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Trushkina, Anna V.; Vasilev, Aleksandr S.; Serikova, Mariya G.; Anisimov, Andrei G.

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High-reflection microprismatic material as a base for passive reference marks in machine vision metrology applications

Anna V. Trushkina[a], Aleksandr S. Vasilev[a], Mariya G. Serikova[a, b], and Andrei G. Anisimov[c]

[a]Dept. of Optical-Electronic Devices and Systems, ITMO University, Kronverkskiy pr., 49, Saint-Petersburg 197101, Russian Federation

[b]Optical-Electronic Devices LLC, Birjevaja line V.O., 14, 199034, Russian Federation

[c]Aerospace Non-Destructive Testing Laboratory, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS, Delft, The Netherlands

ABSTRACT

In this work it is shown that high-intensity microprismatic tapes have a potential to be used as a good substrate for bright and cheap fiducial marks in machine vision metrology applications. The drawback of the tapes is that they have technological netting pattern distributed across the surface. The proposed image processing technique allows good suppression of the parasitic technological netting pattern by a harmonic mean image filtering followed by circle shape recovering based on Fourier descriptors. It was also shown that the combination can provide good results in mark position estimations. In experiments it was shown that subpixel accuracy of position estimation can be achieved after applying proposed image processing, while without filtering the error can exceed 4 pixels in some cases.

Keywords: Reference mark, retroreflectivity, microprismatic retroreflective tape, machine vision, mark position estimation

1. INTRODUCTION

Position estimation of an object is necessary in many industrial applications, such as fabrication tools positioning, traffic management, inspection of large-scale structures such as buildings, parts of ships and airplanes, nuclear plants turbines etc.[1–5] These tasks can precisely and automatically be solved by machine vision systems. The systems traditionally utilize reference marks (called fiducials) mounted on object to improve quality of detection and position measurement. Active reference marks traditionally use brightness-controlled LEDs to simplify detection process and improve signal-to-noise ratio in the mark image. But the active marks require power supply, which is often inconvenient in maintenance. To avoid the problem passive reference marks made as black-and-white or colored printed patterns can be used. They can provide good quality of registration but complicate image processing and pattern recognition procedures.

Figure 1. Traditional application range of retroreflective tape includes zone signs and traffic control devices, high visibility breakaway vests and jackets, road signs and other applications, where visibility of objects needs to be increased.

Further author information: (Send correspondence to Anna V. Trushkina)
Anna V. Trushkina: E-mail: 156783@corp.ifmo.ru

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In this work we suggest to replace traditionally used non-reflective substrates for printed patterns by retroreflective tape (fig. 1) to improve the visibility of marks and performance of measuring process. There are different kinds of retroreflective tapes technologies available on the market.[6–8] The most effective tapes with highest retroreflectivity are based on micro-prismatic technology with hermetically sealed pockets with air located under clusters of microprisms to increase total internal reflection of the incident light. The drawback is that edges of the pockets become visible on the image acquired by machine vision system (fig. 2). The edges form netting pattern distributed all over the surface of a reference mark. This additional undesired pattern distorts shape of printed pattern image, that affects accurate coordinates extraction from reference mark image.

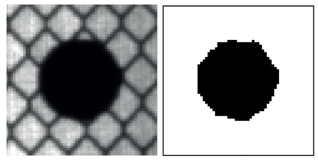

Figure 2. Patterns border deformation caused by a non-reflective netting pattern: (a) grayscale image of a printed pattern and (b) binary image, based on thresholding of the original image (noticeable border deformation takes place)

In the work we test several kinds of high-reflection microprismatic tapes to figure out what technology provides best characteristics for machine vision application. We provide comparison of different shapes of printed patterns to define what shapes can compensate the interfering effect of netting pattern the best. We also present the undesired pattern suppression method, which addresses the border deformation problem and prevents inaccuracy in coordinates extraction.

