Measurements of Highly Abberated Eyes with COAS™

Question: I've heard that the spots in a Shack-Hartmann sensor will overlap when a patient has an unusual cornea and this effect will cause a bad measurement.

- Is this true?
- What does it mean to the measurement?
- How does WaveFront Sciences' instrument address this problem?

Answer: This is a theory that is spread by proponents of alternative wavefront sensing techniques.

Some aspects of this theory are correct; however, a thorough understanding of Shack-Hartmann sensors allows these concerns to be overcome.

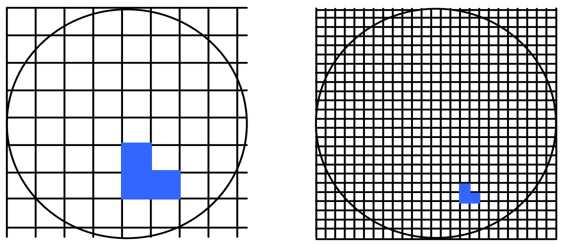

Figure 1 – Resolution plays a critical part in making an accurate measurement. The increased fill factor and smaller area of potential data dropouts are critical in making an accurate measurement.

Spot overlap is conceptually possible with a Shack-Hartmann sensor. The spots associated with the lenslet array can overlap causing data to be lost in that area. However, it is only a problem with systems that have been developed by companies that are not experienced in wavefront sensors. WaveFront Sciences does not have this problem. The COAS™ units produced by WaveFront Sciences provide several specific advantages:

1. COAS™ does not have this spot overlapping problem. This is addressed in a couple of ways. First, WaveFront Sciences' Shack-Hartmann wavefront sensors have the highest dynamic range available in the world. This allows us to make measurements that other instruments cannot make. An eye that exceeds our dynamic range is rare.

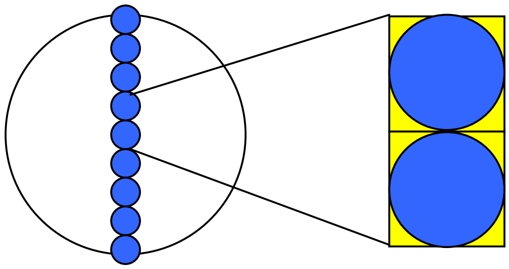

Figure 2 – In this figure, the yellow zones represent areas of the eye which are not sampled due to a circular sample technique if the spots are optimally packed. When spots are overlapped, there remains an unequal weighting of data regardless of the overlap pattern. Ray tracing instruments commonly leave large gaps between samples, resulting in even more area that remains unsampled.

2. Second, the COAS™/WASCA™ instrument design includes proprietary aspects (patents pending) which prevent bad data from being caused by overlapping spots. In the extremely unusual circumstance that an eye will be out of range, the instrument will automatically prevent the generation of a bad measurement. This may result in a slightly reduced data set, but it will assure an accurate measurement of any given eye, even one that taxes the range of the sensor.

In our extensive testing of the machine, we have not encountered an eye that exceeded the dynamic range of the machine. We have performed many successful measurement tests that included the LASIK flap, ablation zone, and beyond. In the unlikely event an eye does exceed the dynamic range, the resulting presentation would be obvious to the trained operator.

3. The COAS™ instrument also has the highest resolution available. This is critical in acquiring and analyzing data associated with a highly aberrated eye. A low-resolution instrument is not capable of accurately analyzing an eye which has fine structure aberrations. High frequency aberrations will also naturally be associated with the need for the high dynamic range associated with the potential of spot overlap.

Higher resolution is fundamentally better, providing a more accurate measurement due to a better fill factor and less potential data dropouts. Figure1 illustrates the more complete fill factor associated with high resolution, as well as the potential bad area if a few samples are bad.

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Fill factor is associated with the number of complete samples that can be acquired and is reduced when the edge of the pupil cuts through the boundaries of a lenslet. The greater the number of complete samples, the more accurate the resulting measurement. In addition, the handling of the edge samples is very important. COAS™ includes these partial samples to provide the most accurate measurement. Note that the typical COAS™ measurement uses more than twice the number of samples shown in the image on the right of Figure1.

Inaccuracy due to low fill factor is further amplified when using the circular samples of a ray-tracing instrument, illustrated in Figure 2. In this geometry, the area covered by the spots leaves areas of the cornea unexposed to the measurement or unequally weighted. This effect is true regardless of potential overlap patterns. WaveFront Sciences' Shack-Hartmann sensor provides 100% coverage of the entire pupil with equal weighting of all surfaces.

4. We have developed special configurations which specifically address the measurement of eyes with keratoconus and larger diameter measurements requiring a sensor with extremely large dynamic range.

5. The COAS™ instrument is also capable of presenting data with a direct surface measurement (surface of the wavefront) rather than a polynomial fit. This provides much more visibility to high frequency and high dynamic range conditions. This view also requires a more educated user. To use this data presentation, the operator requires specific training in the technique.

Comparison to Ray Tracing Instruments

While spot overlap is a problem for some Shack-Hartmann sensors, other approaches to aberrometry have significant technical weaknesses. Competing instruments have a significant issue associated with the time it takes to make the measurement (scan time). It has been shown that the eye has significant saccadic motion during the average scan time required by ray tracing type instruments. This motion will result in both reduced accuracy and reduced repeatability.

The spots analyzed by ray tracing instruments are imaged by the eye. This makes the optical system of the eye an inherent part of the measurement. Good metrology theory requires that the measurement should be independent of the sample in question. By requiring the eye to be a part of the measurement, this technique assures that every measurement is different and nonrepeatable. Further, when performing the spot scan, the instrument must make some assumption regarding the shape of the retina. These two facts both contribute to a technique which is fundamentally less accurate. Again, lower resolution and less accurate.

The Shack-Hartmann sensor is a well established technique dating back to 1901 and has hundreds of refered technical articles in the open literature. WaveFront Sciences has also published multiple papers including a paper that shows that a low-resolution measurement cannot accurately analyze higher-order aberrations. For ray tracing techniques only a few articles are in existence.

The bottom line is, the concern with overlapping spots in Shack-Hartmann sensors is just bad information if the correct techniques to mitigate the problem are applied. Anyone propogating this information is either intentionally spreading bad information or is simply misinformed. WaveFront Sciences has the knowledge and experience to exploit the fundamental accuracy of the Shack-Hartmann sensor; you can rely on us for wavefront sensor solutions.

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