Why steps are like cutting a map in half when using fringe-based measurement techniques

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Step Limitations of Fringe-Based Measurement Systems

Many of the most precise measurements systems for 3D surface characterization use ‘fringes’ as their ruler to equate the signal received from a sample, to surface shape or texture. The underlying technology used by such systems may go by several names depending on the exact construction of the measurement device:

- Interferometry
- Fringe projection
- Structured Light
- Polarized structured light—as in the case of 4D InSpec and 4D InSpec XL

All of these systems in some way use a periodic pattern to reconstruct a 3D surface. The pattern is usually sinusoidal, but it can be just binary, black-and-white stripes. Simple systems construct a 3D representation of a surface by looking at how the pattern bends across the part under test.

The easiest way to visualize the process is to consider something very similar to these systems, which is a topographical map, as in Figure 1. In topographic maps, each line represents a specific height. This is true as well for fringe-based systems like the 4D InSpec: each bright or dark fringe represents one specific height on the surface.

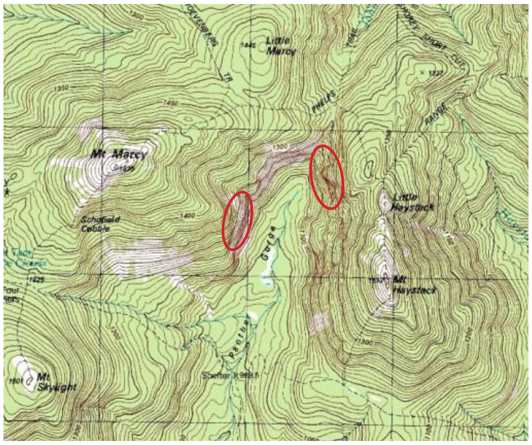


Figure 1: Topographic map of a mountain. In the circled areas, the height changes are so severe the lines all blur together.

Advanced systems don’t just use binary stripes but additionally, they use the phase of the signal, which is a measure, pixel by pixel, of the distance from the brightest points of the pattern. In phase models, each transition in brightness in the periodic pattern, from bright, through dark and back to bright, represents a specific, known, height change. Plotting the heights graphically allows the creation of a 3D representation, where each pixel’s height is known relative to the others.

The method produces systems which are among the most repeatable and accurate measurement systems available. The process suffers from one primary limitation, however. Each dark/bright stripe fundamentally looks the same to the system, so only ‘continuous’ surfaces—those whose pixel-to-pixel height changes aren’t too great—can be perfectly measured. Height calculation errors occur between surfaces with large steps, or have gaps between two islands of data, or possess very steep slopes.

For the 4D InSpec, the limitation on slopes and steps is that, from one pixel to the next, the height cannot change by more than 180 micrometers (.007”). For the 4D InSpec XL, the limitation is 340 micrometers (0.013”). Even so, smaller steps can be unknown, if there are gaps in the data. Gaps can be void areas between unconnected regions. Filling in a void by lowering the signal threshold to allow noise doesn’t solve the uncertainty. The two disconnected zones cannot be related to one another, even if the step is small.

The problem of steps

In Figure 1's topographic map, the height in most areas is easily calculated, by finding a reference number and counting the lines of difference between it and your area of interest. However, in the circled areas, the slope is too steep and the individual lines blur together so much that you don't know the slope within that region.

Attempting to assess the full height step, from the bottom of a cliff to the top, is also impossible unless some lower-sloped areas surrounding it to allow you to connect the two elevations in a roundabout manner.

Discontinous data is like a map that has been cut in half, as in Figure 2. Without knowing by some outside reference that the parts are related, you are unable to determine the relative height difference across the gap.

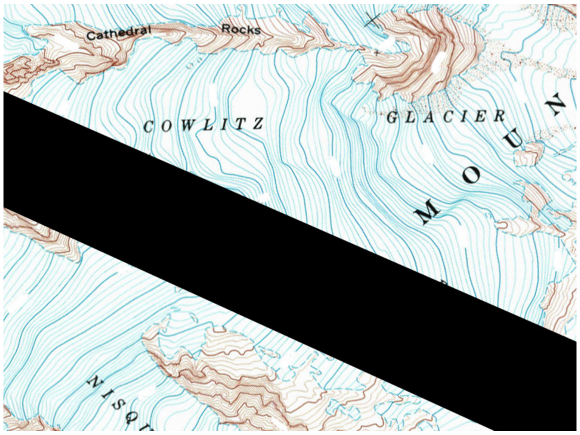


Figure 2: Gaps in the data: without continuity between the lines connecting Nisqually and Cowlitz Glacier, it's not possible to know which areas are at the same elevation, between the two.

