Robust Automatic White Balance Algorithm using Gray Color Points in Images

Jun-yan Huo, Yi-lin Chang, Jing Wang, and Xiao-xia Wei

Abstract — *A robust automatic white balance algorithm is proposed in this paper, using extracting gray color points in images for color temperature estimation. A gray color point is the point where R, G and B components are equivalent under the canonical light source. A little color deviation of the gray color point from gray under different color temperature is used to estimate the color temperature of the light source. The test results show that the proposed algorithm can provide a good perceive effect and has the advantage of easy realization, low complexity and robust convergence*[1].

Index Terms — Automatic white balance, color temperature estimation, gray color points.

I. Introduction

Automatic White Balance (AWB) is one of the most important functions for video cameras to achieve high quality image. Human eyes have the 'color constancy' ability to cope with different lighting conditions by adjusting their spectral response, while video cameras do not. When a white object is illuminated under a low color temperature, it will appear reddish in the captured image; oppositely, it will appear bluish under a high color temperature. Hence the automatic white balance is introduced in order to make a picture more natural than what we see.

Existing AWB algorithms can be classified into two categories, global AWB algorithms and local AWB algorithms. The global AWB algorithms use all pixels of an image for color temperature estimation, while in the local AWB algorithms, only these pixels which satisfy some special conditions are concerned.

For the simplest global AWB algorithm, known as gray world algorithm, it assumes that the average R, G, and B components of an image, denoted as $\overline{R},\overline{G},\overline{B}$, are equal. A modified gray world algorithm is given in [1], which predefines an appropriate region as shown in Fig. 1. When $\overline{R}-\overline{G}$ and $\overline{B}-\overline{G}$ fall within the shaded region, the automatic white balance is considered to be achieved. Another well-known global AWB algorithm is known as the fuzzy rule method [2]. A frame of images is divided into several segments and the weighting factor for each segment is given based on the fuzzy rule derived from a lot of experiments.

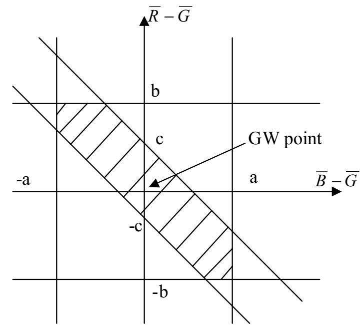

Fig.1. The predefined region for the modified gray world algorithm.

The local AWB algorithms pay their attentions to extracting a number of pixels using some prior knowledge, such as white area [3], [4], human face [5], and so on. Pixels satisfying (1) given by Nakano's algorithm [3] are considered as white color points.

$$\begin{cases} Y > \chi \\ -\alpha < U < \alpha \\ -\beta < V < \beta \end{cases} \tag{1}$$

Reference [4] exploits the relations between U, V, and Y component, furthermore, a modified condition of the white area is given by (2).

$$Y-|U|-|V| > \phi \tag{2}$$

Where ϕ is a fixed value, which is set to 180. Fig.2 shows the white area defined by (2).

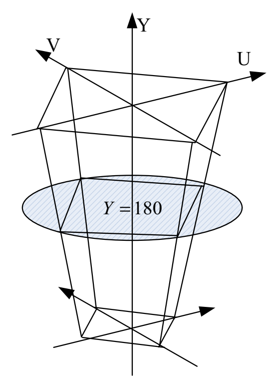

Fig.2. The modified white area in YUV domain, Y is larger than 180.

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The above AWB algorithms do not always get good performances. The global AWB algorithms can not work well if the captured image is dominated by only one or two colors, and the local AWB algorithms will not satisfactorily work if there is no white object or human face in the captured image.

A natural scene image usually has plenty of gray color points such as a white object, a shadow, a black object and so on. What we call a gray color point is the point whose value of R, G, and B components, denoted as R, G, B, are equal under a canonical light source, and appears to be as pure as gray. Therefore the little color deviation of the point from gray, which is introduced by different color temperature light sources, can be used to estimate the color temperature. Motivated by this feature, a novel automatic white balance algorithm is presented. The proposed method is also a local AWB algorithm, but it works more flexibly owing to the ubiquity of gray color points. Experimental results indicate that the proposed algorithm presents a good performance in natural scene.

