# Monte Carlo simulation for speckle reduction using moving diffuser

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## 1. Introduction

We have been working on speckle phenomena, in measurement and reduction, because it is very hazardous in laser projection displays. [1-4]. So far numerical simulation for speckle given in the literature has been limited to speckle formation. [5] More recently numeral simulation for speckle reduction is discussed in terms of the point spread functions, which stand the correlation cell and the resolution cell for the projection and viewing systems, respectively. [6, 7] We will report Monte Carlo simulation for speckle reduction on images, which are formed by a number of point spread functions, where novel ideas in image processing such as image interpolation by zero padding in its frequency domain are introduced. [8]

## 2. Numerical simulation

As shown in Fig.1, optical system for speckle reduction is illustrated as two step Fourier transform, first by the higher numerical aperture (NA) projection lens and second by the lower NA viewing lens. Therefore, projected image on the screen should have higher resolution than image formed on the retina. The random phasor assigned to each resolution cell of projection lens to be summed up within eye resolution cell is simulated by sharp-cut low pass filtering by the second lens.

Left image in Fig. 2 consists of 16 x 16 pixels taken from well- known Lena's test image of 512 x 512 pixels. Middle image is its 64 x 64 pixels version obtained from zero padding to 64 x 64 pixels in Fourier frequency domain, to be located on the screen and multiplied by the same number of random phasors originated the moving diffuser. Right image is generated by summing up intensity distribution formed through the low pass filter for restoration of 16 x16 pixels, while changing the set of random phasors 200 time, implying temporal diversity M=200. On other hand spatial diversity $K$ is measured as the number of projection lens correlation cell within eye resolution cell, $(512/64)^2 = 16^2 = 256$ in this case.

Extracted speckle by subtraction of right image from the left image in Fig.2, is displayed in left of Fig.3, while right shows comparison between the theoretical speckle contrast and the simulated speckle contrast. Theoretical speckle contrast obeys the formula [5]

$$C = \sqrt{\frac{K+M-1}{KM}}. \qquad (1)$$

## 3. Conclusions

Speckle reduction by moving diffuser is fully simulated over a finite size of pixel arrays on the image, applying image processing technique known as interpolation by zero padding in frequency domain.

## References

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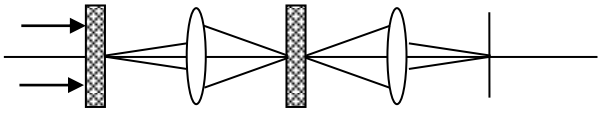

Fig.1 Schematic optical layout for speckle reduction; laser illuminated test image on moving diffuser, resolution resizing by projection lens, screen diffuser, sharp low pass filtering by viewing lens and retina or imager (from left to right).

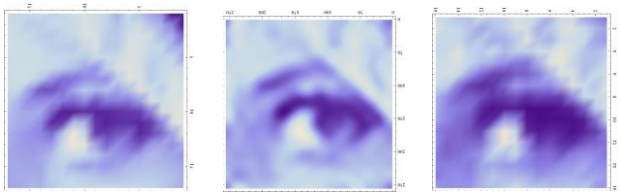

Fig.2 Original test image, resampled test image, and speckled image after propagation, measuring C=0.127.

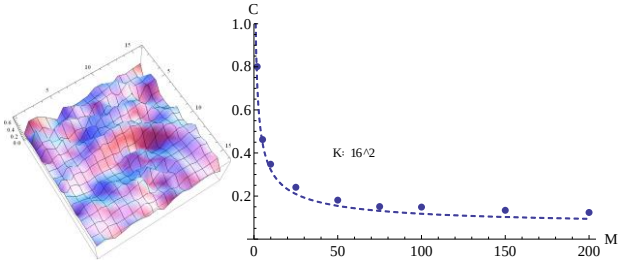


Fig.3 Extracted speckle and plot of speckle contrasts, simulated (dots) and theoretical (dashed line) as a function of temporal diversity $M$ at spatial diversity K=256.

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