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On the recognition of wood slices by means of blur invariants

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ABSTRACT

In the recent paper [6] the authors presented an automatic system for visual recognition of wood slices, which are placed on a moving platform. The original method was based on moment invariants. In this comment we explain the mistakes of the method and show how to properly use moment invariants in a wood-slice recognition system. This correction immediately leads to an increase of the recognition rate.

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1. Introduction

This paper is a comment on the paper [6] published recently in this journal. In [6], the authors proposed an automatic system for recognition of wood slices depending on their color and texture. The wood specimens are placed on a platform or belt, which is moving linearly with a constant velocity. The down-looking camera is fixed above the platform and connected to the computer.

As the authors correctly realized, in this setup the images are degraded by so-called "blur", under which the fine texture of the specimen disappears and the recognition is more difficult. The primary source of the blur is the relative motion of the specimen and the camera. Potential wrong focus and diffraction also contribute to the blur. The blur can be (at least approximately for a flat scene, constant velocity and short acquisition time, which is the case here) modelled by a 2D convolution

$$g(x, y) = (f * h)(x, y) \tag{1}$$

where $g(x, y)$ is the observed blurred image of the object $f(x, y)$ and $h(x, y)$ is the *point-spread function* (PSF) of the system, which fully characterizes the blur. In practice, $h(x, y)$ is a composition of (usually few) particular PSF's corresponding to the individual blurring factors: $h = h_1 * h_2 * \ldots * h_K$. However, the authors of [6] consider all blur sources other than motion and defocus negligible, which may be true in case of their measurement device.

The parametric form of the motion-blur PSF is known. In case of a linear horizontal motion the PSF has the following form:

$$h(x, y) = \begin{cases} \frac{1}{vt}\delta(y) & \Leftrightarrow 0 \le x \le vt \\ 0 & \text{otherwise,} \end{cases} \tag{2}$$

where v is the motion velocity, t is the exposure time and δ is a Dirac function (see Fig. 1). If the motion vector has another direction, the PSF is just rotated accordingly. If an out-of-focus blur was also present, its particular PSF would be a cylinder whose radius determines the size of the blur, and the composite PSF would be a convolution of these two particular PSF's.

The authors of [6] also correctly pointed out that, in order to beat the blur effect, the recognition should either be performed after the images had been restored or, alternatively, it can be based on image features which are not affected by blur. Since the image restoration is relatively slow (even the simplest non-iterative algorithms require at least three Fourier transforms of the full-size image) and vulnerable to noise, we agree with the authors that the second option is the right choice.

The features which can be used for this purpose are called *blur invariants* and were introduced by Flusser et al. [2,1]. This blur-invariant solution is much faster than the restoration approach (the time superiority of the invariants was in [6] verified experimentally) since the features are calculated directly from the blurred image. Unlike the restored image, they do not provide a complete information but they are sufficient for recognition purposes.

However, in [6] a very important point was ignored: the blur invariance of these features is a direct consequence of the *symmetry* of the PSF. Different invariants exist for PSF's with different symmetries. Invariants for centrosymmetric PSF were published in [1],

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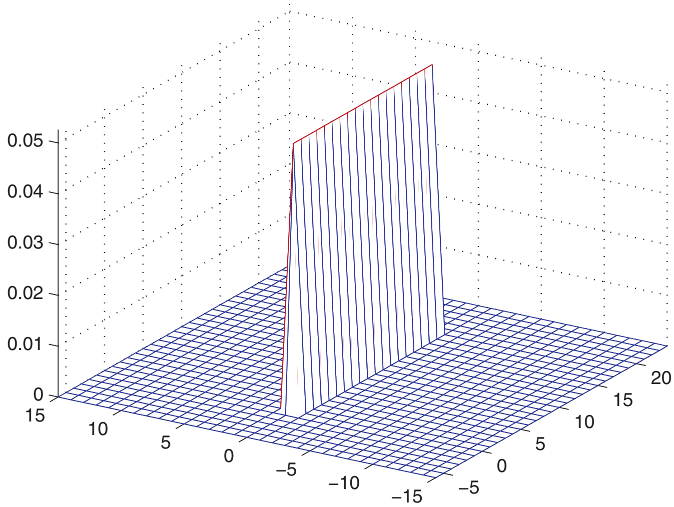

Fig. 1. The PSF of a horizontal motion blur of the length 20 pixels.

for PSF symmetric w.r.t. both axes and diagonals in [2], for PSF with circular symmetry in [5], and for motion blur, Gaussian blur and PSF having *N*-fold rotation symmetry in [4] (see Fig. 2 for symmetry examples). It is necessary to use only invariants corresponding to the actual shape of the PSF, otherwise the invariance property is violated and the system performance decreases. Unfortunately, in [6] the authors applied invariants designed for axial and diagonal symmetry adopted from [2] to the recognition of images, blurred by the motion blur and combined motion-defocus blur. This is incorrect because neither motion nor motion-defocus blur have such a symmetry and this choice diminishes the recognition rate.

