Platform motion blur image restoration system

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Abstract: We present a computational imaging system that incorporates an optical position sensing detector array, a conventional camera and a method to reconstruct images degraded by spatially variant platform motion blur.

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Image degradation caused by platform motion blur is a common problem for space based imagers. Platform motion blur is accentuated by long exposure times, large object distances, or rapid motion [1] and in many applications it is dominant over object motion blur. Platform motion blur varies across the image field in a structured fashion, characterized by translation and rotation; therefore, it can be modeled using an affine transform. Image deconvolution with a point spread function (PSF) estimate is used to deblur images degraded by spatially variant (SV) motion blur [2]. Limitations in this process can be reduced by measuring the PSF during image acquisition using additional hardware. A low spatial resolution, high temporal resolution video camera can be used to process a PSF [3], however, this increases size, weight, power and processing costs. One approach is to measure motion using accelerometers unfortunately the resolution of the measurements do not scale with the focal length of the lens [4]. The structured nature of platform motion blur makes it sufficient to detect motion from the image itself at a few locations in order to generate a SV PSF. We fabricated a prototype system capable of acquiring images while simultaneously tracking relative camera scene motion at specific image locations using position sensing detectors (PSD) and used it to form a SV PSF from which to significantly restore blurred images, Fig. 1.

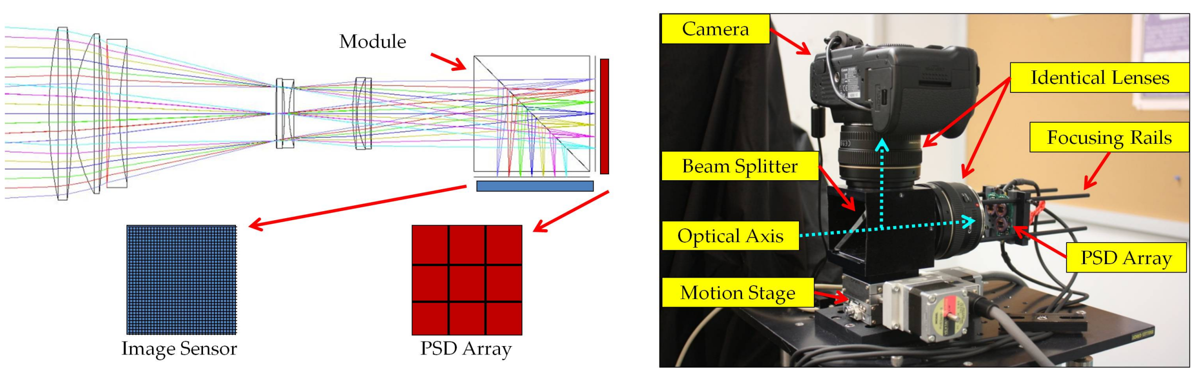

Fig. 1. (Left) Schematic: a lens and beamsplitter form identical image planes for the image sensor and PSD array. (Right) Photo of the Imaging, Position Sensing & Motion Actuated System.

1. Measuring Image Motion using Position Sensing Detectors

The large energy collection area of the PSD allows it to provide fast analog position outputs. Light incident on the lateral effect PSD [5] generates a photo-current that flows across the uniformly resistive sensor surface and whose distribution is proportional to the centroid position of light intensity (X, Y) (1). L is the distance between contacts and i_i are the currents at the electrodes, see Fig. 2a. The PSD also provides a *Sum* output which is proportional to the net intensity at the sensor. We modeled PSD tracking behavior of different scenes with varying contrast. The simulation showed that localized features (bright features on dark background) are easily tracked with sub-pixel error. The plot in Fig. 2b shows that when image features have low contrast they are less localized making motion tracking worse. The PSD motion estimate of the centroid is skewed toward the sensor's center as ambient light increases, Fig. 2c. Tracking is not possible if the feature moves off a sensor's surface. This event can be monitored using the PSD outputs. These simulations were confirmed experimentally by projecting videos onto the PSD. A PSD array is shown schematically in Fig. 2d, where valid and invalid tracking are denoted by green and red arrows, respectively. We propose grouping the array into many blocks to recover invalid data, since it can be valid over a PSD aggregate group using (2), where m and n are the total number of sensors in a block in the x and y direction, respectively. This requires closely tiled PSDs to create a contiguous measurement space and was not explored experimentally.

