Color calibration in 3d computer vision

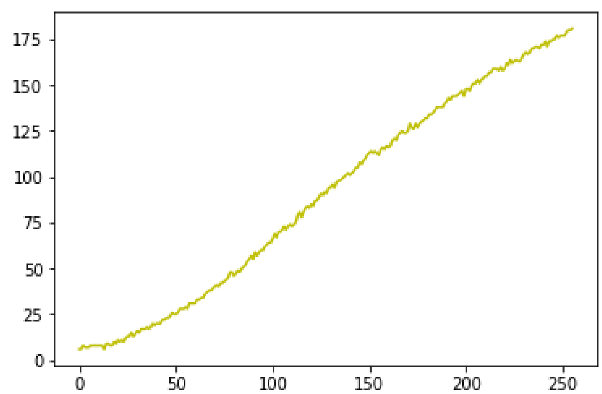
fringe: projector + camera color calibration

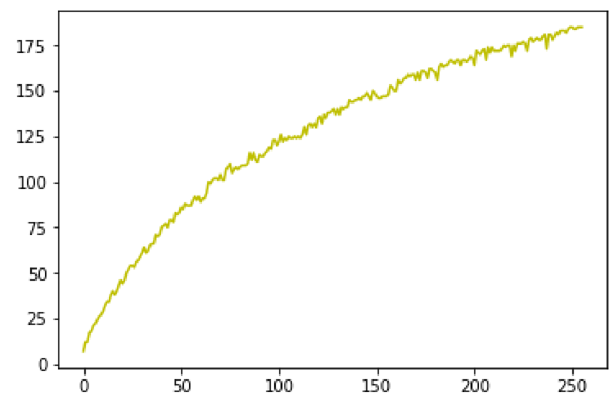
Many of the algorithms in computer vision use pixel intensities to perform measure a scene geometric property or to do 3D reconstruction. The images are captured using cameras and optionally also involves other optical hardware like projector. While, one uses the pixel intensities to perform calculations, one tends to disregard the fact that these intensities are not the true values representing the captured scene but an outcome of the interaction of the scene intensities and the device characteristics. Geometric and chromatic distortions are one of these characteristics that need to be corrected for finding an accurate pixel value but the device characteristic that largely affects all the scene intensities is the gamma of the optical device. It is a non-linear relationship between pixel value and actual luminance in the scene and helps in displaying image closer to our perception of the scene. This results in the darker pixels getting more enhanced that than the brighter pixels and hence differs from the true representation of the scene. Our visual system is more sensitive towards darker intensities than brighter ones and gamma encoded images try to bring the captured image closer to how our visual system would have perceived. But this nonlinear mapping may not useful for carrying out calculations and measurements in the real scene. We can perform color calibration to linearize the optical device response and use the true luminance values for calculations. We investigate few computer vision algorithms as test cases and observe how color calibration affects the results.

One of the areas in 3D computer vision is 3D reconstruction using structured light where we typically use more than one optical device. We generally use a projector to project structured light patterns and a camera that captures the structured light projected object. One of the methods to do 3D reconstruction using structured light is fringe projection, where we project, and capture phase shifted sinusoidal fringes on the object. We calculate wrapped and unwrapped phase, subtract it from a reference plane and finally scale it to get its 3D reconstruction. The projector is an inverse of a camera and has a gamma associated with it. The pixel intensities we want our projector to project as a sinusoid would get non-linearly mapped to produce different intensities than we desired. Similarly, the camera needs to capture the sinusoids-projected image, but the intensities are again mapped non-linearly to values that no longer is a perfect sinusoid. For the algorithm to work to calculate accurate phase maps, we need to have an accurate fringe-captured image. In other words, we need our device to have a linear response between the input and the output. We can perform color calibration individually to the camera and the projector in order to linearize them and then use the captured intensities to find phase maps.

