MULTIPLE SENSORS' LENSLETS FOR SECURE DOCUMENT SCANNERS

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Abstract - *Miniaturization, scanning speed, image resolution and robustness trends lead to document scanners based on a matrix of solid-state image sensors. The overall document image is retrieved from parts provided by the sensors positioned at a fixed distance from the document. The lenses' fields of view need to overlap to avoid distortion at their borders. In addition, scanners of secure documents such as ID cards or passports need to be sensitive to infrared light to detect possible forgeries. Thus, infrared-passing lenslets with short focal length (i.e., wide angle of view) distributed with low deviation need to be mounted on the sensors. The lens tests, results and the final lens solution for the document scanner are described in the paper.*

1. INTRODUCTION

The ever increasing needs of mobility and efficiency spur the development of fast and portable document scanners and readers. Our goal was to develop a document scanning device that uses white, infrared and ultraviolet illumination for verifying authenticity and integrity of the document. The speed and robustness of the document scanner have been increased by using a fixed image sensor instead of a movable optical sensor. The portability has been achieved by using a matrix of image sensors. Namely, each of the sensors captures a smaller part of the document, requiring thus a narrower field of view, hence a shorter optical path (i.e., total track length, TTL) between the sensor and the document, resulting in overall device size reduction. The respective parts of the document image are stitched together to recreate the overall picture.

Full document scanning under white, infrared and ultraviolet illumination is the unique feature among the state-of-the-art portable scanners. The lenses used in this device need to pass infra-red light, but also to provide as large as possible field of view in order to minimize the number of image sensors and to reduce distortion. The latter might impair the overall quality of the document image.

This paper focuses on the techniques for correction of barrel distortion and on the stitching method for composing the overall document image. An overview of existing distortion correction methods is given, with a rationale of our choice for this particular purpose.

Image sensors are grouped in the form of a matrix as shown in Figure 1. Their purpose is to capture partial images of the documents. All lenses in matrix are the same, and we call them lenslets. A lenslet literally means a small lens. In practice, a lenslet is always a part of a lenslet array. A lenslet array consists of a set of lenslets in the same plane. Each lenslet normally has the same focal length.

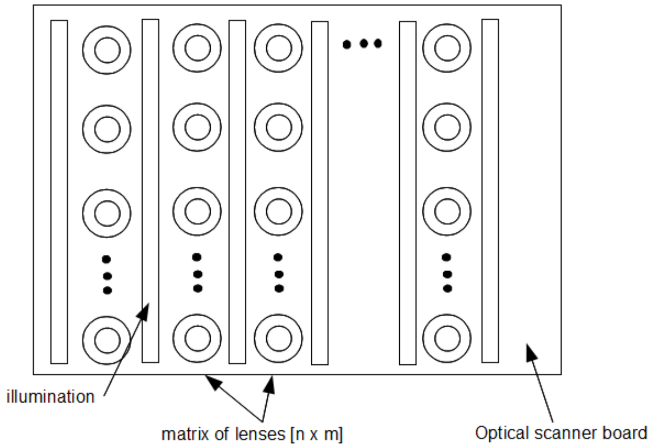

Fig. 1. The Optical Scanner Board

2. LENSES – SELECTION METHODS AND EXPERIMENTAL SETUP

As the portability of the device requires a miniaturized design and a dense mechanical packing of supporting elements, such as sensors and LED illuminators, our choice of lenses was limited to smaller ones. Because of other requirements, such as small focal length, i.e. wide field of view (FOV), small total track length (TTL) and transparency to infrared light, it was difficult to find a lens of appropriate size. The optical area of the sensor is given on Fig. 2.

