Integrated Optical-Based Position and Force Estimation for the Active Control of Micro and Nano-Robotic Tasks

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Abstract: This paper investigates new integrated and high performances measurement for micro and nanorobotics purpose. Works notably consist in achieving simultaneous position and force measurement based on optical-based Fabry-Pérot interferometric principle. Experimental investigations validate the proposed working principle demonstrating their high interest for many applications.

1. Introduction

Investigating micro and nanoscales through robotic tool pays a high and rapidly growing attention. It notably enables to better understand phenomena through characterization tasks [1] or to fabricate new components through assembly [2]. Strong efforts are being done to propose new robotic structures or gripping tools able to achieve complex and high accurate motions. Nevertheless, many factors are influent and the extensive use of smart materials induce intrinsic difficulties to reach high accuracies [3]. The capability to integrate sensors the closest to the area of interest, i.e. the contact between the tool of the robot and the object to characterize or manipulate, then appears as a key solution: sensory feedback notably enables to achieve closed loop control (position or force).

Existing solutions result from clean-room microfabricated sensors that are then integrated into the robot [4]. They usually require cabling and their integration also often strongly affects the behavior of the robot, for example, by adding unwanted compliance. Reaching good static (high range to resolution ration) and dynamic performances at the same time is also still a very opened question. Finally, sensors usually enable to measure either position or forces whereas both are of great interest.

Through recent previous works, we investigated an optical-based approach that provided very high accuracy position measurement due to intrinsic interferometric principle [5]. The principle also provides contact-free measurement and does not induce modification of the system to be measured. Based on all these interests, the present paper aims to consider this optical-based principle for simultaneous position and force measurement.

2. Working principle

A laser beam passes through an optical fiber and reflects onto a component, whose position has to be measured, and whose surface reflects partially the light. The component can be the end-effector of a robot, the tools of a gripper or a component to be assembled…. Multiple reflections of the laser happen between the component surface that partially reflecs light and the tip surface of the fiber (that is also semi-reflexive) that is called Fabry-Pérot cavity. Indeed, in this area, these reflections recombine inducing Fabry-Pérot interferences. When the component surface moves along $\vec{x}$, a change of the Fabry-Pérot cavity length (L) happens. Fig. 1(b) shows typical interferences when L vary, the periodicity of the signal (T) directly depends on the wavelength of the laser signal (λ) as L = $\lambda/2$.

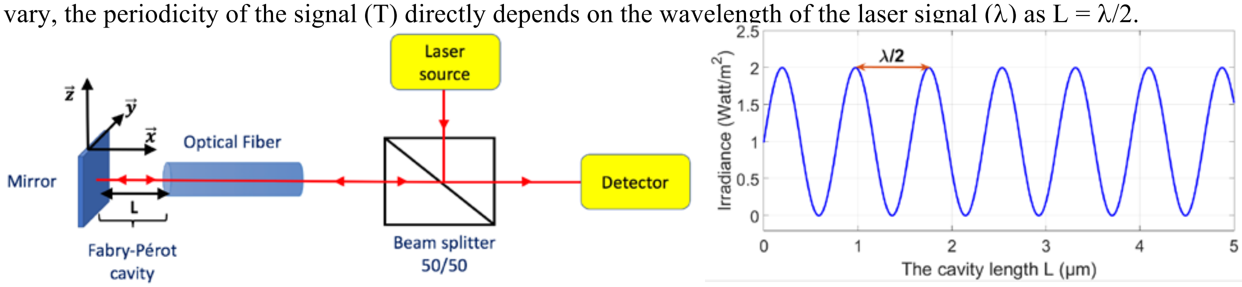


Fig. 1: (a-left) Principle of the Fabry-Pérot cavity (b-right) Optical signal obtained through the detector when the cavity length L varies resulting from Fabry-Pérot interferences.

