Encoded pseudo-periodic patterns for robust visual pose determination at the microscoale

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Abstract

At the microscale, computer vision requires specific approaches because of the short working distance, short depth-of-focus and quasi-orthographic projection of microscope objectives. This paper presents a 3D pose determination method based on the spectral analysis of images of encoded pseudo-periodic patterns. Periodicity ensures subpixel accuracy through phase computations whereas out-of-plane angles are retrieved through shifts induced on the main pattern spectral lobes. The binary encoding of the pattern avoids ambiguities of an entire number of periods and of π/2 rotations. Information redundancy and a phase-based self-adaptive decoding make the method robust against common imaging problem, such as noise, defocus and occlusion.

1. Introduction

Computer microvision is a convenient tool for position or displacement measurement at the microscale. Natural texture of objects of interest can be used for displacement retrieval through image correlation or edge detection approaches. However, when the displacemet range becomes larger than the field of observation, laser interferometers, despite their complexity and their very limited range of acceptable rotation, remain the reference tool to achieve accurate measurements with nanometer resolutions. The observation of diverse grating-like patterns by microvision constitutes a more flexible alternative and different designs were recently proposed for one up to six degrees of freedom position measurements (Yao et al. *IEEE Transactions on Instrumentation and Measurement*, 2021). This paper summarizes the 3D pose measurement capabilities allowed by phase-based encoding and decoding of pseudoperiodic patterns imaged by conventional microscopy (André *et al.*, 2020a, André *et al.* 2020b).

2. Phase preserving encoded patterns

Combining high resolution and wide measurement range requires the use of encoded patterns in order to remove ambiguities related to the absolute period order. The Manchester code has been proved to be efficient but, because of shifts of bright/dark elements, this kind of encoding distorts the spectral phase and induced non-linearities are detrimental to the eventual method resolution. Fig.1.a,b presents the scheme of a phase-preserving encoding technique in which each (x,y) position is encoded through a set of nine dot sites. Three corners are always present in such a way that the missing one removes π/2 rotation ambiguities. The median dots are either present or absent in accordance with the corresponding bit value. The period order is encoded through the Linear Feedback Shift Register (LFSR) method in order to multiplex words of n bits into a single bit line. This choice allows unequivocal position retrieval from the identification of n consecutive bits without inducing phase distortions and thus allowing best resolution performances. Furthermore, the redundancy of information of this encoding method reinforces the eventual robustness of the phase-based decoding.

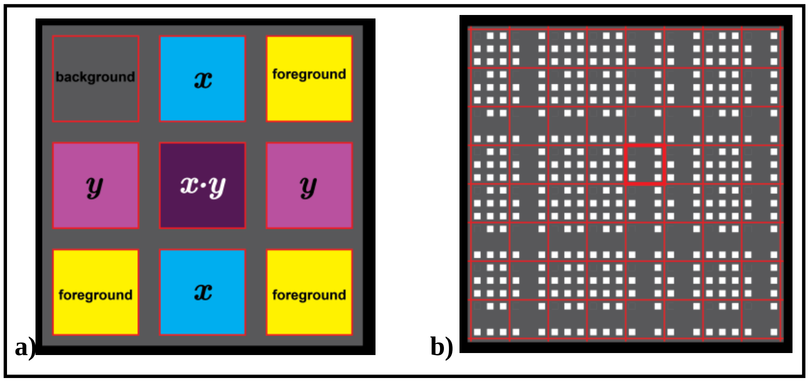

Figure 1: Periodic pattern endocing principle with a) Nine dots (x,y) encoding cell and b) View of an extended zone of encoded pattern.

3. Robust phase-based decoding

Because of the phase-preserving design of the encoded patterns, the bright dots are known to be located at sites where the phase associated to the pattern frequency is close to zero. Similarly, a phase close to ±π indicates a background location. This *a priori* knowledge allows the definition of local self-adaptive thresholds to determine whether dots are present or absent. Furthermore, the redundancy of information along pattern lines and columns makes the decoding reliable despite a proportion of misidentifications. The decoding procedure has thus been proved to be robust against randomn noise, defocus, low light levels and occlusion (André *et al*. 2020b). Out-of-plane angles are retrieved through induced increases in the phase slopes of the main spatial directions. The axial distance z cannot be extracted from images recorded with an orthographic projection but is accurately retrieved when a perspective projection is used.

4. Performances

The method is scalable by adjusting the actual pattern period and the vision system magnification to the application aimed. With a 10x microscope objective and a 9µm physical period, in-plane position is retrieved with a 1 nanometer resolution in x,y and 10^{-6} radian for in-plane orientation, together with a measurement range larger than $10\text{x}10\text{cm}^2$ (André *et al*. 2020a). Out-of-plane angles are also retrieved with a resolution of 10^{-6} radian within the [-π/8,π/8] interval (André *et al.* under review). The resolution on the axial position z depends on the focal length of the perspective projection and an experiment over a Z-range of 10mm shown a resolution below 0.1mm. The current frame rate is about 7Hz with a C^{++} software running on an uptodate personal computer on 10^6 pixel images. The library can be downloaded for free from this site: https://projects.femto-st.fr/vernier/en.

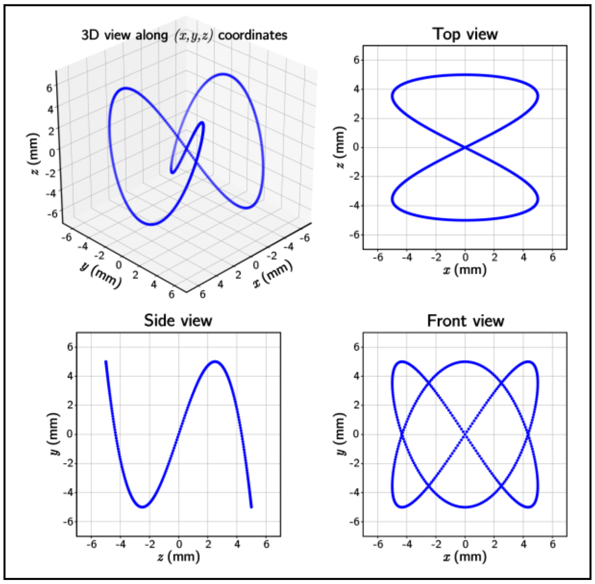

Figure 2: Exemple of a 3D reconstructed trajectory.

5. Conclusion and Discussions

At the price of a pseudoperiodic pattern produced with accurate clean room processes, microvision provides a convenient tool for precise 3D position and displacement measurements versus 5 or 6 degrees of freedom over wide ranges and with resolutions down to the nanometer and microradian ranges. This approach provides a convenient and cost effective alternative to interferometers and with significantly increased angular range capabilities.

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