# 공간 주파수 다중화 off-axis 디지털 홀로그래피에 의한 multiple-depth endoscopic imaging

우성수 [1,*], 강필성 [1], 최재관 [1], 구정식 [1]
[1,*]구미전자정보기술원

[*]sswoo@geri.re.kr

# Multiple-depth Endoscopic Imaging by the Spatial Frequency Multiplexing Off-axis Digital Holography

Woo Sung Soo[1,*], Kang Pil Sung[1], Choi Jae Gwan[1], Koo Jung Sik[1]
[1,*]Gumi Electronics & Information Technology Research Institute

## 요 약

Three-dimensional (3D) mapping of a macroscopic object is crucial in diverse fields ranging from manufacturing to the gesture recognition and automated navigation systems. A range of approaches – white-light OCT, structured illumination and interferometric methods [1-3] – have been reported so far with each approach having its own pros and cons. In the case of the interferometric methods, the depth-resolution can be achieved independently of the lateral resolution by using a broadband light source with a short coherence length [4].

## Ⅰ. 서 론

In this study, we developed an endoscopic digital holography system for 3D imaging of an object located within a hard-to-reach region. We aimed to develop an intraoral scanner capable of mapping 3D morphology of human teeth. To achieve this, we constructed a low-coherence interferometry with a light source having the coherence length of about 400 um, which led to the depth resolution of 200 um. In addition, to reduce the size of the system, an optical fiber bundle was used as an imaging probe. For the illumination, a speckle field generated by a multimode optical fiber combined with a galvo-scanner was introduced onto a sample. By employing a 2D diffraction grating and an echelon in the reference beam path, 9 reference waves were sent to the camera simultaneously, each having a different path length and propagation angle. Those reference waves spatially separate the object information returning at different depths in the Fourier space. This enabled the multi-depth 3D imaging at a fixed reference position, which shortened the scanning time by 9 folds.

## Ⅱ. 본론

To obtain the depth-resolved images, we built an off-axis digital holographic imaging system based on the Mach- Zehnder type interferometry. The schematic diagram of the experimental setup is shown in Fig. 1. The output beam from the diode laser (Thorlabs, LP637-SF70) was split into the sample and reference beams by the beam splitter (BS1). The sample beam was coupled to the multi-mode fiber (MMF; Thorlabs, M59L01) via a 1-axis galvanometer mirror, and then illuminated the sample.

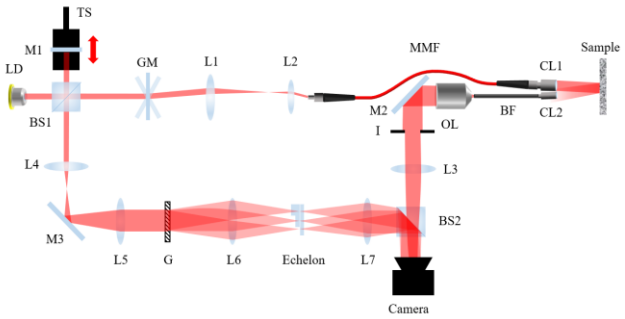


Fig. 1. Experimental setup. L1-L7: Lenses, BS1 and BS2: Beam splitters, TS: Translation stage, GM: Galvanometer mirror, MMF: Multi-mode fiber, BF: Bundle fiber, CL: Collimating lens, OL: Objective lens

The output field from the multimode fiber was a speckle field due to the mode dispersion. The speckle field was changed by steering the galvanometer mirror and the object images were acquired at different speckle patterns. The returning wave from the sample was captured by a lens and delivered through the fiber bundle (BF; Fujikura, FIGH-40-920G), and further relayed to the camera (Lumenera, LM135) via an objective lens (OL) and a relay lens (L3). In the

reference beam path, the laser beam was divided into 9 different waves by the 2D grating composed of two diffraction gratings (Edmund Optics, 80 grooves/mm) of which axes were orthogonal to each other. Each reference beam passed through the different position of the echelon having different optical path length. The reference beams were combined with the sample beam at the beam splitter (BS2) with an off-axis configuration. The multiple-depth images were obtained by recording and processing the interferograms.

The experimental results are presented in Fig. 2. Due to the different angles of the 9 reference beams, each of information was separate in the Fourier space (Fig. 2a). Since each of the reference beam has its own path length, the 9 object images have different depth information according to the path length set by the reference beams. In Fig. 2a, the depth difference between neighboring images is 250 um, which is determined by the echelon's step size (Fig. 2b). To reduce the noise and to enhance the SNR of the measurement, 200 images of a plaster tooth (Fig. 2c) were measured at different angles of the galvanometer mirror. By averaging the speckle images at each depth, the final multiple-depth images could be obtained (Fig. 2d). The field of view is 10.1x7.5 mm2 with the lateral and depth resolutions of 7.2 um and 200 um, respectively.

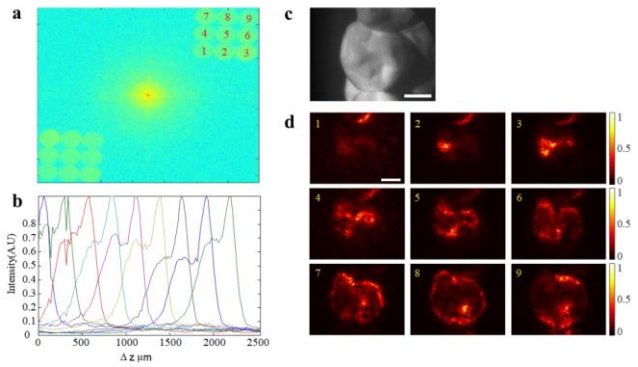


Fig. 2. Multiple-depth images using echelon. (a) Fourier transformed image of interferogram with 9 different optical path length reference beams, (b) coherence function of each 9 depths which have different peak position, (c) LED image of plaster tooth, (d) depth images using echelon. scalebar: 2 mm.

## Ⅲ. 결론

We developed a probe-type endoscopic system capable of multi-depth imaging by combining a 2D grating and an echelon with a digital holographic imaging system. By the spatial frequency multiplexing technique, 9 object images carrying all different depth information were acquired simultaneously. Since a multi-mode fiber and a fiber bundle were used as an illumination and an imaging optics, our system has a potential for being developed as a compact system such as a handheld device.

## ACKNOWLEDGMENT

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