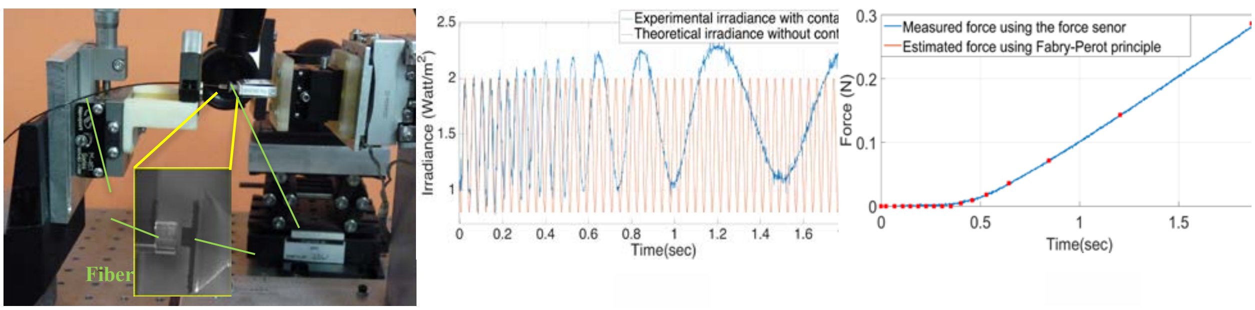
To enable simultaneous position and force measurement, it is proposed to place the component surface onto a compliant structure. As a consequence, when there is no contact between the mirror surface and the fiber, the periodicity of the signal keeps constant providing pure position measurement. When a contact happens, the periodicity changes enabling force estimation. Knowing the stiffness of the compliant structure it is then possible to derive an estimation of the contact force.

3. Experimental validation of the approach

To validate the proposed principle, an experimental set-up has been developed and can be seen on Fig. 2 (a). It is composed of a monomode fiber, and a mirror placed on compliant structure, itself being the tool of a 6 Degrees-of-Freedom nanopositioning robot. A force sensor is also placed at the tool tip of the robot and will be used to validate the experimental estimation of force based on optical Fabry-Pérot signal.

A translation along $\vec{x}$ (the optical axis) is generated using a P-563 PIMars Nanopositioner. Fig. 2 (b) displays a typical curve that can be obtained through the optical detector. The signal consists in an irradiance having a sinusoidal shape but whose frequency varies. First 0.3 second motion does not induce contact between the mirror and the fiber. Indeed, the period of the signal is 780 nm corresponding to half of the 1560 nm laser wavelength used. After 0.3 s, a contact happens conducting to a reduction of the frequency of the measured signal. The difference between this measured signal and the one when no contact happens (red curve named theoretical irradiance without contact) enables to estimate the compression of the compliant structure. Knowing the stiffness of the compliant structure (11.5 mN/µm), it is then possible to estimate the applied force through optical Fabry-Pérot signal.

Fig 2 (c) compares this force estimation using Fabry-Pérot principle with the force measured by the reference sensor. Results highlight a very good correspondence between both curves. They also show that it is possible to estimate the location of the contact with precision (down to 500 nm). These results validate the proposed approach and clearly state the interest for force measurement based on optical Fabry-Pérot principle.



Photonic component (a) (b) (c)

Fig. 2: (a) experimental set-up: a 6 Degrees-of-Freedom nanopositioning robot enables to move a photonic component in front of a monomode fiber, a Fabry-Pérot cavity happens providing interferences used for position and force estimation (b) Experimental Fabry-Pérot interferences evolution when the photonic component is translated along the optical axis, a contact happens at t = 0.3s (c) reconstruction of the contact force estimation based on Fabry-Pérot interferences.

4. Conclusion

Works achieved shows that optical Fabry-Pérot based interference measurement can be used to provide hybrid position and force measurement in a very integrated and high performing way. This principle can be integrated in many kinds of micro and nanorobotics systems such as nanopositioning stages, gripping tools or products to be assembled. They also open the possibility to achieve active alignment techniques for integrated optical system assembly by bringing together position and force estimation.

5. References

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