influencing how the organism interacts with its optical environment [4]. Understanding these phenomena requires the development of experimental platforms capable of simultaneously probing optical properties and cellular behaviour in real time.

The aim of this Master Thesis project is to develop an optical system and use it to investigate the photonic properties of living *Euglena gracilis* cells using the Fourier Transform Imaging Spectroscopy (FIS) microscope recently developed at the BIOPHOT Laboratory of the Instituto de Óptica (CSIC)[5]. The student will adapt the existing optical setup to enable spectroscopic measurements of freely moving living microorganisms and establish protocols for the acquisition of spatially resolved optical spectra from individual cells. The uniqueness of this optical setup should allow to obtain

evidence of the photonic properties of the grating-like membrane of single cells and could open the door for further studies in light-managed biological computing

Optionally, the student could develop a real-time cell tracking platform integrating microscope imaging, motorized stage control, and computer vision algorithms. This system will enable continuous monitoring of individual cells during spectroscopic measurements, allowing the optical response of each organism to be associated with its morphology and motion patterns. Artificial intelligence and machine learning tools will be implemented to analyse the trajectories of individual cells and identify behavioural features that may correlate with their optical signatures.

This research will constitute the first step towards understanding whether the photonic structures present in *Euglena gracilis* may contribute to light-guided behaviour and cellular navigation, opening new avenues of research at the interface between biological photonics, microscopy and artificial intelligence.

The student will gain hands-on experience in advanced optical microscopy, imaging spectroscopy, Python-based image analysis, and AI-assisted cell tracking. The project will provide knowledge of biological photonics, microalgal motility, and light-matter interactions, while developing skills in experimental design, quantitative data analysis, and scientific communication.

Metodología:

Task 1. Adaptation of the FTIS microscope for in vivo spectroscopy of *Euglena gracilis*

The first stage of the project will focus on adapting the Fourier Transform Imaging Spectroscopy microscope available at the BIOPHOT Laboratory for the characterization of living *Euglena gracilis* cells. The student will analyse the experimental requirements associated with the study of mobile microorganisms and implement the necessary optical modifications to optimize spectral acquisition under physiological conditions.

This task will involve optical alignment and calibration, optimization of illumination conditions and integration of image acquisition routines. Particular attention will be devoted to maximizing spectral quality while minimizing perturbations to cell viability and motility.

At the completion of this task, a fully operational platform capable of acquiring spectrally and angle resolved optical information from living *Euglena* cells will be available. The main objective of this task is to demonstrate experimentally whether *Euglena gracilis* shows a nanophotonic structuration.

Task 2. Development of automated cell tracking and microscope-stage synchronization

The second task will focus on the development of an automated tracking system that enables continuous observation of individual cells during spectroscopic measurements.

Computer vision algorithms will be implemented to detect, segment and identify individual *Euglena* cells in real time. These algorithms will be integrated with the

motorized microscope stage, allowing automatic repositioning of the sample to maintain a selected cell within the field of view over extended observation periods.

The outcome of this stage will be a closed-loop tracking platform capable of combining high-resolution spectroscopy with long-term monitoring of single-cell dynamics. At the end of this task the student might implement Artificial intelligence-assisted analysis of cellular trajectories and optical responses using available algorithms that will be adapted to the particular case of study.

Upon movement patterns recognition we will explore computational approaches for extracting relevant patterns from these multidimensional datasets.

Conocimientos previos recomendados:

Knowledge in the following areas would be helpful

- **Knowledge in optics** such lens systems configurations, basic optical alignment and ray-tracing calculations
- **Python programming**

Bibliografía:

- [1] S. Tadepalli, et al. *Chemical Reviews* 117, no. 20 (2017): 12705–63.
- [2] A. Jha, et al. *Chemical Society Reviews* 55, no. 2 (2026): 1089–130.
- [3] A. Tsang, et al *Nature Physics* 14 (2018): 1216–22.
- [4] M. Inchaussandague, et al *Appl. Opt.* 56, no. 18 (2017): 5112–20.
- [5] W. Wardley, et al *Biomimetics* 7, no. 3 (2022): 107.