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Testing and Evaluation System for Camera Shake and Image Stabilizers (TEVRAIS)

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1. Introduction

Hand movement while taking pictures, that is called camera shake, causes undesirable image blur. A quicker shutter reduces the camera shake blur but degrades the signal-to-noise ratio of image due to insufficient exposure. The camera-shake blur is, therefore, unavoidable especially in darker situation that the shutter speed needs to be set in slower range. Increasing pixel count in recent image sensor is more susceptible to the camera shake because even a slight camera movement causes a large pixel displacement in the imaging area. Additionally the higher pixel density requires a longer exposure because the light-sensing areas in each pixel become smaller, and therefore makes the camera image more likely to be affected by the camera shake.

To prevent or reduce the camera shake, various image stabilizers (see Figure 1) have been developed in many camera manufacturers. As the traditional technology, the electronic image stabilizer (Uomori et al., 1990) has been investigated to suppress the camera shake of

Fig. 1. Classification of image stabilizer technology

camcorders or video cameras. This technique shifts the frame image horizontally and/or vertically frame-by-frame to counteract the motion. The visible frame is limited to a narrower area inside of the maximum possible imaging area to provide a buffer for the motion. The digital image restoration technology has also been studied to recover the image blur due to camera shake of still cameras. This technique is based on the deconvolution filter that is derived from the point spread function (PSF) representing the camera motion. The PSF is estimated from the built-in gyro sensors or the camera image itself without any sensors (Fergus et al., 2006). Especially the latter type is called BLIND deconvolution. Recently, many serial images taken by the continuous shooting mode are used to realize the camera shake correction as well as the super-resolution to break out of the resolution limit (Park et al., 2003).

The most efficient technology that is employed in the most consumer products is the OPTICAL image stabilizer (Sato et al., 1993). The common architecture consists of built-in gyro sensors that identify the hand movement and the movement cancellation mechanism that precisely shifts the optical axis or image sensing device to compensate for camera motion. Since the camera motion is canceled mechanically and directly, the trail of camera shake blur does not remain in the camera image, therefore, the optical image stabilizer has superior performance. It is said that the optical image stabilizer allows us to take handheld shots at three or four-step slower shutter speed than without image stabilizers, but it is not known exactly how effective it works for cancellation of the camera shake. It is important to evaluate the performance quantitatively and objectively, because the performance will be improved if drawbacks of the present image stabilizer can be found through the evaluation. This chapter focuses on the measurement of camera shakes and the evaluation of image stabilizers.

If the camera shake draws just a straight line, it can easily be detected by analyzing the PSF shape (Yitzhaky & Kopeika, 1998) or the spectrum distribution (Choi, et al., 1998) since it takes a simple 1D structure. Recently, the 2D trajectory corresponding to the camera motion in yaw and pitch axes, that can be estimated by shooting a point light source, have been investigated (Xiao et al., 2006). The 3D camera motion can be identified with the optical flow computed from the camera image of a stationary test pattern (Park et al., 2004), however, it is impossible to draw the trajectory in temporal sequence. The most popular method is to use the modulation transfer function (MTF) and examine how much high frequency components of MTF are retrieved by the image stabilizer (Choi et al., 2008). Any methods has not, however, been successful detecting the 3D trajectory that corresponds actual camera motions and quantifying them.

Our proposed method makes it possible to estimate the exact 3D trajectory of camera shakes and evaluate the quantitative performance of image stabilizers (Nish & Ogino, 2007). The key idea consists of shooting the quickly changing test patterns that are displayed in the custom-made LED panel and calculating displacements between each pattern that is multiply recorded in the camera image while opening the shutter. The concept of the 3D camera shake detection and the performance evaluation results of some optical image stabilizers are presented.

2. How to detect camera shakes and analyze them

2.1 Point light source

To examine camera motions, the simplest method is to shoot a point light source (Xiao et al., 2006). The trajectory of camera shake appears as a random curve on the camera image (see Figure 2). So we can observe directly the behavior of camera shake and the shrunk trajectory by the optical image stabilizer. However, when camera shakes are small especially in cases of a short time exposure or after-stabilization, it is difficult to discriminate the feature and extract it numerically.