2. MATERIALS AND METHODS

First, we give an overview on the data acquisition procedure and provide a comparison of several types of high-reflective microprismatics to choose a sample with the highest retroreflection. Then, we give general description of the implemented framework and the algorithmic details of the critical steps for the presented approach to the reduction of undesired netting pattern. Third, we provide experimental results, which prove that the approach is able to suppress the weakness of microprosmatic tapes and that the tapes have a potential to be used in optical metrology tasks as a good substrate for bright and cheap reference marks.

2.1 Data acquisition

The experimental dataset used in this work was acquired with experimental setup shown in fig. 3.

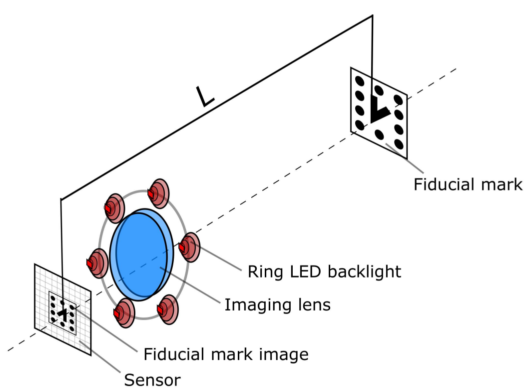

Figure 3. Schematic illustration of the experimental setup

The setup uses Sony ICX274 CCD camera with 25 mm lens, LED backlight (six 860 nm LEDs with maximal radiant flux 1000 mW and viewing angle 7°) and a reference mark (135×135 mm^2). Distance between the camera with LED backlight and the reference mark was set to 1500 mm.

In order to qualitatively compare image brightness obtained with different samples of high-intensity microprismatic tape, we set the samples from different manufactures onto the fiducial mark position in the setup shown in fig.3. So all the samples were identically lighted by LEDs and images were obtained in the conditions close to widespread illuminating scheme for machine vision metrology applications (fig. 4). Evidently the sample presented in fig.4 (d) shows better retroreflectance than four other ones. Therefore this brightest sample was chosen as a substrate for fiducial mark in our following experiments.

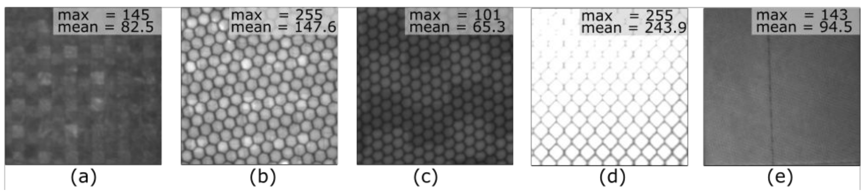

Figure 4. Images of high-intensity microprismatic tapes obtained in qualitative brightness comparison: (a) Avery Dennison HV 1302 REV, (b) Avery Dennison T-7500, (c) Avery Dennison V-6700B, (d) 3M-4090 (e) Nippon Nikkalite 104

However, notwithstanding the markedly bright image formed by chosen sample (fig.4 d), it has noticeably uneven distribution of image intensity. This feature requires extra correction as an additional stage in a bunch of image preprocessing procedures.

In the following experiments we utilized 8 different fiducial marks 135×135 mm^2 large. Each mark has a substrate made of chosen microprismatic tape and a black opaque pattern painted on its surface. Each pattern has its own shape (fig. 5) but in the central part of each pattern we put specific sign for automatic detection purposes, while signs for position measurements were distributed on the periphery of the patterns.[9]

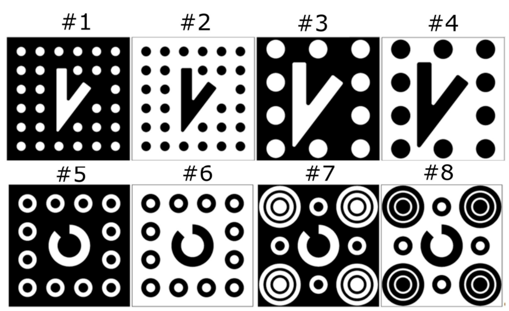

Figure 5. Different shapes of pattern utilized for experiments. Circles for position measurements are distributed on the periphery of the patterns

