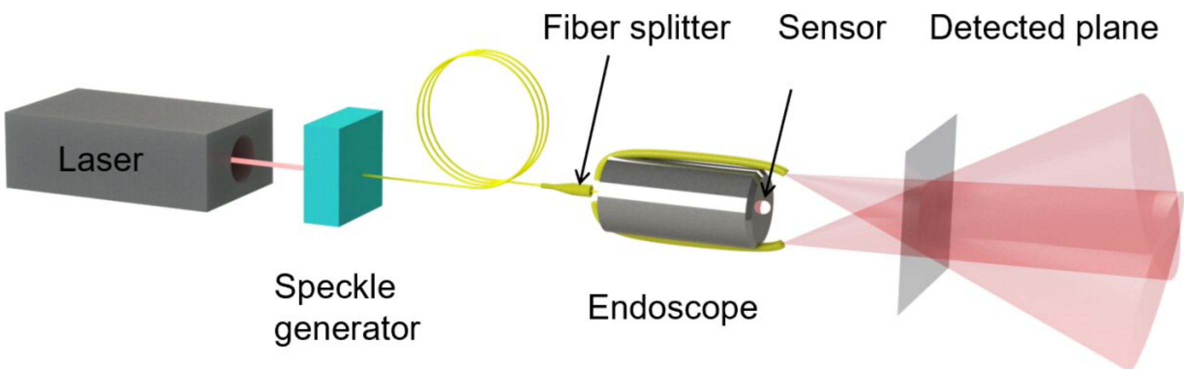
Speckle structured illumination endoscopy with enhanced resolution at wide field of view and depth of field

May 11 2023



Credit: Compuscript Ltd

Super resolution imaging has been a hot topic for over the last few decades in the imaging community, particularly, in the field of microscopy. Although several interesting feats have been achieved in the microscopic imaging community there remains a large gap to bridge between microscopic imaging and the endoscopic imaging community.

Two of the main imaging parameters that bridges the prior gap is image acquisition and processing at a wide field of view (FOV) and large depth of field (DOF) which typically is a bottleneck that one needs to circumvent when attempting to attain super resolution in images. In microscopy, a method that is capable of attaining wide field of view with high temporal resolution and low phototoxicity is called structured illumination microscopic (SIM). A standard SIM can improve the spatial resolution to about two times of the diffraction limit of an optical system.

Because SIM aims to achieve very high spatial resolution, the DOF is typically very small. This means that SIM requires a high level of focusing distance control which is one practical limitation for microscopy applications. In contrast, in endoscopic imaging, the exceptionally wide FOV and large DOF are critical due to the very nature of endoscopic imaging and the samples they image and explore. Hence, to explore the possibility of achieving super resolution in endoscopic images at wide FOV and large DOF is of great interest.

A new technique called speckle structured illumination endoscopy (SSIE) is explored in this work. In the study, published in *Opto-Electronic Advances*, the authors introduce two fibers in a standard white light endoscope (WLE) to deliver high resolution speckles to illuminate the object. The random speckle patterns are generated from the interference between the laser light from the two fibers. A number of images with standard resolution are collected by the WLE camera and then subjected to an image reconstruction algorithm to yield a single super resolution image.

The wide FOV and the large DOF is obtained in this study along with super resolution by fashioning the optical light sources, namely, the multimode fibers carrying the random illumination patterns from the laser in an orientation to not only cover a wide FOV and DOF but also give rise to large angle interference between the illumination beams which contributes to achieving super resolution in imaging. The study is examined on both planar and non-planar surfaces, attesting to the SSIE's objective of imaging at large DOF.

In addition, from a theoretical perspective which is also explored in this study, the FOV and the DOF can be extended to as large as a WLE may allow. Furthermore, the SSIE does not require a stringent control of the illumination patterns, calibration protocols or that of the focusing optics as in the case of SIM, thereby, greatly simplifying the experimental setup.

A demonstration of 2 to 4.5 times enhancement in resolution at wide FOV and DOF over the systemic limit of a standard WLE is demonstrated in this study. The experimental results in the study indicate the potential of the SSIE in presenting a unique route to super resolution in endoscopic imaging at wide FOV and DOF which may be beneficial to the practice of clinical endoscopy. In a broader perspective, this technique of imaging can also be adopted into other similar domains of biomedical, medical, and camera-based systems where high resolution at wide FOV and DOF is preferred or critical.

The authors of this article propose and demonstrate a novel method called speckle structured illumination endoscopy utilized for achieving super resolution in images acquired during the process of endoscopy. The speckle structured illumination refers to nothing more than the usage and direction of random optical illumination patterns originating from a coherent light source such as a laser, onto the sample under study.

The significance of this work mainly lies in enhancing image resolution at optimal imaging parameters of a wide field of view and large depth of field, as wide and large as a typical white light endoscope may allow in comparison to the existing high-resolution endoscopic state of the art which have very limited field of view and depth of field in its image examination and acquisition. High resolution always come with a compromise in the field of view or depth of field as they are typically inversely related to each other.

Hence in this study, the major bottleneck that is being addressed is the capability of achieving super resolution in endoscopic images along with the otherwise inversely related imaging parameters of a wide field of view and large depth of field. Additionally, the system in this study does not rely on any specific properties of the specimen or sample, therefore, any sample can be used for imaging further broadening its potential impact and influence. This study can potentially benefit the endoscopic imaging community in clinics and health centers. Both from an imaging and device-based perspective, no fancy equipment or stringent imaging control is needed for the acquisition and processing of image data.

This makes the speckle structured illumination endoscopic system fairly easy to be translated and adopted into imaging fields broader than just endoscopy. The method will be most feasible if and when it is potentially translated into similar imaging fields that implement an incoherent imaging modality, typically, methods that make use of fluorescent dyes which stain the sample under study. In addition, the speckle structured endoscopic illumination demonstrations are independent of the internal structure, type, or specifications of the scope or probe used. Therefore, the imaging technique can be translated into any white light endoscopic modality with similar resolution improvement factors whether its application is clinical or industrial, since the working principle remains the same.

Furthermore, in a realistic imaging scenario, the sample under study would be possibly non-planar. In this study since we explore the possibility of imaging three dimensional nonplanar surfaces by random optical illuminations, a direct translation of the imaging concept adopted in this study to other imaging fields such as biomedical, medical, or camera-based imaging systems is possible, making it fairly straightforward.

In a broader sense, any imaging system that has a camera to acquire images and that can employ the facility and routing of random pattern based optical illuminations onto the sample by a fashion as demonstrated in this study will be able to achieve super resolution at optimal imaging parameters as explored in this work, particularly in systems that might benefit from having a large imaging depth of field such as in endoscopy, depth-based imaging in camera systems, microscopy and similar fields.

More information: Elizabeth Abraham et al, Speckle structured illumination endoscopy with enhanced resolution at wide field of view and depth of field, *Opto-Electronic Advances* (2023). DOI: 10.29026/oea.2023.220163

Provided by Compuscript Ltd