Our goal is to make it possible to detect detail of camera shakes in any case. For this purpose, not only the point light source but also any static test pattern that is commonly used for camera tests are no longer useful because they overlap densely with slight displacements due to the camera shake and thus can not be discriminated each other.

Fig. 2. Camera images of point light source

Fig. 3. Shooting of video test pattern with camera shake

2.2 Video test pattern

To realize precise detection of camera shakes, we propose using a VIDEO test pattern instead of static ones as the photographic subject. While the camera shutter is opening, each frame of the video test pattern is multiply recorded on an image with some shifts or rotations due to the camera shake. If those test patterns are chosen to eliminate overlap each other, each pattern can be easily discriminated from the multiply-exposed image. This is the key idea to detect camera shakes. Figure 3 shows the process from the shooting of video test pattern to the multiple exposure of them with some displacements or rotations due to the camera-shake. In this study, dot matrix patterns are used for the video test one. For generating dot matrix patterns , we have developed a custom-designed LED panel (see Figure 4), that is composed of a window frame: 193mm × 193mm for the reference of pattern detection and 24 × 24 LED array with 1.5mm ϕ lighting holes and 7mm spacing for dot matrix patterns. By displaying dot matrix patterns repeatedly with a horizontal or vertical shift, no-overlapping video test pattern is realized (see Figure 5). Figure 6 is a camera image of the video test pattern. If camera shakes do not exist, it becomes the distortion-free lattice pattern, or it causes a deformation due to camera shakes. The video test pattern can also be implemented in a high-response liquid-crystal display where each video frame corresponds to each test pattern, but the frame rate is limited to 60Hz.

Fig. 4. Custum-made LED display for video test pattern

Fig. 5. Formation of video test pattern

Fig. 6. Camera images of video test pattern

2.3 Computation of 3D trajectory based on pattern matching

The trajectory of camera shake can be obtained by computing displacements between each pattern in the multiply-exposed image. The pattern matching technique is useful for detecting positions of each test pattern from the image and computing displacements or roations between each pattern (see Figure 7). It is realized by using the shape-based pattern matching function of MVTec's machine vision tool HALCON. The shape-based pattern matching is advantageous to detecting in sub-pixel resolution and noise environment. Finally, the 3D trajectory of camera shake can be obtained by rearranging their estimates in time-sequence. Figure 8 shows examples of 2D trajectory (in yaw and pitch axes) computed through the above procedure.

Fig. 7. Detection of displacements or rotations based on pattern matching

Fig. 8. Examples of detected camera shake trajectory with IS OFF and ON

2.4 Relation between camera motion and image plane

The actual camera shake involves random 3-axis shifts and 3-axis rotations, but the image movement is dominantly affected by rotations in 3-axis because parallel shifts make only a slight movement and are negligible in the camera image. When the camera rotates by $\theta_y, \theta_p, \theta_r$ in yaw, pitch and roll axes, respectively, an arbitrary point (x, y) of the image is moved to the following point (x', y') :

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos \theta_r & -\sin \theta_r \\ \sin \theta_r & \cos \theta_r \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} d_y \\ d_p \end{bmatrix}, \tag{1}$$

where $d_y = L \tan \theta_y \approx L\theta_y$ (2)
 $d_p = L \tan \theta_p \approx L\theta_p$.

d_y, d_p mean image shifts due to yaw and pitch rotations, respectively, where the camera-to-subject distance is L and both of them are assumed to be set to the same scale for simplicity. The above implies that if the displacement or rotation of the target image can be detected from the relation between (x, y) and (x', y') in the camera image, then the camera rotations in 3-axis $(\theta_y, \theta_p, \theta_r)$ can be computed directly (see Figure 9). The left of Figure 10 shows a 3D trajectory of camera shake, that is obtained through the above conversion from the displacements and rotation detected by the pattern matching.

