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Technical Note

Hierarchical structure from motion optical flow algorithms to harvest three-dimensional features from two-dimensional neuro-endoscopic images

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ABSTRACT

Technical advances have led to an increase in the use of the endoscope in neurosurgery in recent years, particularly for intraventricular procedures and pituitary and anterior skull base surgery. Recently stereoscopic three-dimensional (3D) endoscopes have become available and may over time replace traditional two-dimensional (2D) imagery. An alternative strategy would be to use computer software algorithms to give monocular 2D endoscopes 3D capabilities. In this study our objective was to recover depth information from 2D endoscopic images using optical flow techniques. Digital images were recorded using a 2D endoscope and a hierarchical structure from motion algorithm was applied to the motion of the endoscope in order to calculate depth information for the generation of 3D anatomical structure. We demonstrate that 3D data can be recovered from 2D endoscopic images taken during endoventricular surgery where there is a mix of rapid camera motion and periods where the camera is nearly stationary. These algorithms may have the potential to give 3D visualization capabilities to 2D endoscopic hardware.

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1. Introduction

Minimally invasive endoscopic techniques in neurosurgery offer significant advantages, including less tissue trauma, quicker recovery, shorter hospital stay, and better outcomes. The use of the endoscope for the endonasal transsphenoidal approach to the sellar region has been widely adopted because of the potential benefits of improved visualization, preservation of sinonasal function, reduced hospital stay, increased patient comfort, and reduced surgical complications compared to open approaches, and potentially better outcomes [1,2]. Endoscopic approaches have been adapted for approaches to the rest of the skull base and also intraparenchymal and intraventricular lesions [3].

Conventional two-dimensional (2D) endoscopes, however, are limited by restricted depth perception with surgeons operating in a three-dimensional (3D) field visualized on a 2D screen. In order to navigate the 3D surgical field with 2D endoscopes the surgeon must estimate the depth of structures in several ways: by moving the camera (motion parallax); interpreting the chiaroscuro effect of light and shadows as the endoscope moves (analogous to shining a torch into a dark cave); and probing the visualized structures with another instrument (haptic cues). Pre-clinical evaluation of 3D stereoscopic endoscopic visualization has been found to improve depth perception, improve task performance, minimize mistake rates, and reduce task execution times in both novices and experienced surgeons [4–6]. Now, 3D endoscopes are commercially available and have recently begun to be evaluated clinically to see whether they offer advantages over 2D endoscopes. Early clinical experience with 3D systems were reported at the 2010 Combined Otolaryngology Society Meeting in Las Vegas with similar operative times and complications for 2D and 3D endoscopes, and improved depth perception and endoscopic orientation with 3D endoscopes [7,8]. A retrospective clinical study comparing 2D and 3D endoscopes in 58 patients endoscopic transsphenoidal pituitary surgery did not reveal any differences in perioperative or postoperative complications [9]. Barkhoudarian et al. undertook a retrospective review of 65 2D and 95 3D endoscopic endonasal parasellar procedures and reported significantly shorter operating times for pituitary lesions [10]. Subjectively, users of 3D endoscopes for anterior skull base lesions report a more natural feeling, shorter learning curve, increased agility, improved hand–eye coordination, better tissue understanding and increased surgical efficiency compared to 2D system [10–12]. Reported disadvantages of 3D endoscopes include initial feelings of motion sickness in the user, that the images are less

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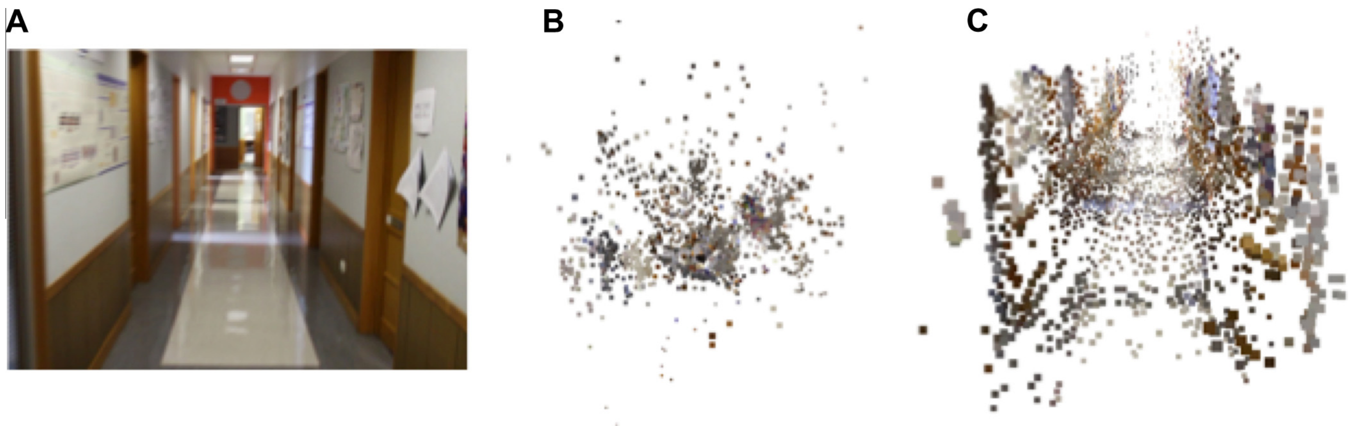

Fig. 1. A hallway scene captured with a digital video camera (A) was reconstructed using sequential frames (B) but was more unreliable than a hierarchical structure from motion algorithm (C) in which features of the hallway scene became identifiable.

