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Automation of Measurements of Selected Targets of Photopoints in Application to Photogrammetric Reconstruction of Road Accidents

1. Introduction

The development of digital image processing methods makes it possible today to employ photogrammetric methods in different measurement systems used in various applications. The automation of measurements is here nearly always a condition for a commercial success, enables the system to be operated by non-professionals, and reduces the time for training them.

One of applications of photogrammetric methods includes the survey of a post-accident situation in road traffic. The use of photogrammetry in that case seems to be absolutely normal: photos are taken at the accident site, which document, first of all, those remains which are later likely to be removed or damaged, like e.g. chips of glass, traces of vehicle braking, stains left by spilled automotive liquids, etc. Such photos, taken in accordance with specific rules, may be used for the photogrammetric reconstruction of the geometry of selected objects and their location in relation to each other.

The recording of identified traces is objective by nature, that is why photography provides full-value evidence in the process of road accident reconstruction. One should, however, bear in mind that only a series of photos of the same spatial situation, shot from various, carefully well-thought-out views and in accordance with specific rules can provide a full-value metric material.

Photogrammetric measurements in post-accident surveys in Poland have been used for many years, although incidentally. In the 1970s and 1980s, some regional police headquarters had their own photogrammetry units and labs, and their job included recording images made with photogrammetric cameras and processing them with the use of analog stereoplotters. Obviously, such measurements were

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made only in the case of selected road accidents, and predominantly, those with fatalities. In addition to that, in the 1980s, the then police started introducing using photo camera images to measure vehicle braking tracks. Presently, attempts are made at introducing various measurement techniques to post-accident surveys: terrestrial laser scanners and total stations, yet photogrammetry, which is based on photo images, has an advantage in that it does not require an expensive measuring equipment which has to be used in inconvenient and hazardous conditions.

2. A Review of Photogrammetric Measurement Methods Applied in Post-accident Reconstruction Projects

The survey of a post-accident situation is made with the use of 2D and 3D photogrammetric methods. The 2D methods assume mutual projectivity of the road plane and that of the photo image recording, and are based on single images, whereas 3D methods require taking a minimum two photos with the same points on them.

2.1. Single-image Methods

A post-accident reconstruction commonly employs a 2D projective transformation of the plane. Based on the knowledge of coordinates of minimum four homologous points in road and digital image planes, one can compute eight projective transformation coefficients. The situation, which is required here is such that no three points may lie in a straight line, and also one must know coordinates of points involved in the transformation in the image coordinate system and in the ground coordinate system [12].

The performance of projective transformation based on a minimum four points allows for the measuring of the event site (e.g. braking trace length) directly on the transformed image.

2.2. Multi-image Methods

The method that is most often used nowadays is the one, that is based on the reconstruction of projection rays described by colinearity equations. It is called the bundle adjustment method. That method allows for the determination of the shape and location of objects in a 3D space on the basis of, at least, a pair of the object images. Within a single process, one computes image orientation elements and coordinates of the points established in the ground coordinate system on the basis of the knowledge of image and ground coordinates of, at least, three photopoints. Beginning with the condition of coplanarity, one writes colinearity equations that provide grounds for solving the majority of issues related to obtaining the spatial location of the points.

The bundle method finds also application in the reconstruction of road accidents. It enables us to determine the spatial coordinates of points. Thanks to that method, it is possible to reconstruct the spatial post-accident situation.

3. An Attempt at Automation of Measurement of Targets of Patterns Used to Prepare Photoplans

Measurement points in photogrammetry include both those, whose planary or spatial location we want to find, as well as such points, which are used for the (planary or spatial) orientation of images. The latter are called photopoints, and their position in the reference system is known. When reconstructing road accidents, only some of the possible ways of indicating measurement points are applied. Commonly applied are signs in the form of small chequered patterns, fixed at the end of the so-called standard referencing cross, which constitutes a metal rod. The dimensions of the cross are known, so ground coordinates for those points can easily be determined. This type of signalling is utilized to perform 2D projective transformations, and a majority of available applications require manual measurement of image coordinates. The automation of that process is extremely important on account of reducing time of working with the program and improving the measurement accuracy, and contributes to the commercial success of the software. However, an automatic measurement in a digital image of target centres in the form of chequered patterns seems to be hindered. Those difficulties result from specific conditions, in which photos designed to be used later for the reconstruction of road accidents are taken (the perspective of a standing person). The photographically rendered signs are subject to great geometric deformation. There appears a difference in the scales of signs, which are close and of those, which are slightly farther. Photos are taken randomly in terms of their orientation in relation to targets. There are also differences in the lighting of patterns. The figure below (Fig. 1) shows targets subjected to deformation.

