Reducing statistical noise improves surface measurement accuracy

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Applying statistical methods to commercial metrology systems enhances the accuracy of surface measurement by an order of magnitude without increasing the time required to complete the task.

Many industries, such as aircraft and automobile assembly, use surface measurement technologies to ensure that vehicles are assembled correctly. In the past, many methods have been used to achieve high accuracy surface measurement. These have included multiple measurements, phase shifting, wavelength control, and various methods of triangulation or other two-camera stereo measurement.[1, 2] Better cameras and wavelength control increase the complexity (and usually the cost) of the metrology system, while multiple measurements and phase shifting increase the time needed for one final measurement. The basic tradeoff, then, is measurement accuracy *vs*. cost, complexity, and measurement time.

The processes described above still lead to data that have the same resolution in all dimensions. In most cases, the desired measurement is not of the absolute locations of points on a surface, but rather the difference between these locations and the design. If x and y locate a measurement along a surface, then, the measured value of z—perpendicular to the surface being measured—usually requires higher accuracy than x and y.

Using statistical methods, we can add an additional tradeoff: accuracy in one dimension against accuracy in the other dimensions. The statistical processing that enables this tradeoff is implemented in software and applied after the measurement is taken. With no increase in complexity or measurement time, cost is the only factor to vary. With our method, the cost increase is minor compared with the cost of purchasing equipment with higher accuracy. We have tested this process on a wide variety of measurement technologies and found that it works well with virtually all of them.

The approach consists of increasing accuracy through post-measurement statistical noise reduction. It helps find surface features that would be hidden without requiring tradeoffs among complexity, time, and cost (see Figure 1). Averaging together the "delta deviation" (the difference between the measured value and the nominal value) over a range of points makes it possible to significantly reduce the noise in the measurement of the center point. If the dimensions along the surface being measured are defined as x and y, and the dimension perpendicular to the surface is defined as z, then the random noise in z can be improved by the same factor as the increase in correlation along x and y. In effect, for a factor of 10 improvement in z, the resolution in both x and y—which is usually less critical—deteriorates by the same factor of 10.

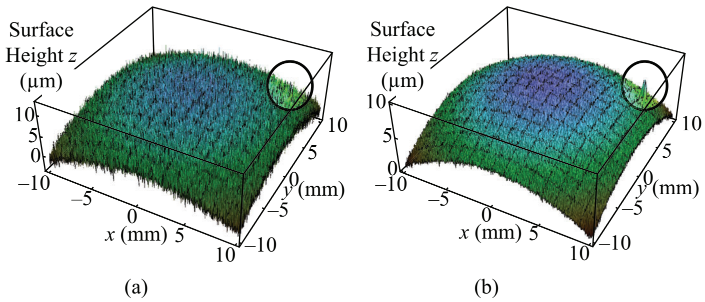

Figure 1. *Metrological measurements have some unavoidable noise, which can hide small surface features (a). Some of these features can be recaptured through the use of statistical noise reduction (b). The feature is in the circled area on these graphs.*

We have identified three components of the difference between the measured and nominal values of a surface. First is the actual deviation of the surface from the design. This is a constant value and cannot be removed by statistical means. The second component is possible offsets or other constant errors in the measurement system. These also cannot be removed statistically, but can be minimized by careful calibration. The final component is random error, or noise. This cannot be reduced by calibration or even, in many cases, by better resolution; this is the error source that is reduced by statistical noise reduction.

We demonstrated noise reduction by measuring the surface of a 1.5-inch diameter calibration sphere whose surface was estimated to match the nominal sphere to an accuracy of ±1 thousandth of an inch (±25.4 μm). Initial measurements using a Cognitens WLS400 metrology system[3] made by Hexagon Metrology showed accuracy of ±1.45 thousandths (±36.8 μm). Using our statistical process to reduce measurement noise by a factor of eight improved the surface accuracy to ±1.24 thousandths (±31.6 μm). Statistical analysis indicated that the actual surface deviation from nominal was ±1.23 thousandths (±31.2 μm), still outside of specification (which was not really a surprise, since the calibration ball measured had noticeable scratches and dents due to long use). Figure 2 shows the noise reduction. We should note that calibration spheres are normally specified only as to average diameter, and our analysis of the measurement data indicated that the sphere diameter was 38.100±0.002 mm, or 1.50000±0.0001 inch, which met the specification of the calibration sphere.

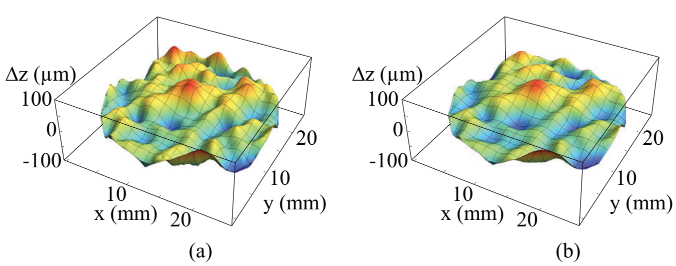

Figure 2. *We reduced the 2σ delta deviation (Δz) of a battered calibration sphere from a raw measurement value of ±36.8 μm (a) to ±31.6 μm (b)—within 1% of the actual value of ±31.2 μm—by applying statistical noise reduction.*

In summary, we tested our technology using measurements from a number of metrological instruments, and showed that noise reduction can help find surface features that would be hidden in the noise without the statistical enhancement. In one example, mapping the surface of a battered calibration sphere, we reduced the random noise by a factor of eight, and used statistical analysis to determine the actual surface figure. We are currently working with manufacturers of metrology software to integrate our technology into their products.

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1. R. Tutsch, M. Petz, and M. Fischer, *Optical Three-Dimensional Metrology with Structured Illumination*, **Opt. Eng. 50** (10), p. 101507, 2011. doi:10.1117/1.3578448.

2. R.M. Kurtz and R. Nesbitt, *Improving the Accuracy of Surface Metrology*, **Opt. Eng. 50** (7), p. 073605, 2011. doi:10.1117/1.3602901.

3. Cognitens, *Cognitens WLS400M Product Brochure*, 2011, available at http://www.cognitens.com/cognitens-wls400m_628.htm.