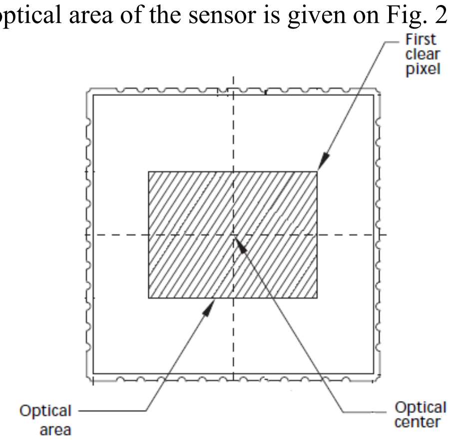

Fig. 2. 1/3-Inch SOC Megapixel Digital Image Sensor

The active parts of the sensor with mounted lenses of different sizes are shown textured in Figure 3. Due to scarce availability of lenses with requested features, their size was not limited to 1/3” lenses, as would have been appropriate for 1/3” sensor. Regardless of the size of the sensor, with a custom-made lens holder, it is possible to use lenses designed for 1/4" or 1/5" sensors. When such smaller lens is used, the useful area of the 1/3." sensor is reduced. For example, when a 1/4" lens is used, the sensor active image area is shown on the right-hand side of Figure 3. The corner areas of the image that should have been captured by the sensor are not visible. Nevertheless, if the images captured by adjacent sensors overlap, one can still use smaller lenses. This leads to a wider choice of lenses that need to cover a large enough field of view. The most lenses made for mobile phones or lap tops are made for 1/4" sensors. This kind of lenses has the field-of-view range that covers a sufficient part of the image, as shown in the right-hand side of Figure 3. Field of view was tested in about 20 different lenses, from 5 leading optical manufacturer companies. These lenses were designed for applications where a small lens is required, such as mobile phone cameras, PDA and portable imaging devices.

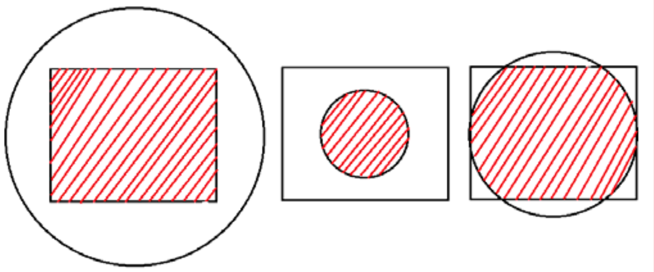

Fig. 3. Active part of the sensor for different sizes of the lens

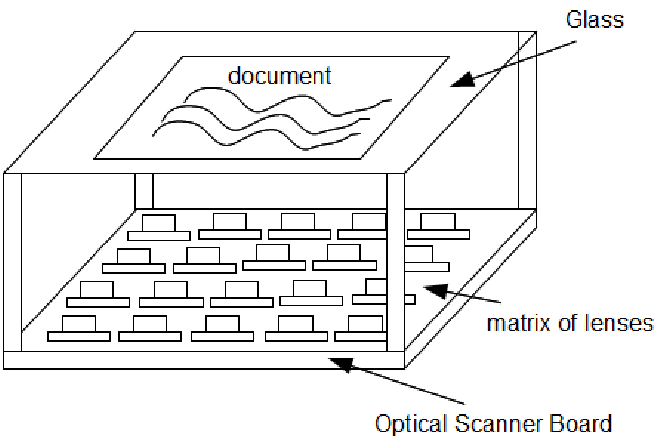

Fig. 4. Experimental setup

The target object was placed on the scanner glass. The scanner glass was placed on pre-defined distance from the board carrying the sensors. The experimental setup is shown on Fig 4. Each of the sensors is capturing 1/N of the target image, where N is the number of sensors in a matrix layout. The target used for testing was a composite picture made of N blocks, each one of them being in the field of view of one of the sensors. Each block is surrounded by margins made of horizontal and vertical lines, as shown in Figure 5. Each block is to be captured by its respective sensor, in the way that margins are visible completely. Margins play an important part in stitching the blocks together into the image of the target. Namely, the blocks’ margins partially overlap, so that each sensor contributes to the overall image with the inner halve of its margins. The lens layout is shown in Fig. 6.