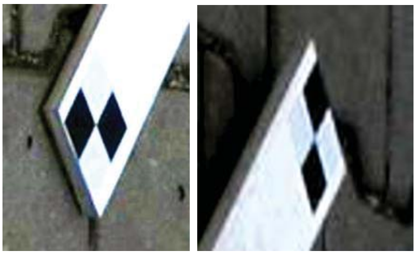

Fig. 1. Perspective deformation and chequered patterns scale difference

There are frequent cases, in which photos that have been taken over an area larger than that in the immediate vicinity of the standard levelling rod. That fact forces the extrapolation of projective transformation coefficients to a much larger area, thus generating bigger transformation errors. At the same time it is not possible to remove that problem completely, since the standard referencing cross must be placed so that it would not obscure the post-accident situation.

While coping with the above-described difficulties, attempts have been made at creating a program in Matlab v. 7.10, which would be measuring the centres of the chequered pattern signs. A number of detection attempts were performed, employing various methods, ranging from Area Based Matching [10], through the application of other methods determining the similarity of the image fragment to the pattern [2], to the Harris operator [5] and Hough transformation [4, 11]. Unfortunately, none of them yielded satisfactory results. Therefore, in order to detect chequered patterns, morphological operations were applied, in combination with relevant mathematical functions, with the thresholding and filtering of the regions [4, 11]. The process of identifying chequered patterns is preceded by the binarization of the image and the detection of the whole cross. Due to a very diversified neighbourhood of the measurement object and distinct differences in lighting, binarization with an automatically selected threshold turned out to be impossible. That stage required an intervention by the user and determination of a proper threshold. In order to identify the cross on the image, a coefficient was applied that compared the shape of the regions with the smallest rectangle, which would contain that region in whole. The isolated cross is subjected to smoothing and thinning. Next, a relevant mathematical function computes points of the skeleton ends. Those points set out the location of chequered patterns. Then fragments are removed from the input image, and the central pixels in those segments are the computed points of the standard levelling rod ends. Images of chequered patterns are in those segments. In order to perform measurement of the chequered pattern centre with sub-pixel accuracy, the participation of the user is necessary. The user will, with the approximation of several pixels, indicate the centre of the target in the source image fragment. Knowing the approximate centre, one can obtain, by means of the multinomial approximation, the exact location of the chequered pattern centre (Fig. 2). The determination of stationary points leads to the problem solving.

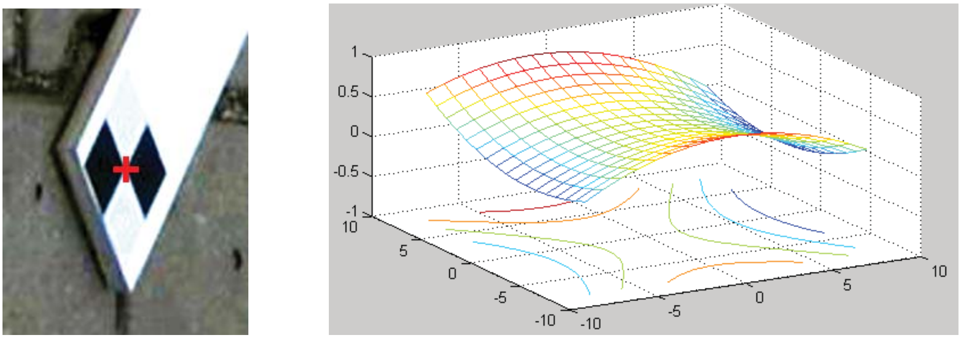

Fig. 2. The target centre set out in the program for the measurement of the chequered pattern sign centres and the image of that centre's neighbourhood

The created program demonstrated that things extremely difficult in that application included the detection and measurement of targets, which were subject to great perspective deformation, were freely oriented in relation to image matrix frames and displayed very big scale differences, while at the same time, being sensitive to twisting. The determination of those target centres with sub-pixel accuracy proved to be possible in the event that the user himself indicated the approximate locations of those centres. The developed program identified the cross photographically rendered in the image, and the possibility of determining any given threshold of the image binarization enabled almost a 100% effectiveness of its detection.

Hope for an effective automation lies in the use of the latest algorithms, the so-called detectors and descriptors, such as SIFT and SURF [3].

4. Automation of Measurement of Targets in the Form of Coded Rings

Automation is slowly becoming a common procedure, normally applied in consecutive measurement projects. Following the development of measurement process automation methods, also the method of target encoding develops. Code targets are used in purely photogrammetric solutions, e.g. for test field signals to calibrate cameras [8] but one can find many applications of such signs in other photogrammetry-related issues like, e.g. reconstruction of road accidents.