Fortunately, 'perfect' steps rarely occur in the real world, except for specially manufactured steps. Pits, scratches, dents, nicks, chamfers and edge break almost always have some slope to them, so that 4D InSpec systems can in fact measure height changes that are quite large, with no errors. However, using a 'perfect' step to try to verify the accuracy of these systems is actually one of the only ways to make the measurement fail.

Below are a couple of actual examples of steps measured on an interferometer or other fringe-based system (Figure 3). Unfortunately, each dark or bright line looks the same, mathematically. For instance, in the simpler image in the left of Figure 3, the center section might differ in height from the edges by 1/10th of the fringe spacing, or 11/10th of the fringe spacing, or 111/10th of the fringe spacing – you don't know how steep the transition is. In the image to the right, again each time there is a sharp step, it could mean a fairly small height change, or a large one. This is why stepped surfaces can cause errors in the height calculation.

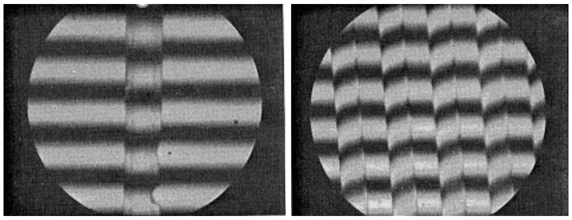
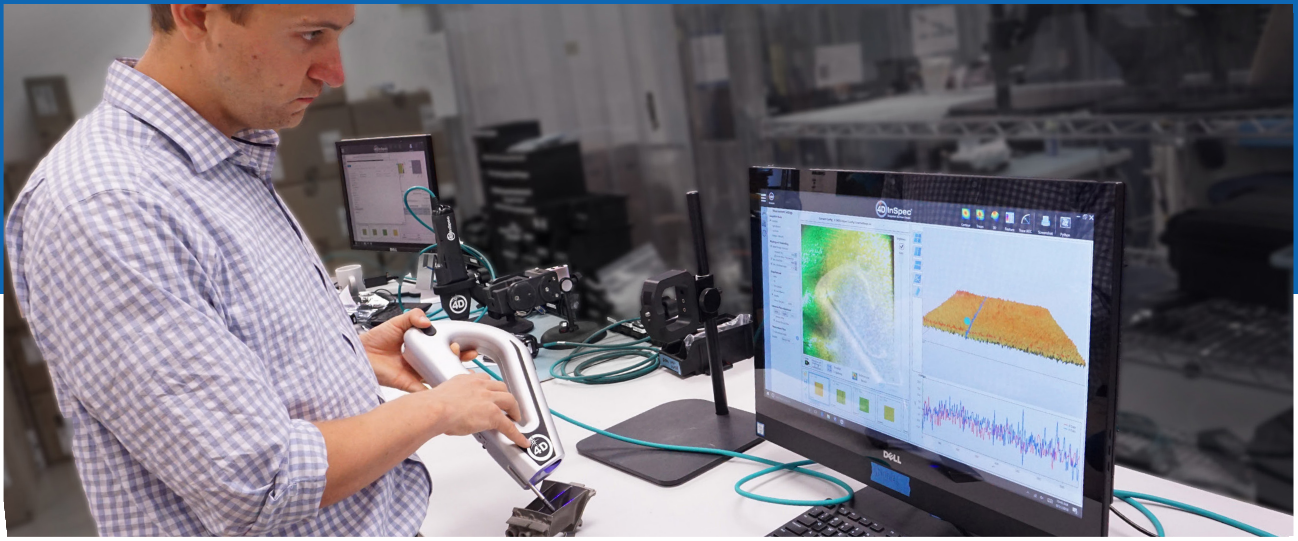


Figure 3: Left: Center area may differ in height from each side, and each side from the other, by any multiple of the fringe spacing. Right: More complex shape, but again, one cannot know the exact difference in height between the stepped zones.

Measure well, and get better parts yield



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