2.2 Framework overview

The previously mentioned air pockets located under clusters of microprisms in the substrate become visible in the mark image. This creates parasitic netting pattern superimposed onto the signs for position measurements (fig. 2, 3). This leads to significant decline in the quality of mark position estimation due to signs' borders deformation. In order to suppress the negative effect of parasitic net we propose combination of two procedures: a harmonic mean image filtering followed by circle shape recovering based on Fourier descriptors. In the following subsections we describe in detail three important steps in this pipeline. First, the detection and shading correction procedures. Second, the netting pattern suppression algorithm, and third the circle shape recovering procedure.

2.2.1 Detection and shading correction

To detect the mark image on the sensor surface we utilized pattern recognition techniques based on moments function.[10] Then we put ROI around the detected pattern and performed a correction of uneven distribution of image intensity in ROI. For the correction a low-pass spatial filter was applied to create a blurred mask of the original image. The low-pass filter was a 2-D Gaussian filter with 300×300 smoothing kernel and standard deviation of 200 for the mark image acquired by the setup described earlier. Obtained mask represents only major variations in image intensity and smoothes all the details in the image. Then the mask was scaled from 0 to 1, and the original image is divided by the mask values on a pixel-by-pixel basis.

2.2.2 Netting pattern suppression

Netting pattern suppression was implemented by applying a harmonic mean filter to an image.[10] In the harmonic mean filter each pixel is replaced with the harmonic mean in NN neighborhood. For rectangular subimage window of size $m \times n$, centered at point (x, y), the filtered image can be calculated from original image $g(x, y)$ as follows:

$$f(x,y) = \frac{m \cdot n}{\sum\limits_{(s,t)\in S_{xy}} 1/g(s,t)} \tag{1}$$

The harmonic mean filter has a blurring effect as another mean filters do, but it preserves edge features. It is also known that the harmonic mean filter is good at removing positive outliers, so prior computation of the image complement can provide better results. For the experiments we utilized 9×9 subimage window, which was equal approximately to a half of a net cell of the substrate image.

2.2.3 Circle shape recovering

Circle shape is an example of simplified two-dimensional shapes, that can rather easily be restored via Fourier descriptors.[10,11] The procedure of shape recovering can be described as follows. The first step is binarization of the image and morphological closure to find coordinates of the circles' boundaries. After that complex-valued vectors can be defined for the coordinates of the edge pixels of the circles and discrete Fourier transform of the vectors can be taken.

$$a(u) = \sum_{k=0}^{K-1} e^{-i2\pi uk/K} \tag{2}$$

$$s(k) = \frac{1}{K}\left(a(0) + a(1)e^{i2\pi k/K}\right) \tag{3}$$

Fourier descriptors contain all the information about the shape. The circle shape can be restored by setting the descriptors corresponding to values above a certain frequency to zero. This procedure can be roughly considered as low-pass filtering of the shape, which has an effect of smoothing the shape's boundary.

After circle shape recovering a center of each circle was found and mean value of all centers for each pattern was calculated to get the coordinates of the reference mark image center.

3. RESULTS AND DISCUSSION

During first stage of the experiments we utilized simulated image of the fiducial mark made of the chosen microprismatic substrate covered by black mask. The covering mask was moved relative to the substrate along horizontal direction with 0.5 px step. After coordinates extraction we calculated difference between the mask position with the substrate and without it. In this test we examined how relative position of the printed mask and parasitic netting pattern affects an accuracy of coordinate extraction process. Results shown in fig.6 demonstrate noticeable periodicity with non-zero mean for the most of the samples. In the worst case (sample 1) an error of the position estimation was about 4 pixels, which is unacceptable in the most of machine vision measurements.