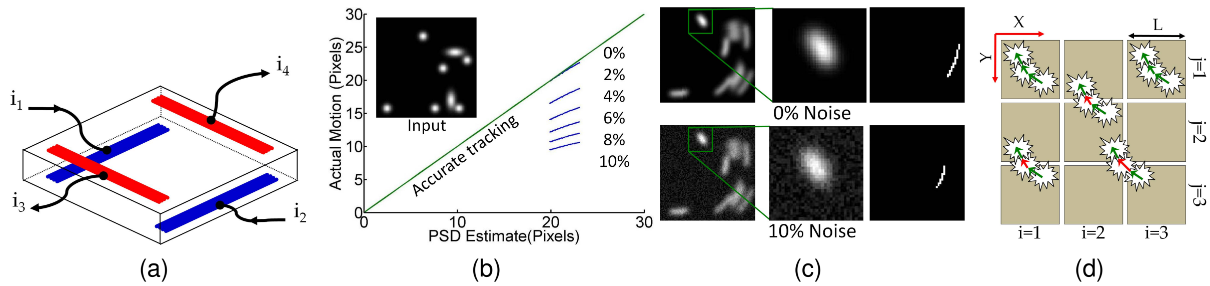

Fig. 2. (a) Lateral effect PSD scematic. (b) Plot of PSD scene tracking error for various noise levels. Input scene is inset. (c) Scene from 2b is blurred (left) and the centroid is tracked (right) in the presence of 0% noise and 10% noise. (d) PSDs can track the moving centroid of high contrast features that remain on the sensors. Invalid data can be recovered by aggregating PSD outputs (2).

$$X = \frac{i_1 - i_2}{i_1 + i_2}\frac{L}{2} \qquad Y = \frac{i_3 - i_4}{i_3 + i_4}\frac{L}{2} \qquad Sum = i_1 + i_2 = i_3 + i_4. \tag{1}$$

$$X_{aggregate} = \frac{\sum_{i=1}^{m}\left[\left[L(i-1) + \frac{\sum_{j=1}^{n} X_{ij} I_{ij}}{\sum_{j=1}^{n} I_{ij}}\right]\sum_{j=1}^{n} I_{ij}\right]}{\sum_{i=1}^{m}\sum_{j=1}^{n} I_{ij}} \qquad Y_{aggregate} = \frac{\sum_{j=1}^{n}\left[\left[L(j-1) + \frac{\sum_{i=1}^{m} X_{ij} I_{ij}}{\sum_{i=1}^{m} I_{ij}}\right]\sum_{i=1}^{m} I_{ij}\right]}{\sum_{i=1}^{m}\sum_{j=1}^{n} I_{ij}} \tag{2}$$

2. Generating a Spatially Variant PSF from PSD Data for Image Deblurring

We model apparent image motion caused by platform motion by an affine transform, which is appropriate for many real scenes [6]. Coefficients of the transform $F = \langle a(t)x + b(t)y + c(t), d(t)x + e(t)y + f(t)\rangle$ for each elementary time step t are calculated based on consecutive voltage information produced by three PSDs placed in known locations of the image plane. As each of three PSDs provides a vector of elementary motion at its coordinates (x,y), this is sufficient for an unambiguous estimate of transform coefficients. Motion integration during the exposure time allows to compute the PSF for an arbitrary image location, which is used for deconvolution using the Lucy-Richardson algorithm [7]. Each pixel value of the restored image is acquired by deconvolving in its square neighborhood and taking the central value.

3. Experimental Proof-of-Principle Result

The system shown in Fig. 1 is computer controlled to simultaneously trigger the motion stage, imaging camera and PSD data acquisition. The design requires the imager and PSDs be in the same image plane and prompted the fabrication of a custom cube assembly to house the beam splitter, imager and PSD array. A motion stage creates reproducible motion blur. We conducted experiments on the image in Fig. 3, where SV blur is evident. The scene contains three bright LED sources focused onto the region where the PSDs are located (shown in cyan). In this way we tailor the experiment to meet PSD requirements by providing localized, high contrast features to track. Overlaying the blurred images are yellow lines describing the calculated SV PSF showing the two are consistent. The system is limited to applications, such as for star imagers, where bright features of specific size and distribution appear on a dark background. The reconstructed image in Fig. 4 shows significant improvement and the effectiveness of the system.