The critical thing, in the case of coded signs, is their proper structure, in which one can distinguish the measurement object, allowing for the measurement of coordinates, and the code object, enabling the identification of the point. Sometimes one can also find signs, which have additional elements, supporting e.g. the determination of the sign orientation [1, 7, 6]. The Figure 3 shows an exemplary ring coded sign.

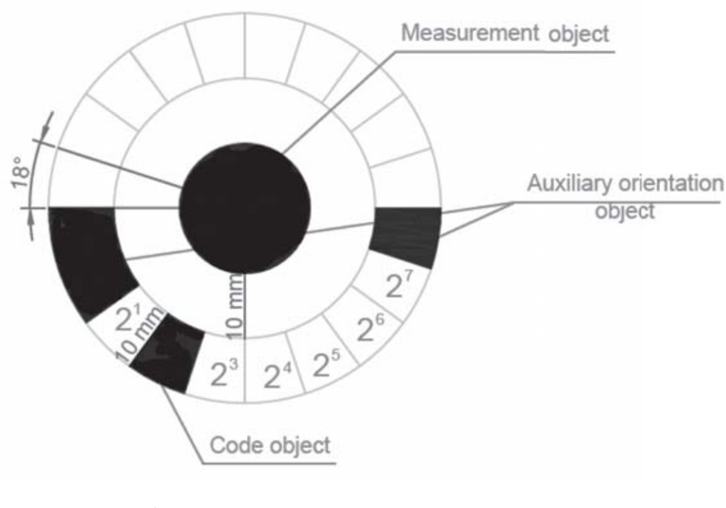

Fig. 3. Ring code with orientation segments

Coded signs are used when it is necessary to provide numbering in order to the identify same targets that have been photographically rendered in several photos and to assign points measured in the photo to their ground coordinates. A ring or a circle is the most popular figure to be utilized in signalling the object of measurement. By contrast, as far as code objects are concerned, there are practically no limitations to their structures. Originators of generated codes must remember, after all, that designed signs should, as far as possible, be independent of rotation, scale and distortions connected with the central projection. From an economic point of view, it is also important that signs should allow for the encoding a large quantity of numbers and a quick identification.

Taking into consideration the above aspects and keeping in mind specific conditions in which photos are taken, these were ring targets that were chosen as most suitable for the purposes of the post-accident reconstruction. From the viewpoint of measurement and identification automation that choice is also justified since it enables the implementation of a relatively simple and, at the same time, effective algorithm of identification. That algorithm is based on the analysis of brightness profile along the encoding ring, and was introduced to the application allowing for an automatic detection, measurement, and identification of targets. Matlab v. 7.10 with *Image Processing Toolbox* library were utilized to create the program.

The target detection algorithm implemented to the program is based on the method of region filtering [4]. Proper characteristics are calculated for the objects and, based on them, objects similar to the standard image target are selected. After marks on the image have been detected, there follows the measurement of target centres with the Center Weighted Method (CWM) [9].

4.1. A Description of Identification Algorithm

The scheme of proceeding in the process of point numbers identification was presented in Figure 4. In the case of ring codes, those numbers are coded on the ring segments. On the basis of target centres and the ellipse semi-axis length of the same second moments there follows the determination of the parameters of a code searching ellipse, and then sampling. Brightnesses from the binary image of the targets along that ellipse are collected at angle intervals of 3°. The so-created brightness profile is processed in such a way that the mean value is calculated for six consecutive elements of the profile. Results are rounded-up to 0 or 1. It is also necessary to find the code read-out beginning, that is the value of 1, followed by ten zero values, and then again the value of 1. Next, non-zero elements of the code are assumed as exponent 2. The given point number is the aggregate of all non-zero elements of the code (Fig. 4). The operation of sampling takes place in three runs. The final number of the target is determined as a modal value of target numbers computed during consecutive sampling sessions.

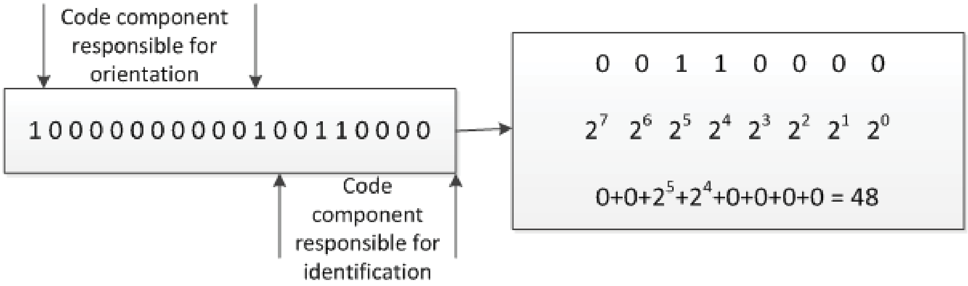

Fig. 4. An example of identification of number 48

4.2. Examination of Target Measurement Accuracy in Various Aspects

A number of tests were performed to verify the correctness of the operation of the program to measure coded ring targets. The tests included measurements in various geometry images. The charts below (Fig. 5) present the relationship between a number of detected and correctly identified signals, and the convergence angle between the target plane and that of the digital camera matrix.