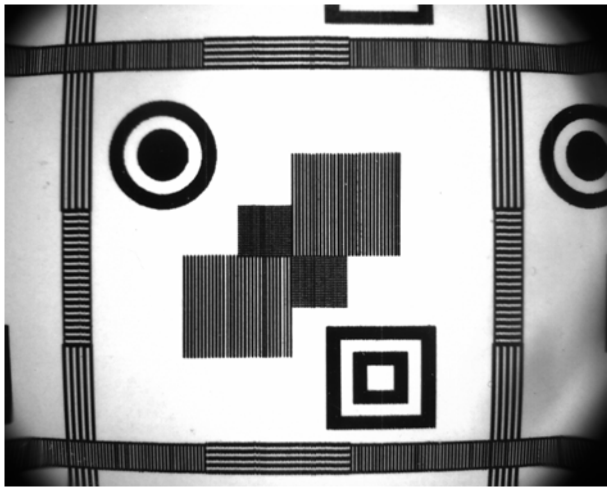

Fig. 5. Target image - block

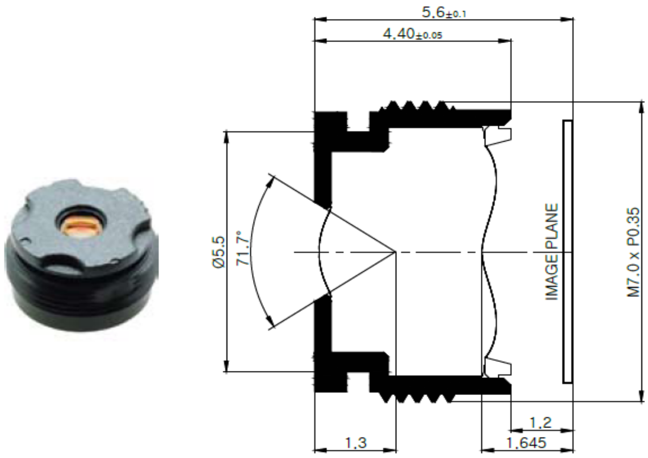

Fig. 6. Lens layout

3. RESULTS AND DISCUSSION

In the paraxial approximation of geometrical optics, a lens forms a point image of a point object and a line image of a line object, [1] - [3]. The focal length of a lens is defined as the distance in mm from the optical center of the lens to the focal point, which is located on the sensor if the subject is "in focus". The camera lens projects part of the scene onto the film or sensor. The field of view is determined by the angle of view from the lens out to the scene and can be measured horizontally or vertically, Fig 7.

For a thick lens or an imaging system consisting of several lenses and/or mirrors the focal length is often called the effective focal length (EFL). In general, the focal length is the value that describes the ability of the optical system to focus light, and is the value used to calculate the magnification of the system.

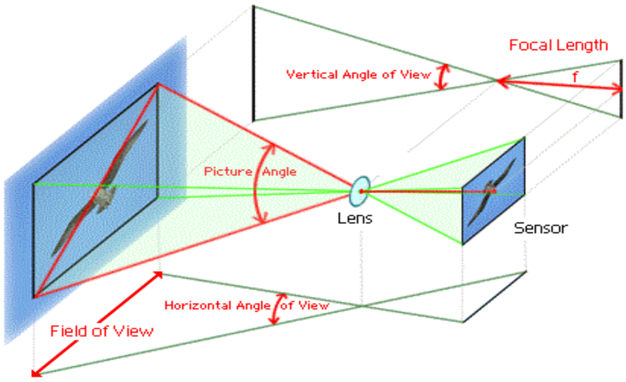

Fig. 7. The focal length (f) and field of view (FOV)

For the case of a lens of thickness d in air, and surfaces with radii of curvature $R1$ and $R2$, the effective focal length f is given by, [4]:

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + (n-1)\frac{d}{nR_1R_2}\right], \qquad (1)$$

where n is the refractive index of the lens medium.

For lenses projecting rectilinear images of distant objects, the effective focal length and the image format dimensions completely define the angle of view. For a lens projecting a rectilinear image, the angle of view (α) can be calculated from the chosen dimension (L), and effective focal length (f) as follows:

$$\alpha = 2arctg\frac{L}{2f}. \qquad (2)$$

L represents the size of the sensor in the direction for which the angle of view is measured, be it vertical, horizontal or diagonal, as shown in Figure 7.

Despite the deterministic relationship between the angle of view and the focal length, the choice of the appropriate lens from the manufacturers' specifications was not straightforward. Since 1/3" sensor was combined with smaller lens, the active image size L' is smaller than L. Here, L' represents the diagonal of the sensor active image area. As shown in the right-hand side of Figure 3, L' can correspond to the lens diameter in the frontal plane. However, the lens systems are often composed of a number of optical elements of different sizes, enclosed in a housing, so the notion of frontal diameter of the lens system makes little or no sense. Instead, some data sheets specify the image size of the lens, but again this information is not made available by most manufacturers. This is a reason why it was not always possible to predict the size of the visible area of a picture or block. In Table 1 are presented the results of experimental lens testing, such as the visible block size, as well as the comparison between the specified and the calculated values of the angle of view. The values of calculated angles of view have been obtained by inserting the lens diameter whenever the lens image size L' was not available.