Proposed image processing shows significant improvement in mark position estimation (compare fig.6 and fig. 7). In the worst case (sample 6) an error of the position estimation was less than a pixel, while in the best cases the error decreased to 0.2 pixels (samples 1 and 2).

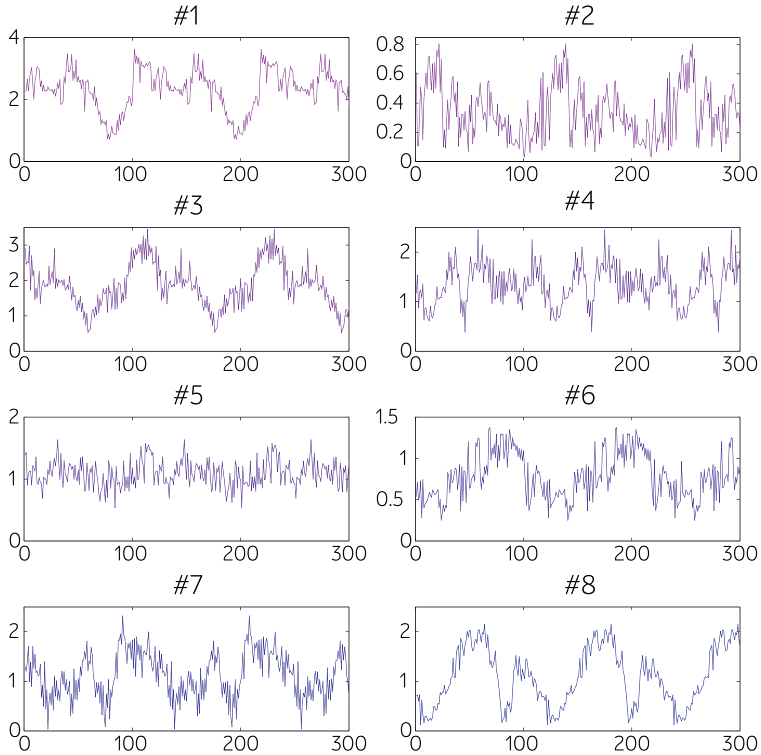

Figure 6. Estimation of mark position before proposed image processing. The covering mask was moved relative to the substrate along horizontal direction with 0.5 px step. The plots show difference between the estimations of mask position in the case with no substrate compared to the case when the substrate was applies to the mark

During the second stage of the experiment a set of 100 images of fiducial mark was acquired by the setup (fig. 3). For this test we implemented two fiducial marks made of microprismatic substrate covered with black industrial paint. The marks' coverage was based on samples 1 and 2, which showed best results in simulations. For each set of images the position of the mark was calculated and variations in estimation for each set was analyzed (fig. 8).

The variation in position estimation do not exceed 0.1 px, what can be considered as a good result of filtering. The proposed method allows to use of retroreflective tapes with air pockets for machine vision metrology applications.

4. CONCLUSIONS

In this work it was shown that retroreflective microprismatic tapes have a potential to be used in optical metrology tasks as a good substrate for bright and cheap fiducial marks. The proposed image processing allows good suppression of parasitic netting pattern distributed across the substrate's image, which in turn helps to recover borders of any sing applied as a mask to the substrate for metrology purposes. It was also shown that the shape of the signs matters and in the case of circle signs a shape recovery procedure based on Fourier descriptors can provide good results in mark position estimations. In experiments it was shown that subpixel accuracy of position estimation can be achieved after applying proposed image processing, while without filtering the error can exceed 4 pixels in some cases.