I. THE PROPOSED ALGORITHM

Generally, an automatic white balance algorithm is accomplished in two steps. The first step is the estimation of the color temperature. The illumination condition is estimated by selecting out gray color points from an image, whose color has a little deviation under a non-canonical light source. The second step is the automatic white balance adjustment which can be realized through adjusting R channel gain and B channel gain. In the above two steps, the estimation of color temperature is more crucial, and its accuracy directly affects the next step's correctness.

A. Color temperature estimation

YUV coordinate is used in our paper, where Y is the luminance component, and U and V are two chrominance components, which are equal to color differences, B-Y and R-Y, respectively. The YUV coordinate is related to RGB coordinate by [8]:

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} Y \\ B-Y \\ R-Y \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.299 & -0.587 & 0.886 \\ 0.701 & -0.587 & -0.114 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{3}$$

With the definition of gray color points, we get

$$R = G = B \tag{4}$$

The YUV components of gray color points can be calculated by substituting (4) into (3) and written as follows:

$$Y = R = G = B, \quad U = V = 0 \tag{5}$$

As known, a captured image appears reddish under a low color temperature light source and bluish under a high color temperature light source, so gray color points under high or low color temperature do not satisfy equation (5) any more.

In order to discern the gray color points under un-canonical light sources, the property of gray color points under a low color temperature light source will be investigated. In this case, the R component of the image, denoted as R', will increase and can be depicted as $R' = (1+K_R)R$, where R is the R component of gray color points in canonical light, K_R is a deviation factor of R component. Then the Y, U, and V components of gray color point under the low color temperature light source, expressed by Y', U', and V' respectively, can be described by

$$\begin{bmatrix} Y' \\ U' \\ V' \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.299 & -0.587 & 0.886 \\ 0.701 & -0.587 & -0.114 \end{bmatrix} \begin{bmatrix} (1+K_R)R \\ G \\ B \end{bmatrix} \tag{6}$$

The substitution of (5) into (6) then yields

$$\begin{aligned} \begin{bmatrix} Y' \\ U' \\ V' \end{bmatrix} &= \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.299 & -0.587 & 0.886 \\ 0.701 & -0.587 & -0.114 \end{bmatrix} \begin{bmatrix} (1+K_R)Y \\ Y \\ Y \end{bmatrix} \\ &= \begin{bmatrix} 1+0.299K_R \\ -0.299K_R \\ 0.701K_R \end{bmatrix} [Y] \\ &= \begin{bmatrix} 1 \\ -0.299K_R/(1+0.299K_R) \\ 0.701K_R/(1+0.299K_R) \end{bmatrix} [Y'] \end{aligned} \tag{7}$$

The similar result also can be obtained under a high color temperature light source as follows:

$$\begin{aligned} \begin{bmatrix} Y'' \\ U'' \\ V'' \end{bmatrix} &= \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.299 & -0.587 & 0.886 \\ 0.701 & -0.587 & -0.114 \end{bmatrix} \begin{bmatrix} R \\ G \\ (1+K_B)B \end{bmatrix} \\ &= \begin{bmatrix} 1 \\ 0.886K_B/(1+0.114K_B) \\ -0.114K_B/(1+0.114K_B) \end{bmatrix} [Y''] \end{aligned} \tag{8}$$

where Y'', U'', and V'' represent the Y, U, and V components of gray color points in the high color temperature light source respectively. K_B is a deviation factor of B component which can be calculated by $B'' = (1+K_B)B$, where B'' is the B component under the high color temperature light source, and B is the B component under the canonical light source.

