Optik 152 (2018) 21–28

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Full length article

Optimization of SIFT algorithm for fast-image feature extraction in line-scanning ophthalmoscope

Yi He[a,b,*,1], Guohua Deng[d,1], Yuanyuan Wang[a,b,c], Ling Wei[a,b], Jinsheng Yang[a,b], Xiqi Li[a,b], Yudong Zhang[a,b]

[a] The Key Laboratory on Adaptive Optics, Chinese Academy of Sciences, Chengdu 610209, China
[b] Institute of Optics and Electronic, Chinese Academy of Sciences, Chengdu 610209, China
[c] School of Optometry and Ophthalmology and Eye Hospital, Wenzhou Medical College, Wenzhou 325035, China
[d] Department of Ophthalmology, The Third People's Hospital of Changzhou, Jiangsu, China

ARTICLE INFO

Article history:
Received 16 March 2017
Accepted 19 September 2017

Keywords:
Confocal microscopy
Retina scanning
Medical and biological imaging
Feature extraction
Image matching
SIFT

ABSTRACT

The Scale Invariant Feature Transform (SIFT) algorithm is utilized broadly in image registration to improve image qualities. However, the algorithm's complexity reduces its efficiency in biology study and usually requires real-time. In this article, we present an improved SIFT technique in software architecture for matching sequences of images taken from a line-scanning ophthalmoscope (LSO). The method generates the Gaussian Scale-space pyramid in frequency domain to complete the SIFT feature detector more quickly. A novel SIFT descriptor invariable with rotation and illumination is then created to reduce calculation time, implementing the original SIFT method, our improved SIFT method, and the graphic processing unit (GPU) version of our improved SIFT method. The experiments have shown that the improved SIFT is almost 2–3 times faster than the original while maintaining more robust performance, and the GPU implementation of the improved SIFT is 20 times faster than central processing unit (CPU) implementation and achieves acceleration at real-time as expected. Although tested on an LSO system, the improved SIFT method does not rely on the acquisition setup. As a result, this method can be applied to other imaging instruments, e.g., adaptive optics to increase their resolution in agreement.

1. Introduction

High-quality imaging of the retina is significant important to an improved understanding of the biophysical and vision systems in the human eye, as well as resolving retinal structures in high-resolution and high-contrast can diagnose retinal diseases early [1–3]. However, motions of the eye cause intense tremor movements, or distortions of the retina images [4]. These distortions are especially apparent in scanning systems such as a confocal-scanning laser ophthalmoscope (SLO), since motions happen on time scales of the scan rate [5]. Getting rid of the distortions is important in creating high-fidelity visualization of the retina, either as a series of stabilized videos or as a group of high signal-to-noise (SNR) frames [6,7]. Because the signal in a single frame is bounded by the restraints of safe light exposure, and since the quality of retinal images suffers from Gaussian noises with a laser light, an undistorted series of frames must be added to make the SNR

* Corresponding author at: The Key Laboratory on Adaptive Optics, Chinese Academy of Sciences, Chengdu, 610209, China.
E-mail address: heyi_job@126.com (Y. He).

[1] These authors contributed to the work equally and should be considered co-first authors.

http://dx.doi.org/10.1016/j.ijleo.2017.09.075

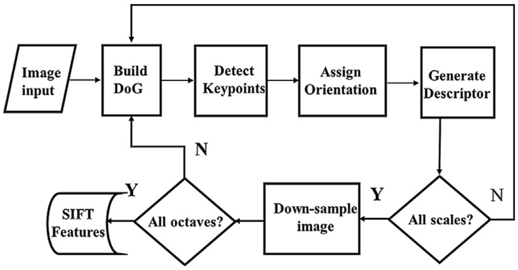

Fig. 1. Flow chart of the original SIFT algorithm.

of static images better. In order to improve image quality, sequences of images are registered to reduce noise, and retinal distortions must first be corrected to determine the image matching.

Over the years, the image matching method has been a key technology in computer vision, pattern recognition, and moving-target detection, including many algorithms based on feature points [8,9], template [10], boundary chain code [11], and so on. O'Connor first utilized a frame-to-frame cross-correlation based on templates to average SLO images [12]. Next, patch-based cross-correlation techniques were suggested, requiring just sequenced frames of scan data to estimate motions and match images [13]. Paterson showed a multi-scale B-spline model of one-deformational filed to register SLO images [14]. More recently, the Scale Invariant Feature Transform (SIFT) algorithm was successfully used to automatically abstract corner points with subpixel resolution and match the points in two frames [15–18]. The point features abstracted by SIFT are do not change with rotation, scale, and illumination, and maintain some stability for the visual angle, affine transformation, and noise. Therefore, the SIFT algorithm can provide stable point features for image matching.

The SIFT algorithm is, however, relatively complex for the computationally intensive cost, and is too slow to be of routine use for retina imaging. More recently, accelerate feature detection were suggested [19], mostly focusing on the improvement of the SIFT algorithm providing more reliable feather matching which aims to an increase in the number of correct features matched and a decrease in the number of outliers[20]. Although they divide the features into several sub-collections to obtain a 40% reduction in processing time, this method must use a suitable mechanism to perform the matching process, which is under a constraint introduced by the scale factor, and this method is not common to any kind of object, particularly for very small object like the high-resolution images in biological researches. On the other hand, hardware improvement of the SIFT algorithm is also proposed such as the graphic processing unit (GPU)-based systems[21], but these systems often need too much hardware and consume excessive amounts of power. Thus, they might not suit an embedded system being used in a portable device. Consequently, we present an improved SIFT method in software architecture for matching sequences of images. This method generates the Gaussian Scale-space pyramid in frequency domain to complete the SIFT feature detector more quickly. A novel SIFT descriptor invariable with rotation and illumination is then developed to reduce calculation time. To investigate this technique, we used it on retinal images from a simplified confocal scanning setup called line-scanning ophthalmoscope (LSO), implementing the original SIFT method, our improved SIFT method, and the GPU version of our improved SIFT method. The experiments have shown that the improved SIFT method is almost 2–3 times faster than the original SIFT while maintaining more robust performance, and the GPU implementation of the improved SIFT method achieves an acceleration at real-time as expected. In general, the novelty of the suggested method is that it significantly improves computing precision and velocity. Although tested on an LSO system, the improved SIFT method does not depend on any acquisition setup. As a result, this technique is also able to be applied to different imaging instruments, e.g., adaptive optics to improve resolution in agreement.

2. Materials and method

2.1. Original SIFT algorithm

The SIFT algorithm is popular for extraction of interest feature points which are invariant to translation, rotation, scaling, and illumination alterations in images, and in Fig. 1 we presented the flow chart of the original SIFT algorithm. The following computation stages were utilized to produce the image feature points: Building Gaussian Scale space using a difference-of-Gaussian (DoG) function; Keypoints detection and localization; Orientation assignment; and Descriptor generation.

2.2. Optimization of SIFT algorithm

These key four modules comprise 99.8% of the SIFT algorithm's execution time [22]. The serial algorithm shows that 72.85% of the time is needed to construct the DoG pyramid and 18.57% of the time is needed to generate descriptors [23]. In this paper we propose an all-software high-performance SIFT improvement. This improved SIFT performance will come from using the Fast Fourier Transform (FFT) in frequency domain and the most computation-intensive modules in the SIFT