Super-resolution Optical Profilometry Using Maximum-likelihood Estimation

W. Sun, G. Barbastathis, in collaboration with M.A. Neifeld (University of Arizona)
Sponsorship: Montage Program, DARPA

Highly precise and accurate profile measurement is important in various kinds of precision engineering, such as precise parts manufacturing, optical element grinding and polishing, etc. Several techniques have been developed for high-resolution profilometry in different application areas. We presented a number of volume-holographic imaging (VHI) based profilometry systems recently. The VHI-based profilometer optically slices the object to be measured layer-by-layer, and then the acquired raw images from each layer are sent to a computer. The computer reconstructs the 3-D profile of the object. The plane wave reference volume-holographic imaging (PR-VHI) based system with active monochromatic illumination can achieve ≈ 2 mm depth resolution at a 50 cm working distance. For stepwise object metrology, the resolution can be improved to ≈ 50µm at the same working distance. In this report, we present Viterbi Algorithm (VA) based maximum likelihood estimation data processing method for PR-VHI profilometry with multiplexing holograms. The method can resolve object’s features at 8 different depth layers with 4 times super-resolution with raw images captured at only one lateral scanning process.

The experimental demonstration of the VA-based, super-resolution VHI profilometry was applied to a plastic LEGO® model. We set the VHI profilometer at the working distance at 50cm. To demonstrate the super-resolution, we deliberately closed down the aperture to degrade the nominal depth resolution to 6.5mm. The active illumination is from a Coherent Verdi®-5 Nd:YAG laser operated at 532nm. We repeated the experiments at the laser output powers of 25mw, 15mw, and 8mw to test the super-resolution performance at different SNR levels. Two multiplexing holograms recorded in a single LiNbO3 crystal were used in the experiment. These two holograms were [consistent tense for experiment] focused on two different depth layers with the spacing of 6.4mm, equivalent to four LEGO® layers. In the profilometry process, the two holograms were set to focus on the 3rd and 6th layers of the LEGO® model (with distances \( z_1 \) and \( z_2 \) from the PR-VHI system, as shown in Figure 1). With mechanical scanning only at one lateral dimension (x direction shown in Fig. 1), two raw images of the profilometry slices at the 3rd and 6th layers of the LEGO® were acquired. These two slices were then sent to the VA based, post-processing to reconstruct the object. Figure 2 shows reconstructed LEGO models with the VA-based method and cross-correlation-based method. The results show that the VA-method generates a reconstruction almost without error.

![Figure 1: Schematics of the PR-VHI super-resolution experiment with multiplexing holograms.](image1)

![Figure 2: Reconstructed LEGO® model with VA-based post-processing method.](image2)