Then we define $F(Y,U,V)$ as follows:

$$F(Y,U,V) = \left(\left|\frac{U}{Y}\right| + \left|\frac{V}{Y}\right|\right) = \frac{(|U|+|V|)}{Y} = \begin{cases} \dfrac{K_R}{1+0.299K_R} & \textit{in low color temperature} \\ \dfrac{K_B}{1+0.114K_B} & \textit{in high color temperature} \end{cases} \tag{9}$$

According to (9), for any given light source, its K_R or K_B is a fixed value, therefore $F(Y,U,V)$ of gray color points also is a fixed value. Table 1 lists the relation between $F(Y,U,V)$ and K_R or K_B. From the data in table 1, we can conclude that the value of $F(Y,U,V)$ of gray color points caused by non-canonical light sources is more less than 1. So we can construct the gray color points' extraction criterion as follows:

$$F(Y,U,V)=\frac{(|U|+|V|)}{Y}<T \tag{10}$$

Where T is a threshold which is far less than 1. As defined in (10), if the value of $F(Y,U,V)$ of some pixel is less than T, this pixel is considered as the gray color point. The value of T decides the number of pixels of an image extracted as gray color points. For example, if T is set to 0.097, those pixels whose R components have an increment by 10% or whose B components increase by 9.6% under the non-canonical light source than that under canonical light source can be selected out.

TABLE 1
T 'S SELECTION BY CALCULATING $F(Y,U,V)$ WITH DIFFERENT K_R AND K_B

$F(Y,U,V)$	0.097	0.1321	0.2753
K_R In Low color temperature	10%	13.7%	30%
K_B In High color temperature	9.6%	13%	26.7%

After selecting gray color points out, we calculate the average of U component and V component of all pixels satisfying equation (10), that is,

$$\overline{U}_\Omega=(\sum_{(i,j)\in\Omega}U_{i,j})/N,\quad \overline{V}_\Omega=(\sum_{(i,j)\in\Omega}V_{i,j})/N \tag{11}$$

where Ω is the set of pixels extracted as gray color points, and N is the total number of pixels in Ω . (11) can be rewritten as follows:

$$\begin{aligned}\overline{U}_\Omega&=(\sum_{(i,j)\in\Omega}(B_{i,j}-Y_{i,j}))/N=\overline{B}_\Omega-\overline{Y}_\Omega\\ \overline{V}_\Omega&=(\sum_{(i,j)\in\Omega}(R_{i,j}-Y_{i,j}))/N=\overline{R}_\Omega-\overline{Y}_\Omega\end{aligned} \tag{12}$$

where $\overline{R}_\Omega,\overline{B}_\Omega,\overline{Y}_\Omega$ are the average of R component, B component and Y component of Ω . As far as these gray color points are concerned, both $\overline{U}_\Omega$ and $\overline{V}_\Omega$ are expected to be zero. So the differences of $\overline{U}_\Omega$ and $\overline{V}_\Omega$ from zero, i.e. the absolute value of $\overline{U}_\Omega$ and $\overline{V}_\Omega$, can reveal the color deviation of the whole image. If the absolute value of $\overline{U}_\Omega$ is greater than that of $\overline{V}_\Omega$, that is to say the difference between $\overline{B}_\Omega$ and $\overline{Y}_\Omega$ is larger than the difference between $\overline{R}_\Omega$ and $\overline{Y}_\Omega$. Therefore the B channel gain needs to be adjusted. Similarly, if the absolute value of $\overline{U}_\Omega$ is less than that of $\overline{V}_\Omega$, R channel gain need to be adjusted.

B. Automatic white balance adjustment

Fig.3 shows a block diagram of an image capture system. The captured video can be obtained by scanning the photosensitive surface which converts optical signals into electrical signals. Then the electrical signals are amplified by three individual amplifiers known as R channel amplifier, G channel amplifier and B channel amplifier. These are followed by some basic processes such as color coordinate conversion and A/D conversion for digital output, and some digital processes (including automatic white balance and so on) to improve the image quality. As shown in Fig.3, automatic white balance algorithm is realized by adjusting channel gains in a feedback loop.

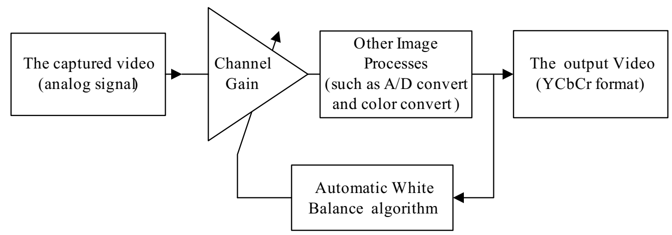


Fig.3. A block diagram of a capture system.