No.	Manufacturer and Model	FOV	Focal length [mm]	Active Image Sensor Size , L' [mm]	Intended Sensor Size	Visible block size (vertical) [mm]	Calculated angle of view
1	Manufacturer 1, Model 1	63.6°	3.4	4.52	1/4"	34	67.2°
2	Manufacturer 2, Model 1	65.9°	4.35	5.90	1/3.2"	28	68.3°
3	Manufacturer 2, Model 2	64.6°	4.48	5.90	1/3.2"	27.1	66.7°
4	Manufacturer 3, Model 1	63.5°	3.7	4.52	1/4"	30.5	62.8°
5	Manufacturer 1, Model 2	75°	2.94	4.52	1/4"	~50	75.1°
6	Manufacturer 4, Model 1	53.4°	4.57	4.59	1/4"	21	53.3°
7	Manufacturer 4, Model 2	112°	1.94	4.60	1/4"	~70	99.7°
8	Manufacturer 5, Model 1	67°	4.27	5.90	1/3.2"	28	69.3°
9	Manufacturer 5, Model 2	67.4°	4.27	5.90	1/3.2"	30	69.3°
10	Manufacturer 2, Model 3	71.7°	3.94	5.90	1/3.2"	33	73.6°
11	Manufacturer 4, Model 3	63°	3.87	4.80	1/4"	32	63.6°
12	Manufacturer 4, Model 4	66.56°	3.37	4.53	1/4"	38	67.8°
13	Manufacturer 3, Model 2	77.1°	2.8	4.52	1/4"	31	77.8°
14	Manufacturer 3, Model 3	80°	3.2	4.52	1/4"	46	70.5°
15	Manufacturer 3, Model 4	69.2°	3.7	4.52	1/4"	37	62.8°
16	Manufacturer 3, Model 5	94.7°	2.5	4.52	1/4"	54	84.2°
17	Manufacturer 3, Model 6	88.3°	3	4.52	1/4"	43	73.99°
18	Manufacturer 4, Model 5	66.56°	3.37	4.53	1/4"	38	67.8°
19	Manufacturer 5, Model 3	68.9°	3.36	4.59	1/4"	37.5	68.66°
20	Manufacturer 5, Model 4	67.4°	3.37	4.54	1/4"	37	67.88°

Table 1.Characteristics of the tested lenses, measured visibility of the picture and calculate values for field of view