Fig. 9. Relation of camera-to-subject

2.5 Scatter diagram analysis

It is difficult to analyze the general trend of camera shake from just one of detected trajectories because it behaves randomly. The scatter diagram that is computed by accumulation of motion vectors between each frame interval (see the left side of Figure 10) from many images is useful for analyzing the camera shake trend. The quantification can be

Fig. 10. 3D trajectory of camera shake and scatter diagram

Fig. 11. Cumulative distribution of camera-shake trajectories

given by the principal component analysis, that means the average amplitude and orientation of camera shakes. The right side of Figure 10 shows an example of the scatter diagram obtained from many camera shake images. The oval sphere corresponds to the result of principal component analysis and shows the rough trend of camera shakes. So we can investigate differences of camera shake property in individuals or camera models through this analysis. When taking pictures with the image stabilizer, the distribution shrinks in origin. The degree of shrinkage shows the efficiency of image stabilizer. Another way for quantification of the camera-shake trend is to compute the cumulative distribution of the detected trajectories, where all the start points of each trajectory are placed in origin, and apply the principal component analysis to that distribution (see Figure 11). The longer the shutter speed causes the larger the camera shake, therefore, more spread the distribution.

Figure 12 is an overview of developed GUI for displaying all the above results.

Fig. 12. Visualization and analysis tool of detected camera shakes

3. Experiments

3.1 Camera shake simulator

A camera shake simulator (see Figure 13) is used to examine the accuracy of detected camera shakes and compare the performance of image stabilizers under a definite motion. It consists of two stepping motors for vibrating in two axes chosen from among yaw, pitch and roll directions. The stage configuration for realizing arbitrary motion in yaw and pitch axes is shown in the left side of Figure 14. The case of yaw and roll axes is shown in the right side.

Fig. 13 Camera shake simulator for evaluating the detection accuracy and the effectiveness of image stabilizer

Fig. 14. Two types of vibration mode for realizing artificial camera shakes

3.2 Comparison of detection accuracy

A single-lens reflex camera is used to evaluate the detection accuracy in our measurement system. The left side of Table 1 shows standard deviations of detected vibrations from the camera images in static condition without any motions, where the camera is mounted on a

tripod and no mirror shocks exist. The right side of Table 1 shows measurement results under the motion by the camera-shake simulator that is controlled by an uniform circular motion in pitch and yaw axes.

This experiment is performed under the following conditions. The sizes of test pattern in the camera image are 800×800 pixels and 1200×1200 pixels, respectively. The rotation speed of the camera-shake simulator is constant at 1.68 degree/sec. The camera-to-subject distance is 3090mm.

The use of high resolution image in 1200×1200 pixels succeeds to reducing detection errors by 55%, 64% and 38% in pitch, yaw and roll axes, respectively, compared with the low resolutioni mage in 800×800 pixels. In the case of the circular motion, error reductions by 17%, 20% and 20% in pitch, yaw and roll, respectively, are also observed. These results show that the detection accuracy is improved by use of the high resolution pattern compared with the low resolution one.

	Static			Moving		
	pitch (deg.)	yaw (deg.)	roll (deg.)	pitch (deg.)	yaw (deg.)	roll (deg.)
800×800 pix.	0.0011	0.0014	0.0214	0.0030	0.0030	0.0270
1200×1200 pix.	0.0005	0.0005	0.0133	0.0024	0.0024	0.0176

Table 1. Comparison of accuracy with standard deviation of detected camera shakes

3.3 Personal differences of camera shake

Here we measured camera shake amplitudes on eight photographers. Each person shot about 140 pieces with the same camera. The size of test pattern in the camera image is about 1200×1200 pixels. The camera-to-subject distance is 3600mm.

Table 2 shows minimum and maximum camera rotations on each person, that is estimated through our measurement system. It shows that average values in pitch and yaw are about 0.03 degree and the average value in roll is 0.1 degree that means greater than pitch and yaw ones.