For clarity, the detail of a closed-loop adaptation for AWB adjustment is given in Fig.4. There is an input signal vector P_i with elements $p_{i,R},p_{i,G},p_{i,B}$ which represents electrical analogy signals converted from optical signals, a corresponding set of channel gain, $w_{i,R},w_{i,G},w_{i,B}$, and a output signal vector Q_i with elements $q_{i,Y},q_{i,Cb},q_{i,Cr}$.

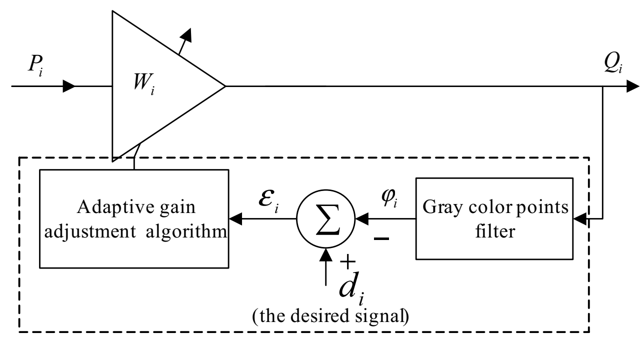


Fig.4. Automatic white balance.

Automatic white balance consists of three key processings, namely gray color points filtering, error calculating and adaptive gain adjusting as shown in the dotted block in Fig. 4. The function of gray color points filter is to extract the pixels as gray color points from a captured image and calculate $\overline{U}_\Omega$ and $\overline{V}_\Omega$ referred in section II-A. The output of the filter, φ_i , is obtained as follows:

$$\varphi_i=\begin{cases}\overline{U}_\Omega & |\overline{U}_\Omega|>|\overline{V}_\Omega|\ or\,|\overline{U}_\Omega|=|\overline{V}_\Omega|\neq 0\\ \overline{V}_\Omega & |\overline{U}_\Omega|<|\overline{V}_\Omega|\\ 0 & |\overline{U}_\Omega|=|\overline{V}_\Omega|=0\end{cases} \tag{13}$$

An error signal, noted as ε_i , is obtained by comparing the output of the filter with the desired signal d_i . The error signal can be expressed as

$$\varepsilon_i = d_i - \varphi_i \tag{14}$$

where the desired signal d_i is set to zero for both U component and V component of the gray color point are equal to zero (see in (5)). Then ε_i is utilized to adjust the channel gain vector W_i to force the output of the filter to close to the desired signal. In the process of the adaptive gain adjustment, iterative algorithm is adopted in order to keep the chrominance of the video smoothly changed. The iterative procedure can be represented algebraically as

$$\begin{cases} w_{i,R} = w_{i-1,R} & \\ w_{i,G} = w_{i-1,G} & \text{if } \varphi_i = \overline{U}_\Omega \\ w_{i,B} = w_{i-1,B} + \mu\, K(\varepsilon_i) & \end{cases}$$
$$\begin{cases} w_{i,R} = w_{i-1,R} + \mu\, K(\varepsilon_i) & \\ w_{i,G} = w_{i-1,G} & \text{if } \varphi_i = \overline{V}_\Omega \\ w_{i,B} = w_{i-1,B} & \end{cases} \tag{15}$$

Where i is the iterative number. Based on (13), if φ_i is equal to $\overline{U}_\Omega$, the B channel gain $w_{i,B}$ will be adjusted, $w_{i,R}$ and $w_{i,G}$ stay unchanged. And if φ_i is equal to $\overline{V}_\Omega$, only the R channel gain $w_{i,R}$ will be adjusted. The adjustment step parameter μ is a constant and the value of function $K(\varepsilon_i)$ is related to ε_i. More descriptions of μ and $K(\varepsilon_i)$ are given in the next section.

The whole process is oriented toward minimizing the error signal ε_i by adjusting the channel gain vector. If well converged, φ_i is equal to d_i, i.e. $\overline{U}_\Omega = \overline{V}_\Omega = 0$, that can also be said $\overline{R}_\Omega = \overline{G}_\Omega = \overline{B}_\Omega$, which just is the aim of our algorithm.