We performed the experiment and studied the relationship between digital pixel values sent to the projector and pixel values captured by the camera. Here are few observations:

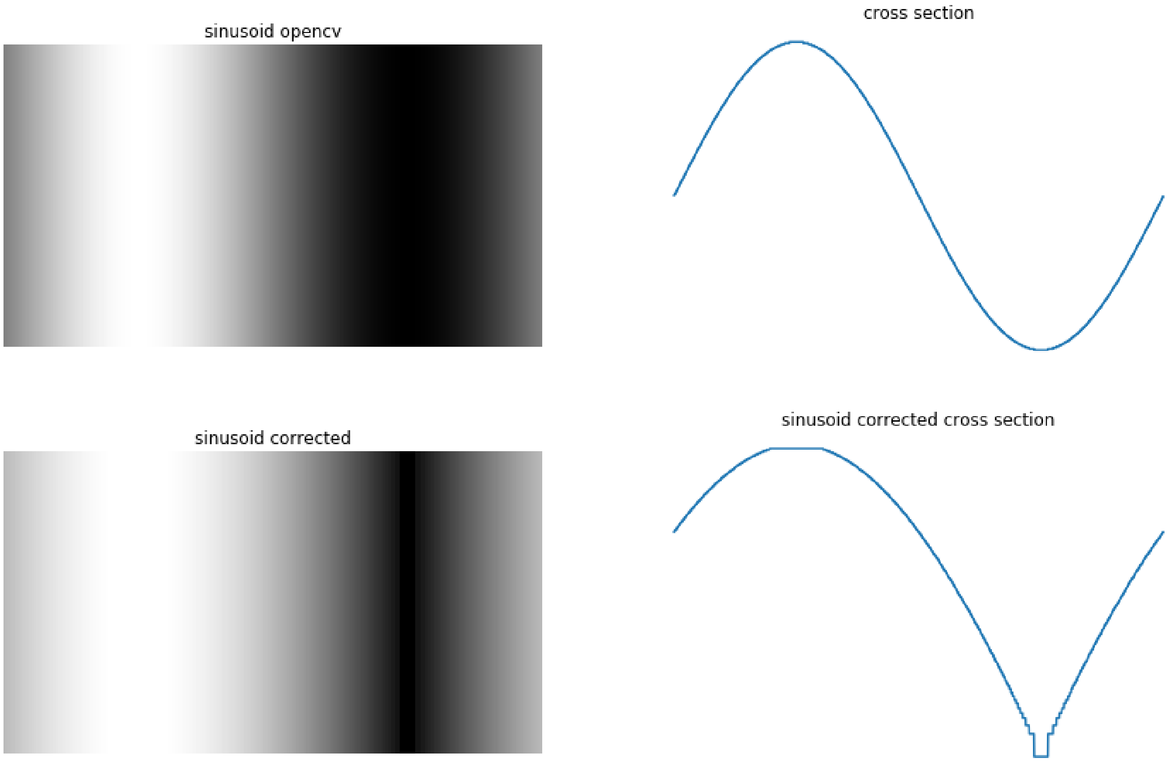
1. It was interesting to see that the gamma of the camera and the gamma of the projector when seen as a system tends to complement each other's effect and produce a linearized response. In order to understand how non-linearized response would affect the results, we did color calibration on the projector so that as a system the camera-projector is no longer linear and observed the results. We projected gray scale uniform images ranging from 0 – 255 and observed intensities captured by the camera. We did this for both uncalibrated and projector-calibrated values. We found that the uncalibrated version gave a more linear response than the projector-calibrated one.