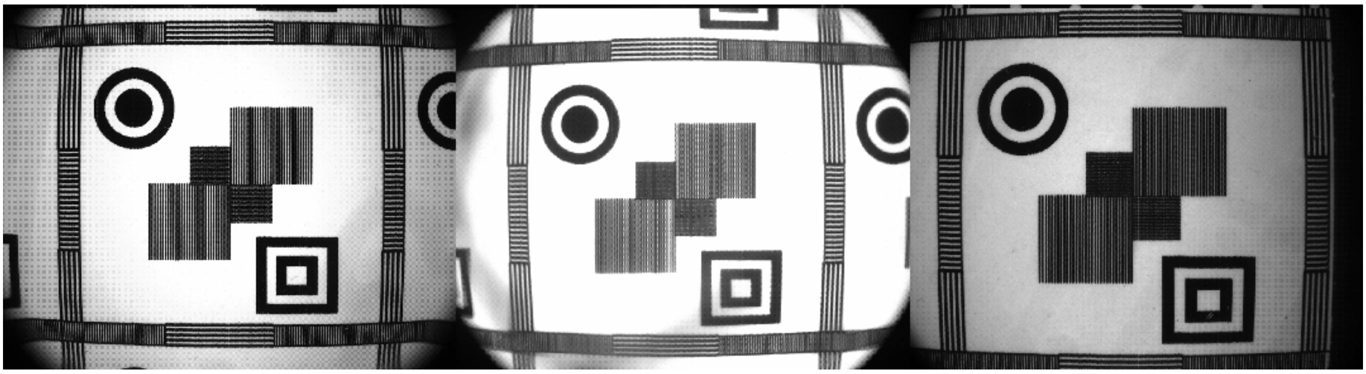

Fig. 8. Captured blocks with white light for three different lenses

Examples of obtained image blocks are shown in Fig. 8. These blocks are part of a calibration image used for focus adjustment and for measuring the visible block size. The left-hand side of Figure 8 represents the block captured through the lens No. 20 from Table 1, in the middle is the block obtained through the lens No. 18, and the right-hand side shows the image captured by the sensor through the lens No. 1. Let us denote the aforementioned lenses by A B and C, respectively. The lens A gives the least distorted image for an average angle of view. The lens B has the largest field of view, but its barrel distortion is very pronounced. The lens C has smaller visible block size than permitted since the margins are partially invisible.

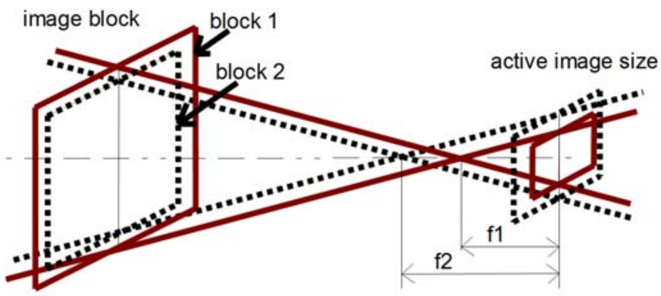

Fig. 9. Visible block size for different focal lengths and the same angle of view

Figure 9 shows the lens image sizes for lenses intended for 1/3.2” (dashed) and 1/4” (red solid line) sensors. It would be reasonable to expect that larger lens would better fit the 1/3” sensor and yield a larger visible area of a block, as illustrated in Figure 3. Despite this expectation, the larger 1/3.2” lenses did not provide a larger visible area of the block. This lens provides a slightly wider image block size than active part of the sensor can capture, that is why visible block size is smaller than 1/3.2” lens could provide. The larger lenses available on the market had slightly longer focal length, which for the same distance from the target results in smaller visible area. On the other hand, 1/4” lenses with shorter focal lengths and similar angles of view do meet the margin visibility requirement explained in Section 2. Although these lenses are originally produced for smaller image sensors, they are very suitable for the sensor matrix based scanner.

4. CORRECTION OF BARREL DISTORSION, STITCHING IMAGES

Distortion is a deviation from rectilinear projection, a projection in which straight lines in a scene remain straight in an image. The most commonly encountered distortions are radially symmetric, or approximately so, arising from the symmetry of a lens. The radial distortion can usually be classified as one of two main types: barrel distortion and pincushion distortion, Figure 10. Wide-angle lenses have pronounced barrel distortion, where the image appears to be squeezed on its periphery with respect to the central area, decreasing the effective peripheral resolution.

The design a portable scanner requires a short distance between the document and the lens. This is why wide-angle lenses are used, as mentioned in section 3. However, these lenses have a very pronounced barrel distortion. Other distortions arise from mechanical irregularities, e.g., when soldering the sensor or mounting a lens in a plane that is not parallel to the scanning document.

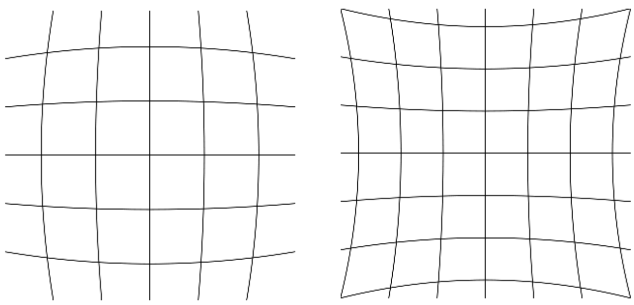

Fig. 10. a) Barrel Distortion; b) Pincushion distortion

The barrel distortion model, [5]-[6], is described by the following equation:

$$r_u = r_d(1 + kr_d^{\,2}), \qquad (3)$$

where r_u and r_d are the distance from the center of distortion in the undistorted and distorted images respectively, as shown in Figure 11, and k is the distortion parameter, which is specific to the lens.