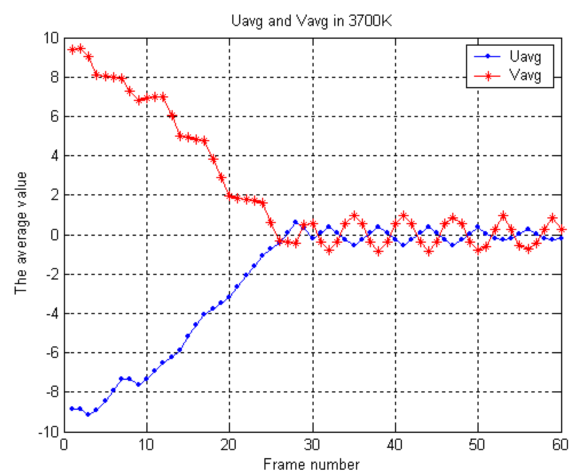
II. Experimental Results and Analysis

In order to evaluate the performance of the proposed algorithm, we have tested a series of different scenes under different color temperature light sources. Two typical color temperature light sources used in the experiments are 3700K and 7400K respectively.

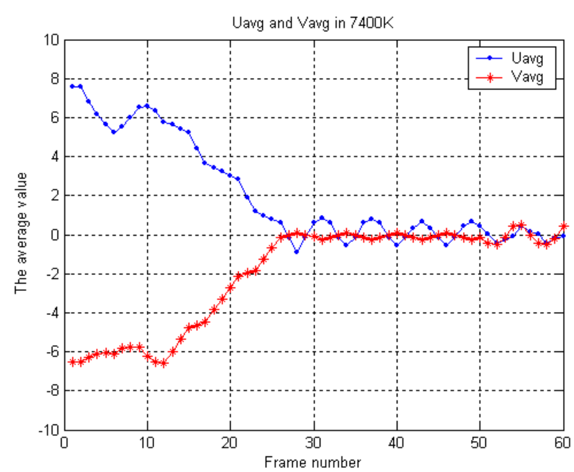
Below, we first discuss several key parameters in our algorithm are discussed now. In our experiment, T in (10) is set to 0.1321 which indicates that under non-canonical light source with R components have an increment by 13.7% or whose B components increase by 13% our algorithm can accurately extract gray color points. In practice, the implementation of the proposed AWB algorithm can be accomplished by adjusting the channel gains of a CMOS sensor, which can be read from EEPROM through I2C-bus interface. A minimum channel gain increment with a typical value of 0.0312 is recommended in our experiments. In the closed-loop adaptive adjustment, the adjustment step μ is a key parameter which governs stability and the convergence rate of the algorithm and is set to the recommended minimum channel gain increment in our algorithm. The error weighting function $K(x)$ is described as

$$K(x) = \begin{cases} 2sign(x) & |x| \ge a \\ sign(x) & b \le |x| < a \\ 0 & 0 \le |x| < b \end{cases}$$
$$\text{where} \quad sign(x) = \begin{cases} 1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases} \tag{16}$$

where a, b are the error thresholds, a is set to 0.8 and b is set to 0.15 in our experiments. At the beginning of the AWB processing, there exists a large error $(|\varepsilon_i| \ge a)$, according to equation (16), the channel gain will be adjusted in a large step, equal to $\pm 2\mu$, in order to accelerate the convergence of AWB. If the error signal falls within $[b, a]$, the adjusting step is set to $\pm\mu$. It is assumed that the white balance has been achieved and the channel gain vector is not changed if the error is less than b.



(a)



(b)

Fig.5. Convergence curves of $\overline{U}_\Omega$ and $\overline{V}_\Omega$ in different color temperature (a) 3700K and (b) 7400K.