Person	Pitch(degree)		Yaw(degree)		Roll (degree)	
	min	max	min	max	min	max
A	-0.021	0.023	-0.016	0.025	-0.080	0.065
B	-0.030	0.035	-0.029	0.028	-0.075	0.085
C	-0.036	0.039	-0.033	0.033	-0.140	0.150
D	-0.032	0.032	-0.023	0.022	-0.065	0.065
E	-0.031	0.033	-0.041	0.040	-0.110	0.100
F	-0.021	0.025	-0.020	0.020	-0.105	0.011
G	-0.038	0.040	-0.036	0.040	-0.095	0.100
H	-0.039	0.044	-0.035	0.037	-0.115	0.115
Average	-0.029	0.031	-0.031	0.034	-0.098	0.099

Table 2. Personal differences and average trend of camera shakes

3.4 Performance evaluation of image stabilizers

Next experiment results for comparing the camera-shake reduction performance on four different cameras of single-lens reflex type with image stabilizers are shown. The pattern size is set to be 1200×1200 pixels in the camera image. All cameras on the camera-shake simulator take uniform circular motion at 1.59 Hz in yaw and pitch axes. Two cameras of them have lens shift-type stabilizers and another two have sensor shift-type ones. The camera-to-subject distance is 3160mm.

Figure 15 shows 2D distributions of motion vectors of the detected camera-shakes in the case that image stabilizers are off and on. It means that camera A has most effective performance of image stabilization because the distribution is most concentrated in origin.

Fig. 15. Performance comparison of image stabilizers

Fig. 16. Performance evaluation of an image stabilizer by means of cumulative distributions

The image stabilization of camera D becomes ineffective in 45-degree direction. Through these analyses, we can examine the tendency of image stabilization and exploit the result for the next development.

An example of evaluation using the cumulative distribution is shown in Figure 16. The distribution is widely spread due to camera-shakes, but the image stabilizer shrinks it in origin. From each distribution, amount of camera-shakes or the remaining one after the image stabilization are defined by the sum of long axis and short one of the oval sphere given by the principal component analysis. The right side graph of Figure 16 is the computational results in various shutter speeds. In this graph, the shift distance between both curves of IS off and on means the total efficiency of image stabilizer.

3.5 Measurement of camera body and tripod vibration

Our system has a sub-pixel resolution in detection of displacement due to camera motions. So not only camera-shakes but also slight vibrations in camera body and tripod when taking pictures can be detected.

Fig. 17. Comparison of vibration suppression performance

Fig. 18. Vibration waveforms at the moment the shutter opens

Figure 17 shows how much the camera vibration increases without mirror-up delay. Camera D', that the distribution is most concentrated in origin, has the most superior performance for suppression of the camera vibration. The waveform of camera vibration on a triod can be also observed with a sub-pixel resolution (see Figure 18).

3.6 Measurement of camcorder-shakes and efficiency of image stabilizer in camcorder

The video image taken by camcorder is composed of sequential still images. The camera-shake in each still image, that is called *intra*-frame camera-shake, can be detected as with the above method. However the camera-shake arising in the interval between each frame, that is called *inter*-frame camera-shake, needs to be detected by another way. The inter-frame camera-shake corresponds to the image movement from previous frame to next one. Therefore the movement can be easily detected by using the pattern matching because each pattern is recored in different frame. By connecting between the estimated inter and intra-frame camera-shakes, the overall camera-shake can be obtained.

Figure 19 shows examples of detected camcorder-shake when the image stabilizer is off and on, respectively.

Fig. 19. Detection of the artificial camera-shake under a uniform circular motion

4. Conclusion and future work

A novel method for detecting the trajectory of camera-shake from the camera image itself was presented. The main feature is to use a video test pattern, detect positions of each test pattern multiply-recorded in the camera image by the pattern matching and obtain the camera-shake trajectory by connecting them. The LED display was also developed for realizing the high-response video test pattern. Many experimental results and examples that show usefulness of this system were presented.

Now we are aiming at commercialization of this technology and standardization for measurement of camera-shake and evaluation of image stabilizers.

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