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Superresolution far-field imaging by coded phase reflectors distributed only along the boundary of synthetic apertures

ANGIKA BULBUL,* A. VIJAYAKUMAR, AND JOSEPH ROSEN

Department of Electrical and Computer Engineering, Ben-Gurion University of the Negev, Beer-Sheva, P.O. Box 653, 8410501, Israel
*Corresponding author: angikabulbul@gmail.com

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The resolution of imaging by space and earth-based telescopes is often limited by the finite aperture of the optical systems. We propose a novel synthetic aperture-based imaging system with two physical subapertures distributed only along the perimeter of the synthetic aperture. The minimum demonstrated two-subaperture area is only 0.43% of a total full synthetic aperture area. The proposed optical configuration is inspired by a setup in which two synchronized satellites move only along the boundary of the synthetic aperture and capture a few light patterns from the observed scene. The light reflected from the two satellites interferes with an image sensor located in a third satellite. The sum of the entire interfering patterns is processed to yield the image of the scene with a quality comparable to an image obtained from the complete synthetic aperture. The proposed system is based on the incoherent coded aperture holography technique in which the light diffracted from an object is modulated by a pseudorandom coded phase mask. The modulated light is recorded and digitally processed to yield the 3D image of the object. A laboratory model of imaging with two synchronized subapertures distributed only along the border of the aperture is demonstrated. Experimental results validate that sampling along the boundary of the synthetic aperture is enough to yield an image with the resolving power obtained from the complete synthetic aperture. Unlike other schemes of synthetic aperture, there is no need to sample any other part of the aperture beside its border. Hence, a significant saving of time and/or devices are expected in the process of data acquisition.

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1. INTRODUCTION

In general, imaging with a synthetic aperture is a technique in which a relatively small physical aperture scans a relatively large (much larger than the physical aperture) synthetic aperture over time [1]. The accumulated data in time are processed to yield an image with qualities equivalent to that of an image acquired by a single exposure of the complete synthetic aperture [2]. Since the minimal resolvable detail of an image is inversely proportional to the aperture size, the image resulting from the synthetic aperture has better resolution than the image obtained from the physical aperture by direct imaging. Commonly, the resolution improvement is equal to the ratio between the sizes of the synthetic and the physical apertures.

Usually, in order to avoid information loss, the synthetic aperture is sampled by the physical aperture, with a sampling rate higher than the sampling limits [3,4]. This sampling restriction is valid for synthetic aperture radar (SAR) in the radio frequencies [1], or for Michelson stellar interferometry [5], very large baseline interferometer (VLBI) [6], and synthetic aperture with Fresnel elements (SAFE) [7] in the optical regime. Sparse SAFE (S-SAFE) is an example in which the synthetic aperture is sampled according to the rules of compressed sensing [8,9]. Nevertheless, the entire synthetic aperture is sampled also in the case of S-SAFE. Herein, for the first time to the best of our knowledge, we propose to sample the synthetic aperture only along its perimeter with a much smaller pair of physical apertures with respect to the total synthetic aperture area at a time. Although only the margin is sampled, the resulting image maintains the resolution and other qualities similar to the image obtained by sampling the complete synthetic aperture.

Synthetic aperture techniques such as SAR [1] and VLBI [6] are indirect imaging techniques, where the image is not directly obtained on the sensor, but exhaustive digital signal processing is implemented to retrieve the image in the computer. Another well-known indirect, multistep but simpler, imaging method is digital holography [10]. First, a hologram is recorded, usually by an interference of the light diffracted from an object with a reference wave. Following a digital process of the hologram, the next step comes in, in which the image is reconstructed from the processed hologram. The space between the stages of recording and reconstruction offers ample opportunities to apply synthetic aperture procedures. Techniques of imaging by synthetic aperture