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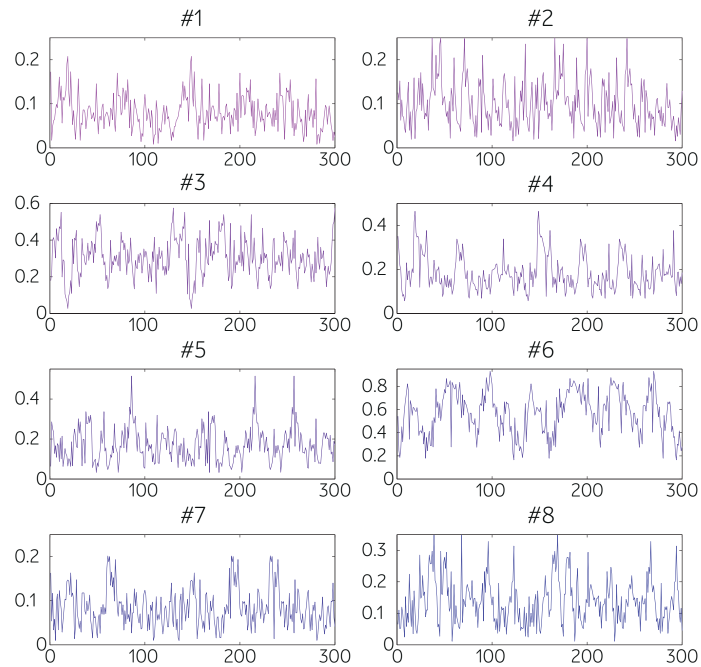

Figure 7. Estimation of mark position after proposed image processing. There is a significant error decrease, as well as reducing periodicity

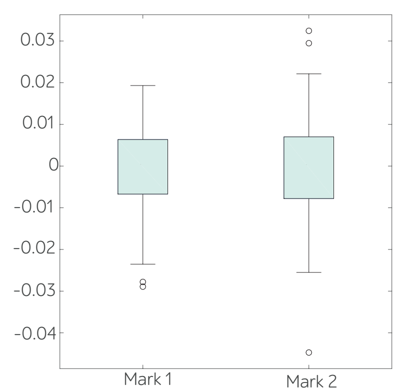

Figure 8. Variations in position estimation of mark samples 1 and 2

REFERENCES

[1] Korotaev V., Pantiushin A., S. M. and A., A., "Deflection measuring system for floating dry docks," *Ocean Engineering* **117**, 39–44 (2016).

[2] Pantyushin A., K. V., "Control measurement system for railway track position," *SPIE Optical Engineering+ Applications* , 84861B–84861B (2012).

[3] Vasilev A., Konyakhin I., T. A. L. O. and F., M., "Electrooptic converter to control linear displacements of the large structures of the buildings and facilities," *SPIE Optical Metrology* , 95252W–95252W (2015).

[4] Konyakhin I., Kopylova T., K. A. and A., S., "Optic-electronic systems for measurement the three-dimension angular deformation of axles at the millimeter wave range radiotelescope," *International Symposium on Precision Engineering Measurement and Instrumentation 2012* , 87593E–87593E (2013).

[5] Estler W., Edmundson K., P. G. and D., P., "Large-scale metrology - an update," *CIRPAnnals - Manufacturing Technology* **51**(2), 587–609 (2002).
[6] "Avery dennison. metallized prismatic film for emergency vehicle and fleet high night visibility applications." http://www.averydennison.com/en/home.html. (USA).
[7] "Nippon carbide industries." http://www.nikkalite.com/. (Japan).
[8] 3M, "Diamond Grade DG^3 Reflective Sheeting Series." http://www.3m.com. (USA).
[9] Gutierrez J., A. B., [*Precision Landmark Location for Machine Vision and Photogrammetry: Finding and Achieving the Maximum Possible Accuracy*], Springer Science Business Media (2007).
[10] Gonzalez R., W. R., [*Digital Image Processing*], Prentice Hall, New York (2007).
[11] Trushkina A., S. M. and A., P., "Position estimation for fiducial marks based on high intensity retroreflective tape," *SPIE Photonics Europe* , 98961H–98961H (2016).