Improved 3D-position detection by holographical point replication

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I. Introduction

Nowadays, one major task of camera vision systems is to integrate functionality, which has formerly been realized by highly specialized metrology hardware. One well-known application is the measurement of positions in two- or three-dimensional space. The main focus is not merely measuring as accurately as possible, but also receiving positional information in real-time. However, accuracy is often obtained by averaging information in time, which in turn results in a loss of speed.

Our field of application is the position measurement of several object points, which can move independently. To reconstruct the position of a single object-point, a commonly used technique is to calculate the center of gravity (COG) of the corresponding grey values of the image spot. Well-known problems of this technique are amongst other things lens distortion, discretization errors and camera as well as photon noise. The first mentioned problem can be compensated by calibration, whereby the latter ones are not easy to overcome.

In this paper we use a simple technique to improve the measurement accuracy of COG substantially and apply it in an interactive stereo setup to measure 3D geometry of objects.

II. Noise and Discretization

When position detection has to be accurate, the main problem is to overcome noise and discretization. The nature of the photon limits our ability to measure its position. Due to Heisenberg's uncertainty relation, imaging based position measurements have always a limited accuracy. This becomes clear when tracing the ideal position from the object all the way to the image sensor, where the error is dictated by the numerical aperture of the optical system, which in turn translates into the wave-typical point spread function. A measurement is practically a series of independent measurements, done by taking the mean over many photons. If N is the number of photons, the accuracy of the series of measurements is improved by a factor of $\sqrt{N}$.

Obviously, this corresponds to the theoretically best achievable accuracy. Using a real (pixelated) sensor, each pixel with a limited quantum well capacity will limit the amount of photons N and therefore positioning accuracy. Furthermore, discretization leads to additional inaccuracies. These problems are partly bypassed by the multipoint technique.

III. Multipoint Technique

We use a simple technique that uses spot-replication to enhance measurement accuracy. The camera lens hardware is upgraded solely by a computer-generated hologram (CGH) which realizes the spot-replication. In our example the CGH is placed in front of the lens "Fig. 1". One single object point is replicated N-times to a predefined spot-pattern. In the following context, "spot" refers to the image of an object point whereas "spot cluster" refers to the replicated pattern consisting of N spots. The spot cluster itself "fig.2" is symmetric with respect to its center spot (0^{th} order) so that the average displacement results zero. The object position is calculated by averaging the centers of gravity of the N-replicated spots of the spot cluster. The object position is made of the combined information of each of the spots composing the spot cluster. By using these predefined spot clusters it can be shown, that errors caused by the imager (such as discretization and noise) can be reduced by the square root of the number of replicated spots [1, 2]. A spot cluster of N = 16 spots therefore should theoretically improve the accuracy by a factor of 4.

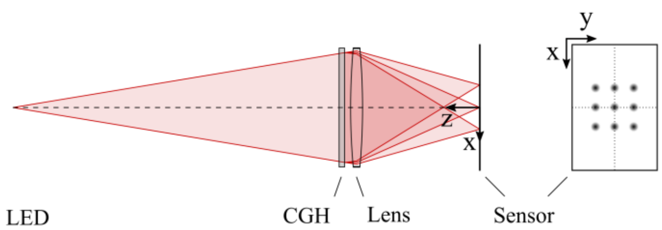

Fig. 1. By use of a hologram in this example one image point is replicated to N = 9 points. [2]

In recent years, various investigations concerning achievable positioning accuracy have been undertaken [3, 4]. Using different approaches, RMS deviations of up to 1/150 of a pixel have been reached [4]. With the prementioned multipoint method, the standard deviation of the measurement result had been reduced to 1/350 of a pixel (where N = 16 spots) [1, 2].

IV. Laboratory Setup

A new approach is to use this method in a stereo camera setup. In order to measure a distance z as accurately as possible, commonly a stereo setup needs to have a large stereo baseline b, because the measurement error dz depends linearly on the length of the baseline:

$$dz = dp \cdot z^2 / (f \cdot b) \quad (1)$$

where f is the focal length and dp the disparity.

The ambition is to increase accuracy using a small stereo baseline, keeping the system compact and portable.

The laboratory setup consists of two cameras with a base of 100 mm and a working distance of 2 m to observe the z-position of a LED light source. The multipoint method improves depth uncertainty dz of the measurement from 0.185 mm to 0.066 mm (with N = 16).

V. DEMONSTRATOR

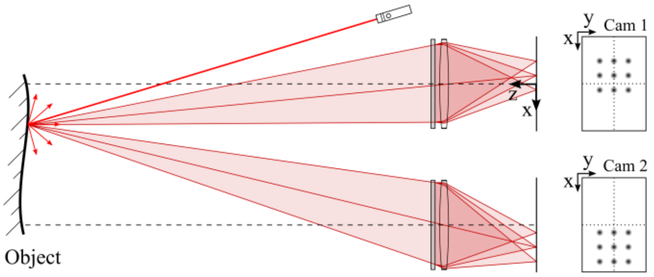

Fig. 2. Light coming from the laser is being scattered from the object, which then acts as a light emitter for the stereo camera setup.

For the EUVIP demo session we are planning to extend this stereo setup to interactively measure X-Y-Z coordinates of an object surface. The main difference is that the formerly mentioned light source is replaced by the scattered light spot of a laser pointer. In doing so, the laser spot acts as if it was a proper light source. Afterwards, a real object is placed into the field of view and illuminated by the laser pointer. By applying a short exposure time, the laser spot position on the object can be traced accurately using the prementioned replication technique. The resulting 3D-object information will be recorded in real-time (>50 fps, <1 fps latency) and shown on a screen.

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