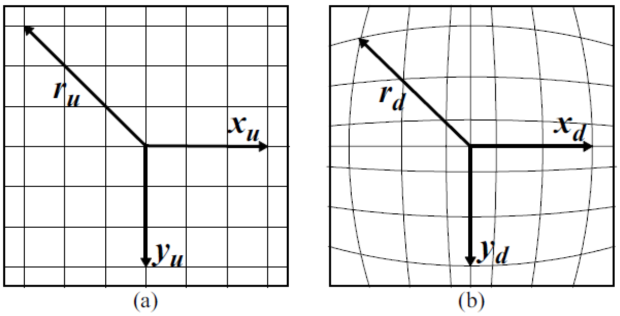

Figure 11: Illustration of barrel distortion model

Distortion is corrected by translating a pixel from the distorted image to a new position in a corrected image. Unfortunately, the calculated, i.e., corrected, coordinates are rarely integer values. This means that the new location lies “between” the pixels in the original image.

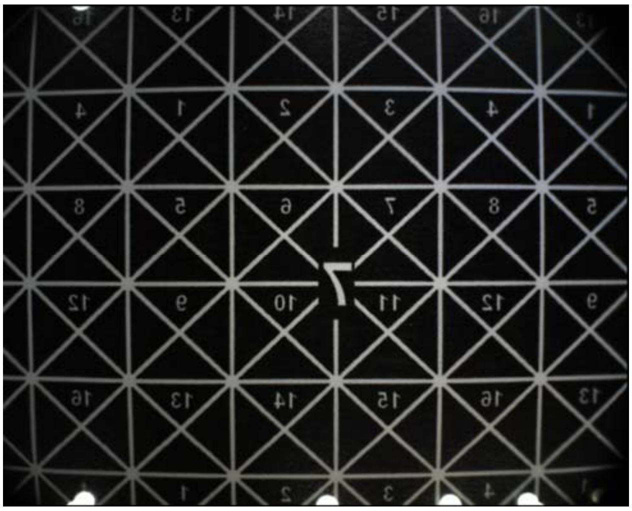

Fig. 12. Before Barrel distortion correction

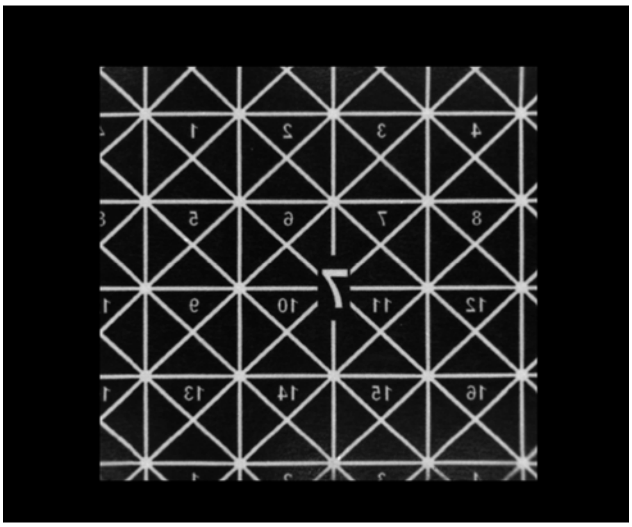

Fig. 13. After Barrel distortion correction

Instead of removing barrel distortion by re-computing locations of the pixels in the original image, a calibration method is used, as follows. First, the markers, whose correct positions are *a priori* known, are detected on the image using 2D correlation. Second, the magnitude and orientation of their displacements are computed with respect to the *a priori* known positions. Third, the vector displacement of every single pixel is computed by interpolation with respect to the neighboring markers’ shifts. The pixels are replaced to the correct position using this information. Figure 12 shows a picture with barrel distortion, while Figure 13 displays the corrected result.

The final step in making the overall picture is block stitching. This algorithm is implemented in software and relies on block margins. Each block contributes to the overall picture by the inner halve of its margins.

5. CONCLUSION

This paper presents a solution for multiple sensors' lenses for secure document scanner. Selection methods and the test setup were described, including a comparison of test results with theoretical models. The barrel distortion correction and a method for recomposing the overall document image were presented. These image processing methods will be explained in more detail in a future paper. All results presented in this paper are developed and implemented as a part of a secure document scanner.

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