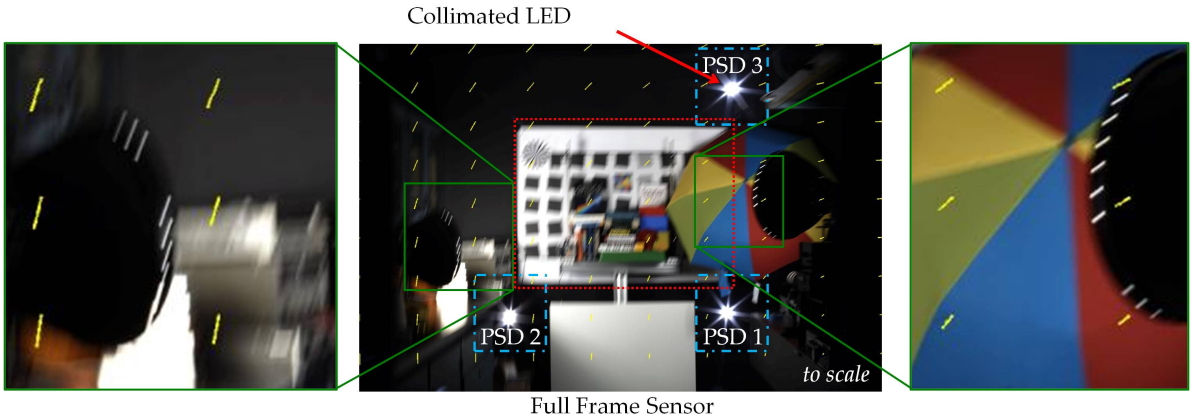

Fig. 3. Experimentally blurred image. Magnified sections of the image are shown. The calculated SV PSF is shown superimposed as green lines and is consistent with the image motion blur.

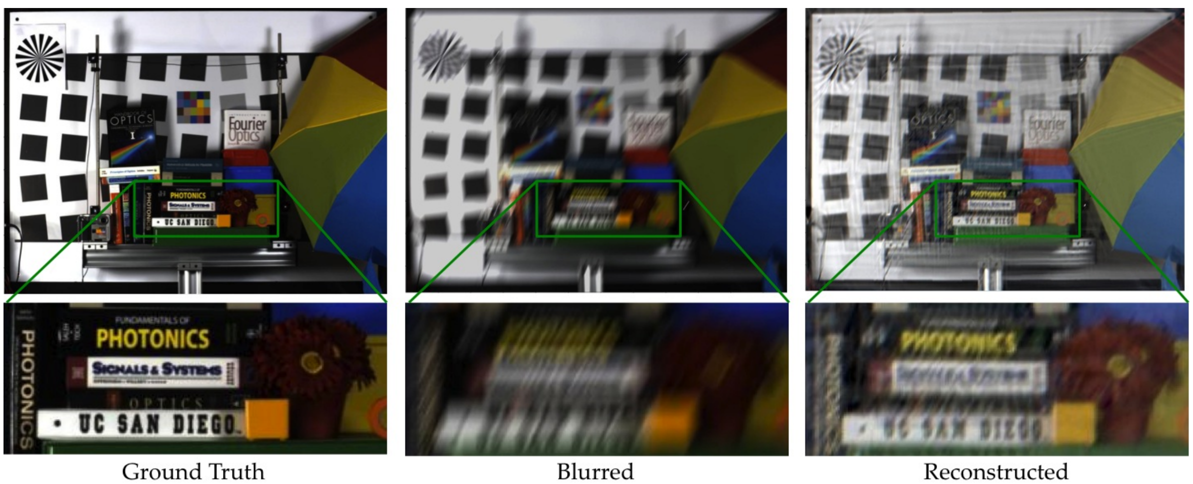

Fig. 4. The region of Fig. 3 enclosed in red is deblurred using a pixel by pixel method with the Lucy Richardson algorithm set to 15 iterations. Magnified sections of the images are shown.

References

1. B. Hulgren and D. Hertel, "Low light performance of digital cameras," *Proc. SPIE Imaging Science and Technology*, **724214**, 1–9 (2009).
2. M. Šorel and J. Flusser, "Space-variant restoration of images degraded by camera motion blur.," in IEEE Transactions on Image Processing, (IEEE, 2008), pp. 105–116.
3. S. K. Nayar and M. Ben-Ezra, "Motion-based motion deblurring," Pattern Analysis and Machine Intelligence, IEEE Transactions on **26**, 689 -698 (2004).
4. N. Joshi, S. B. Kang C. L. Zitnick and R. Szeliski, "Image deblurring using inertial measurement sensors, "ACM Trans. Graph. **29**, 30:1–30:9 (2010).
5. J. T. Wallmark, "A New Semiconductor Photocell Using Lateral Photoeffect," *Proceedings of the IRE* **45**, 474 -483 (1957).
6. A. Gupta, N. Joshi, C. L. Zitnick, M. Cohen and B. Curless, "Single image deblurring using motion density functions," *Proceedings of the 11th European conference on Computer vision: Part I*, 171–184 (2010).
7. R. C. Gonzalez and R. E. Woods, *Digital Image Processing (3rd Edition)* (Prentice-Hall, Inc., 2006).