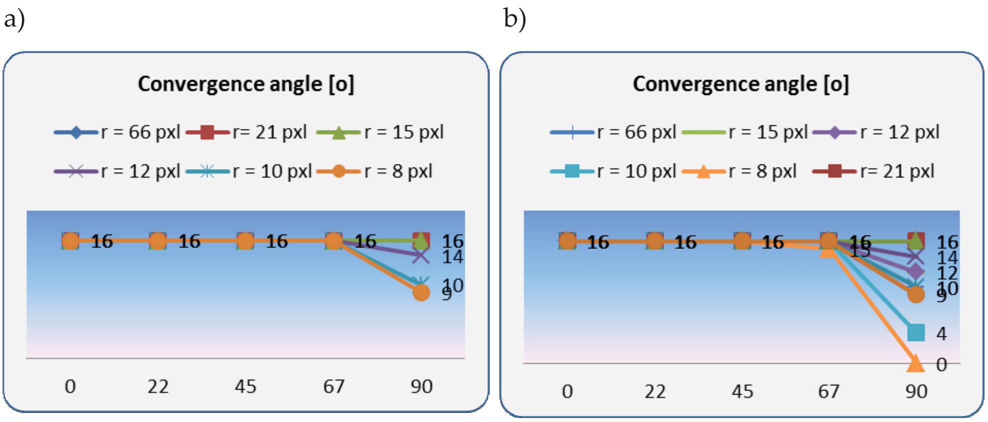

Fig. 5. Relationship between the quantity of detected targets (a) and correctly identified numbers (b), and the convergence angle. Data for different pattern sizes

The data demonstrate that the limit value of the convergence angle, at which full detection occurs, is ca. 60°. By contrast, the correctness of the target number identification drops already at the convergence angle exceeding 45°. For the convergence angle of about 60°, the correctness of identification remains on the level of 90%. One can assume 60° as a limit value, allowing for the execution of measurement and performance of a correct identification.

Tests also covered the correctness of the detection and identification for various targets size. The obtained results relate to patterns, which do not demonstrate a perspective flattening. Tests proved a definite downward trend in the correctness of the target number identification when using patterns, whose rays in the image have less than 8 pixels. Yet, full target detection takes place even if their dimensions are very small.

A examination of the correctness of the operation of the program algorithms in the case of any target rotation was carried out in the test field. It demonstrated the full effectiveness of the detection and identification, independent of the rotation.

The final trial for the created program was a field test and the determination of the program operation correctness based on images made under real conditions. There were ring targets applied, which were stuck on stands, placed on the roadway. Such signalling enables the minimization of target flattening. Ten measurement photos were made, for which the image-target convergence angle did not exceed 40°. The completed tests demonstrated a very high correctness for the program operation under field conditions, because all targets were detected in each of the photos. In addition to that, there were two instances, in which the program measured and identified points that represented no targets. Such situations are hard to avoid, since the environment of targets is highly diversified (roadways, curbs, sidewalks, nearby cars, trees, etc.), and their sizes, as well as parameters describing their shapes show high fluctuations. The performance of the field test made it possible to confirm that the program could be utilized in practice.

5. Summary and Conclusions

At close range, photogrammetric systems as used in various applications, and the automation of measurements is a condition for a commercial success. It not only makes it possible for the system to be operated by non-professionals, but also enhances the measurement accuracy.

This paper presented an attempt at the automation of measurement in digital images utilized in the reconstruction of road accidents. The first attempt at automation was a qualified success: a program was created for the operator-aided automatic measurement of targets of patterns used for the rectification of images with the application of a 2D projective transformation. Targets in the form of black and white chequered boards as used in standard templates proved to be difficult for an automatic measurement. This type of sign is highly sensitive to distortions and perspective foreshortenings. The proposed method of segmentation and a subsequent measurement on the basis of detection of standard levelling rod ends required the “manual” setting of certain parameters. Full automation can be achieved through the application of another, more advanced algorithm of detection, insensitive to twisting, great scale differences and significant perspective distortions. Another, and a more economic solution, is changing targets to other ones that are easier for an automatic measurement, e.g. ring signs.

The automation of measurement of that second type of sign, i.e. ring signs, succeeded superbly. The created program is effective, enabling targets of substantial perspective distortion and various scales to be measured. The completed research made it possible to frame optimal conditions for the imaging of signs for their automatic detection, measurement, and identification. This, in turn, will allow for the implementation of the algorithm into the program, which is used in reconstructing post-accident situations.

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