The aim of this paper is to explain how to choose proper invariants for motion and combined motion-defocus blur and, consequently, how to increase the performance of the recognition system. We believe this is helpful for all users who want to use or re-implement the system proposed in [6].

2. The basics of blur invariants

Blur invariants are functions of the image moments. They can be defined for any kind of moments [7] but for simplicity let us stay with *geometric moments* only. Anyway, no other kind of moments was considered in [6]. *Central* geometric moment of image f is defined as

$$\mu_{pq}^{(f)} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x-x_c)^p (y-y_c)^q f(x,y)\,dx\,dy, \qquad (3)$$

where x_c, y_c are the coordinates of the image centroid. Central moments are invariant to translation.

Under convolution, the central moments are transformed as

$$\mu_{pq}^{(g)} = \sum_{k=0}^{p}\sum_{j=0}^{q} \binom{p}{k}\binom{q}{j} \mu_{kj}^{(h)} \mu_{p-k,q-j}^{(f)}. \qquad (4)$$

For each particular kind of symmetry, certain moments of the PSF are zero. This allows us to properly combine the moments of

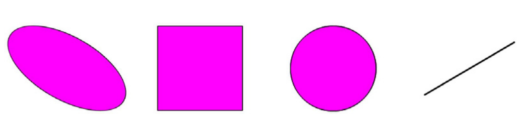

Fig. 2. Examples of the PSF symmetries – central symmetry, symmetry w.r.t. both axes and diagonals, circular symmetry, motion blur. Specific blur invariants exist for each particular case.

the blurred image and in this way to eliminate all the non-zero moments of the PSF and to obtain the desired invariance (see [4] for details).

3. Invariants to motion blur

In [6] it is proposed to use the following invariants of the 4th and 5th order which were borrowed from [2].

- 4th order:

$$B(1,3) = \mu_{13} - \frac{3\mu_{02}\mu_{11}}{\mu_{00}},$$

$$B(3,1) = \mu_{31} - \frac{3\mu_{20}\mu_{11}}{\mu_{00}},$$

$$B(4,0) = \mu_{40} - \mu_{04} - \frac{6\mu_{20}(\mu_{20}-\mu_{02})}{\mu_{00}}.$$

- 5th order:

$$B(3,2) = \mu_{32} - \frac{3\mu_{12}\mu_{20} + \mu_{30}\mu_{02}}{\mu_{00}},$$

$$B(2,3) = \mu_{23} - \frac{3\mu_{21}\mu_{02} + \mu_{03}\mu_{20}}{\mu_{00}},$$

$$B(4,1) = \mu_{41} - \frac{6\mu_{21}\mu_{20}}{\mu_{00}},$$

$$B(1,4) = \mu_{14} - \frac{6\mu_{12}\mu_{02}}{\mu_{00}},$$

$$B(0,5) = \mu_{05} - \frac{10\mu_{03}\mu_{02}}{\mu_{00}},$$

$$B(5,0) = \mu_{50} - \frac{10\mu_{30}\mu_{20}}{\mu_{00}}.$$

As we already pointed out, this is incorrect since they are not invariant to motion blur. They require PSF symmetric to both axes and both diagonals (see [2] for the proof), which is not the case of the motion blur (horizontal or vertical motion PSF is not symmetric to diagonals; motion in a general direction is symmetric neither to the axes nor to diagonals). To see this, let us investigate how these invariants are transformed under motion blur. Let us do that here for instance for $B(4,0)$ and for horizontal motion.

$$B(4,0)^{(g)} = \mu_{40}^{(g)} - \mu_{04}^{(g)} - \frac{6\mu_{20}^{(g)}(\mu_{20}^{(g)} - \mu_{02}^{(g)})}{\mu_{00}^{(g)}}.$$

Since we assume $\mu_{00}^{(h)} = 1$ (brightness preserving constraint) we have $\mu_{00}^{(g)} = \mu_{00}^{(f)}$. Using the convolution property (4), the fact that $\mu_{10} = \mu_{01} = 0$ for any image, and calculating the moments of the motion PSF explicitly, we obtain for the other moments

$$\mu_{20}^{(g)} = \mu_{20}^{(f)} + \mu_{20}^{(h)}\mu_{00}^{(f)} = \mu_{20}^{(f)} + \frac{s^2\mu_{00}^{(f)}}{12},$$

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