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A new control mark for photogrammetry and its localization from single image using computer vision

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ABSTRACT

Computer Vision takes part in many industrial applications mainly in robotics and measurement systems. Geodesy uses computer vision rather indirectly using specialized software tools for measurements of data captured with digital cameras or LIDAR systems. This paper describes new control mark and its advantages for deformation measurements, and surface reconstruction. Furthermore, we describe control mark detection method using computer vision algorithms, and its localization from single image. We also compare this method to spatial polar method.

1. Introduction

Reconstruction of surface and structure of objects is important task in many industrial applications. Very popular method for surface or object reconstruction is known as photogrammetry well described in Kapica and Sladkova [5]. The information we obtain from most photogrammetric systems using control marks are three-dimensional positions of the marks. We have focused on stereo-metrical system with control marks, where the main measurement tool is a camera. The user takes multiple images of the measured object with control marks from different angles, and then the three-dimensional coordinates of each mark are computed. This measurements are done repeatedly over time to measure the shift and deformation of the monitored object well described in DIAS-DA-COSTA [14]. The important part of every photogrammetric system is detection of control marks using computer vision techniques. Good detection rate and precise measurement of the control mark are essential for reliable results. We have been working on an improvement of detection rates of control marks and a way for extraction of more data from them.

Every control mark have to be easily distinguishable from the environment it is located in. Therefore, the control mark is often realized as an image with high contrast colors or intensities (in most cases black and white), MORIYAMA [15]. Also, the shape of the mark should be very different from shapes of the objects that are naturally present in surveyed locations. These premises allows photogrammetric tools to easily detect those marks in the image with higher reliability (lower number of false detections). Hereby we can say that the use of control marks with simple shape like circle is highly unreliable and the user is forced to mark the marks on the image manually.

We have designed a new control mask, which is more complex, and therefore, it is less likely that there will be similar objects in the image causing false detection. Furthermore, the mark is designed in such a way, that we can easily extract its three-dimensional rotation. This is useful mainly when we are measuring deformation of the object of interest. We also propose a photogrammetric method using only single camera image for three-dimensional localization. We describe the new control mark, and new localization method in greater detail in following sections.

Testing detection of newly proposed targets took place both in the laboratory conditions and outdoors on the retaining wall no. 8246 in the undermined part of the D1 motorway in Ostrava, the city district of Svinov. The results of the testing show that the location of targets and their detection can also be successfully applied to more complex constructions in the real environment.

2. Control mark

The control mark must be easily visible and distinguishable from the environment we are going to place it into. Therefore, the mark must have high contrast colors or intensities and its shape should be more complex than objects usually present in most locations to make it more distinguishable from the surveyed environment. It must provide more than one coordinate, so it would be possible to extract its rotation in three-dimensional space, and to estimate it position from single image, for difficult situations, when it is not possible to take more images from different angles (e.g. narrow areas).

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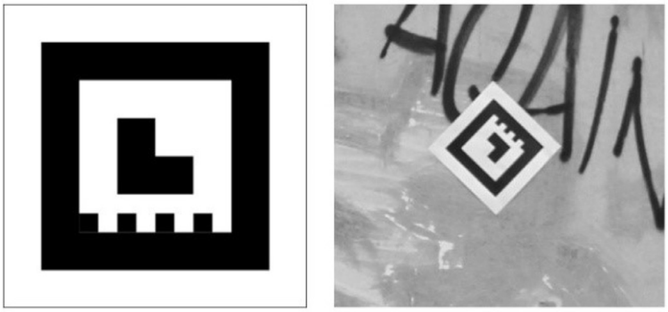

Fig. 1. Proposed control mark and its placement on the testing wall.

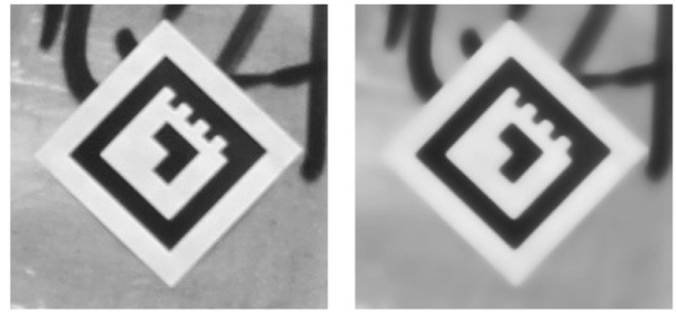

Fig. 3. Control mark before and after filtering.

