Speckle Suppression in Laser Projection

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During the last years, a trend to replace traditional short arc lamps in projectors with solid state light sources is seen. This is mainly driven by the limited lifetime of these lamps, which impacts the system's cost of ownership and reliability. While LEDs are well-suited for low light output products, they can not reach the brightness levels for high-brightness projectors (digital cinema, large venue projection). For that high-end market segment, lasers come into play.

Apart from a longer lifetime, lasers offer other benefits. Their narrow spectrum results in a very large color gamut and due to the very low intrinsic étendue of the laser source, projection engines could become less complex, more efficient, smaller and more powerful. A 230 lm LCOS laser projector demonstrator[1] has been developed and evaluated in the framework of the European FP6-project Osiris (Original System for Image Rendition via Innovative Screens)[2].

We found out that next to challenges such as laser cost, cooling, and safety, the most critical issue regarding image quality is speckle. Speckle appears as a granular pattern on the screen superposed on top of the projected image. The principle behind speckle is shown in Figure 1. All rays arriving at the position of the observer will have a random phase due to the height profile of the screen and constructive or destructive interference can occur. Speckle is evaluated by its contrast, which can be calculated from a photograph of the speckle pattern. The speckle contrast is the standard deviation of the pixel intensities divided by the average intensity.

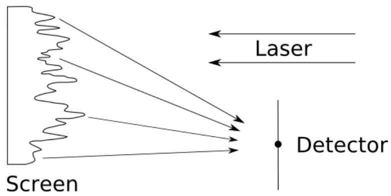

Figure 1: The origin of speckle patterns.[3]

In order to obtain an acceptable image quality, speckle has to be suppressed. All speckle reduction techniques use the averaging of speckle patterns to suppress the perceived speckle contrast. Speckle behaves as a statistical phenomenon: the speckle contrast of the sum of N^2 independent speckle patterns is N times lower than the speckle contrast of each of the individual speckle patterns. This is illustrated in Figure 2.

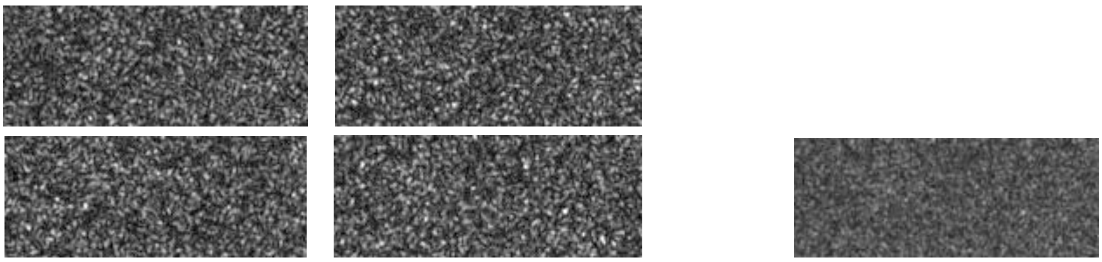

Figure 2: The superposition of the four independent speckle patterns with C_i = 40 % (left) reduces speckle to C_s = 21 % (right). [3]

The averaging can be done by the superposition of several independent speckle patterns at the same time, or by showing the independent speckle patterns sequentially within the integration time of the eye. Several speckle reduction techniques exist and they can be grouped into four groups: angular diversity, wavelength diversity, polarization diversity and screen-based solutions[4].

Angular diversity refers to the use of a light source having a reduced coherence. This can be achieved by breaking the coherence of the laser (e.g. by a rotating diffuser), or by using mutually incoherent sources. This approach is limited by the fact that the angular separation of the sources should be larger than the numerical aperture of the eye of the observer[4]. This has some important implications on the design of a laser projector, as it requires the use of large projection lenses.

Using lasers having a broader spectrum is another approach of speckle suppression. The advantage is that this does not have any impact on the optical design of the projector. This wavelength diversity is easily achieved for direct laser diodes, as they have a spectrum of about 1 nm wide. However, for the green primary such wide sources are not available, because (high-power) green lasers are obtained by frequency doubling of IR lasers. Due to this frequency doubling the lasers typically have very narrow spectra. The consequence is that the speckle contrast of a laser projector is determined by the speckle contrast of the green primary.

The third approach is polarization diversity, where the fact that perpendicular polarization states do not interfere with each other is exploited to reduce speckle. Also the reflection off the screen is different for the different polarization states incident on the screen. Polarization diversity results in speckle suppression by a factor of 2 (at maximum), but it has the disadvantage that it is not compatible with stereoscopic 3D solutions based on polarization.

The origin of speckle is the surface height fluctuation causing the random phase shifts. That is why speckle solutions on the level of the screen are very powerful. One could use screens with engineered surface profiles or one could move the screen. Unfortunately, this can only be used in a limited set of situations.

The conclusion is that there exists no single solution for speckle: all of the categories above have to be combined to improve the image quality of laser projectors.

Acknowledgements

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References

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