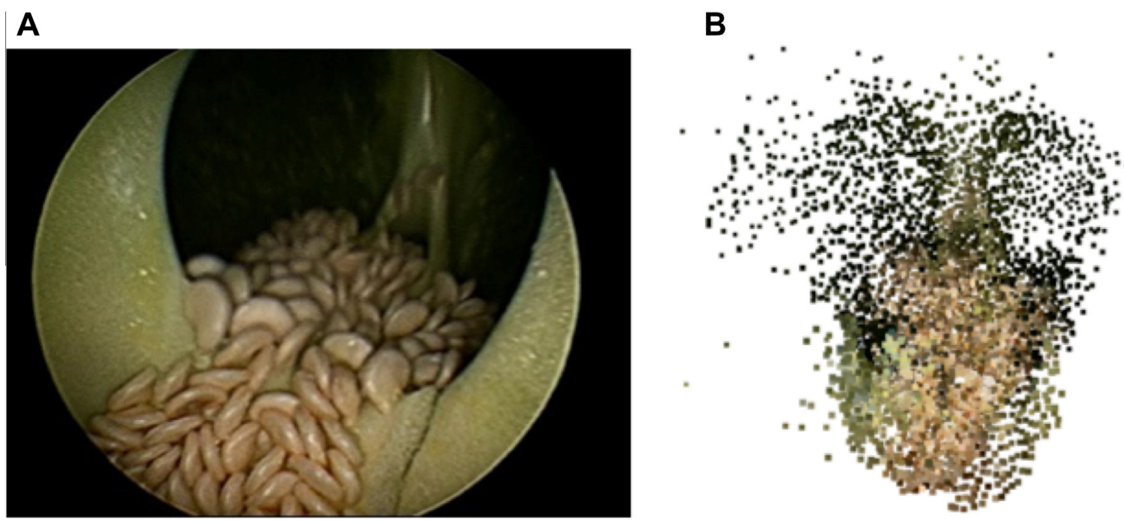

Fig. 2. An endoscopic image from the inside of a capsicum (A) and the reconstructed structure from the hierarchical structure from motion (B).

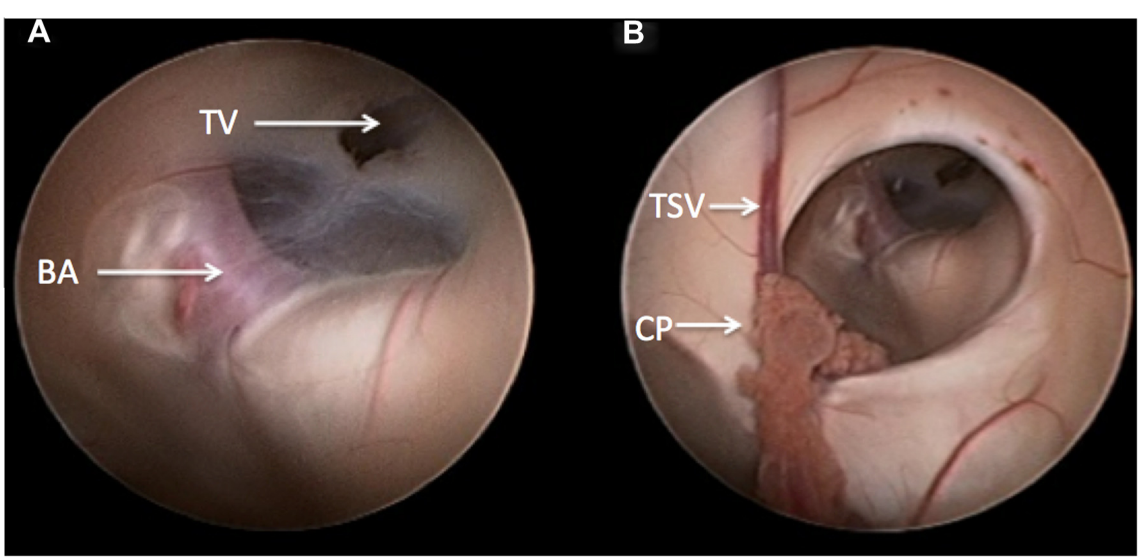

Fig. 3. Two images taken at the end of an endoscopic third ventriculostomy whilst withdrawing the endoscope from the third ventricle. (A) Image taken with the endoscope in the third ventricle demonstrating the third ventriculostomy (TV) and the basilar artery (BA) seen through the floor. (B) Image with the endoscope in the right lateral ventricle with the choroid plexus (CP) and thalamostriate vein (TSV) marking the posterior border of the foramen of Monro.

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