We have designed a control mark, which meets all given requirements. As seen in Fig. 1, it is rectangular with specially designed internal pattern to ensure its uniqueness. It is also diagonally asymmetrical, and therefore, we can conclusively extract its rotation. Consequently, each point on the mark can be uniquely identified. The border around the mark ensures its relatively easy distinction from other objects in the image. We describe the detection algorithm in the following section.

3. Control mark detection

The object detection is important task in computer vision. There are numerous methods for this task. Well researched domains of object detection include face detection described in Yang et al. [12] and pedestrian detection described in Enzweiler and Gavrila [3]. The most known detector tools are SVM developed by Cortes and Vapnik [2] and AdaBoost developed by Viola and Jones [11]. These detectors are trained, and therefore, they need training sets consisting of positive samples (consisting the object of interest) and negative samples (other objects or parts of background image) to work. There are also moving object detectors based on background subtraction described in Malik et al. [6]. These methods are learning the background of the image (slowly moving or stationary objects) and subtracts the foreground (moving objects). Another, method for object detection is to analyze a contour of the object extracted from image segmentation or directly from image gradient. The last mentioned method is most suitable for our task, because it is working correctly also for rotated and scaled images. This is important, because our marks can be positioned from different distances, angles, and with different rotations as it can be seen in Fig. 2.

Our detection method consists of few fundamental steps. First, we filter the image noise to reduce its influence on detection. Then we extract important edges and corners from the image. After that, we find continuous contours from edges consisting only four corners (rectangular control mark). Extracted contours are candidates for our detected mark. The last step is to test each candidate against predefined pattern (expected appearance of the control mark) using algorithm known as pattern matching. This step is done for multiple permutations of the corner points to find the right orientation of the control mark. This method is described in further detail in following subsections.

3.1. Image filtering

Image filtering is a process used for reduction of undesirable properties of the image. Image noise is random component of the image causing variation of color and brightness. It is error caused by sensor chip of the camera. If this noise is not filtered out, the edge and corner detectors will not work properly. Therefore, we use image filtering to reduce noise.

The most used image filter for noise reduction is Gaussian filter described in Stockman and Shapiro [10]. The Gaussian function is used as a kernel function for image convolution with noisy image. Gaussian filter reduces random image noise very effectively, but with the noise also the edges in the image are blurred. This is due to properties of edges and noise in frequency domain of the image. Both noise and edges are represented by frequencies and the Gaussian blurring works as a low-pass filter in frequency domain. To preserve edges in the image other method for filtering must be used.

The filter we have used is known as Perona-Malik filter developed by Perona and Malik [8]. This filter preserves important details in the image, typically edges and lines, which is important for our method. This filter is based on heterogeneous diffusion described by following equation

$$\frac{\partial I}{\partial t} = \nabla \cdot (c \nabla I), \quad (1)$$

where I represents image, t is time, ∇ represents gradient operator, and c is diffusion coefficient. The diffusion coefficient is very important in the equation. It describes behavior along the edges in the image. The basic idea is to slow down the diffusion process (filtering) along the edges. This way, similar intensities are filtered more, and therefore, creating homogeneous areas separated by preserved significant edges. The diffusion coefficient is driven by image gradient magnitude and has the following form

$$c(\|\nabla I\|) = \frac{1}{1 + \left(\frac{\|\nabla I\|}{K}\right)^2}, \quad (2)$$

where K represents a sensitivity to edges. The result of image filtering using the Perona-Malik filter can be seen in Fig. 3. As you can see, the detail of control mark is much more homogeneous than in original image, yet the edges are preserved. This step significantly improves edge and corner detection.

3.2. Edges and corners detection

Corners and edges are important features for our control mark detector. Edges are parts of the image, where image intensities change rapidly (high gradient magnitude). We are often looking for thin edges

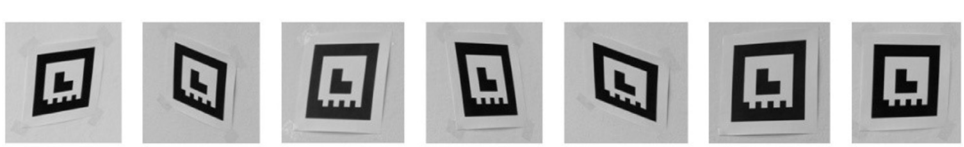

Fig. 2. Views on control marks from different angles.