The curves of the dependence of $\overline{U}_\Omega$ and $\overline{V}_\Omega$ upon the iterative number for the proposed AWB algorithm are presented in Fig. 5 (a) and (b) with different color temperature light sources. Here the horizontal axis indicates the frame number of image sequence, i.e. the iterative number. As illustrated by Fig.5 (a), at the beginning, both $\overline{U}_\Omega$ and $\overline{V}_\Omega$ have a large deviation from zero. But $|\overline{V}_\Omega|$ is greater than $|\overline{U}_\Omega|$, so the R channel gain should be adjusted firstly. Notice that even under one color temperature light source such as 3700K, the gain of R or B channel may be alternatively adjusted depending on the φ_i of each time of iteration (see in (15)). After several steps' adjustment, both $\overline{U}_\Omega$ and $\overline{V}_\Omega$ are close to zero which implies the automatic white balance is achieved. After convergence, the excess mean square errors of $\overline{U}_\Omega$ and $\overline{V}_\Omega$ still exist with their maximum value of 0.35 in 3700K and 0.22 in 7400K, but they can not be perceived.

Fig.6 shows the number of pixels extracted from a scene in different color temperature light sources. After convergence, the respective numbers of gray color points in 3700k and in 7400k are nearly equal, which demonstrates that almost the same pixels are extracted as gray color points.

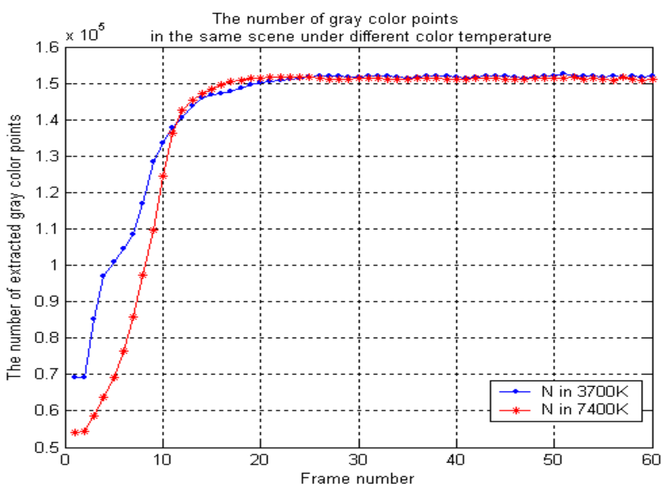


Fig.6. Comparison of the number of gray color points in the same scene in different color temperature.

The following is the discussion of robustness of the proposed algorithm. Generally, there simultaneously exist dark and bright gray color pixels in an image. As known, the deviation of dark gray from pure gray color under different color temperature is always less than that of bright gray (see in [2]). At the beginning of the automatic white balance adjustment, according to gray color points' extraction criterion, those dark gray pixels with small color deviation are detected out as gray color points, and their $\overline{U}_\Omega$ or $\overline{V}_\Omega$ is used to adjust the gain of their respective channel. After several times' adjustments, the color deviation of bright gray becomes less than its original deviation, so that most of them will satisfy equation (10), and then are joined to estimate color temperature. This done, both dark gray and bright gray pixels participate in color temperature estimation. As the final adjusting result, their $\overline{U}_\Omega$ and $\overline{V}_\Omega$ are close to zero.

The experiments also show that the proposed AWB algorithm is suitable for a wide variable range of color temperatures. But there is an exception that the scene is dominated by one light color, such as light yellow or light cyan. For example, in 7400k color temperature, light yellow color becomes bluish and more like white. In this case, pixels with this color will be considered as gray color points. Differently, if the scene contains both the light color and gray color, the algorithm can also work well. In this situation, the values of $\overline{U}_\Omega$ and $\overline{V}_\Omega$ are mainly determined by gray color pixels for the U and V components of the light color pixels are close to zero,. After several steps' adjustment, the color of light color pixels is corrected to their original color. Consequently, these light color pixels are not further joined in the color temperature estimation.

III. Conclusion

A novel local automatic white balance algorithm is proposed based on the property of gray color points under different color temperature. The deviation of these points from gray introduced due to under different light sources can be used to estimate the color temperature accurately. Then an effective iterative adjustment is adopted for avoiding a discontinuous chrominance video caused by gain adjustment. The proposed algorithm has a good performance in both the subjective and objective evaluation and has the advantage of easy realization, robust convergence. This automatic AWB has been applied in practice.

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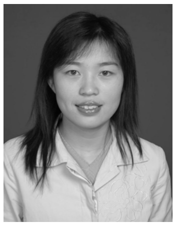

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