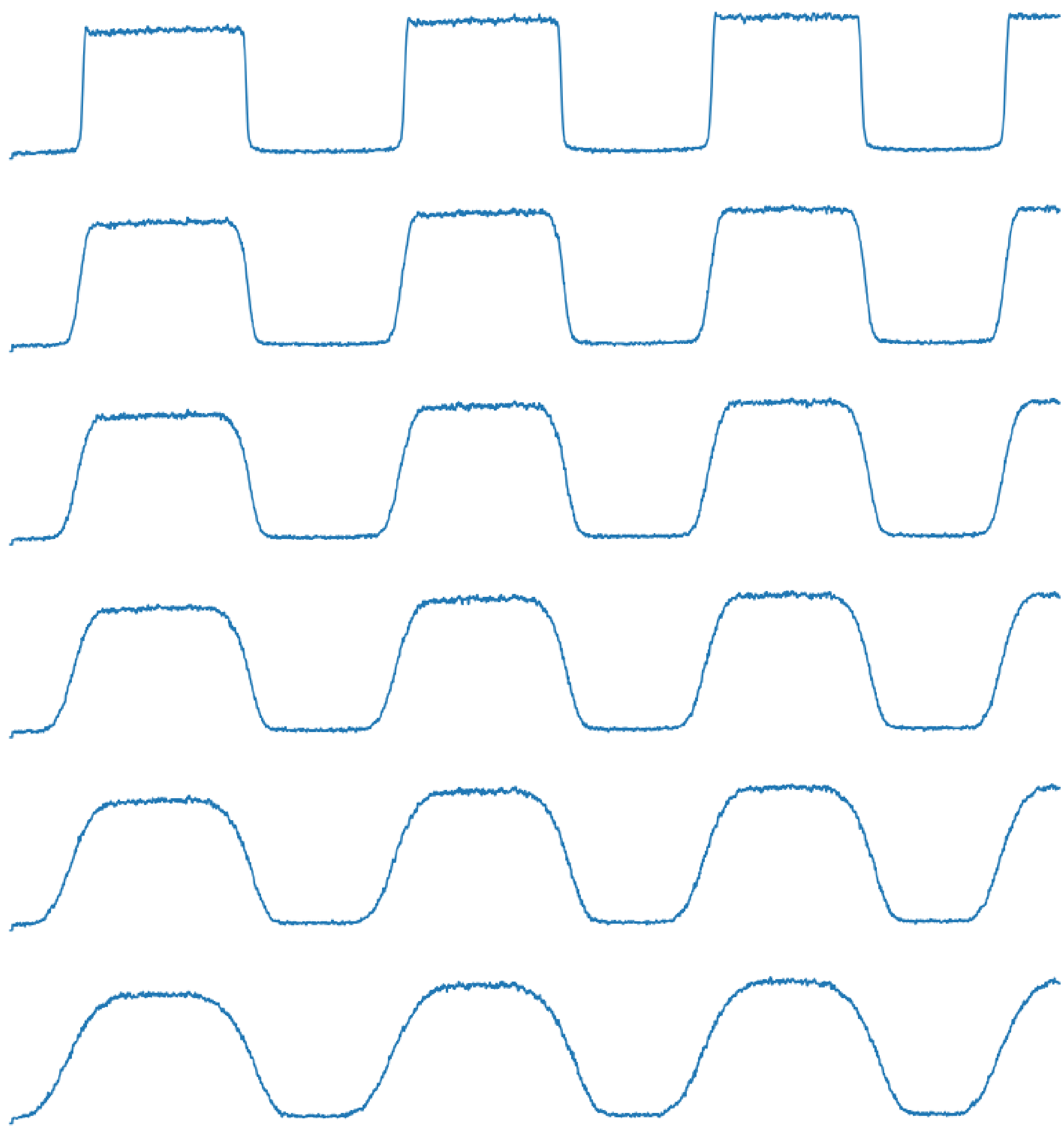
Left: Uncalibrated system camera response, Right: Projector-calibrated camera response.

2. It is important to consider the range of values captured by the camera of the projected sinusoids. We observed that the when we tried to capture projector calibrated values, they were not in the range 0-255 but clipped at a large and quantized at a smaller value. We need to ensure that we project intensity values such that the captured sinusoid lie in the required range of the camera (in our case the camera produces 8-bit image, so 0-255).



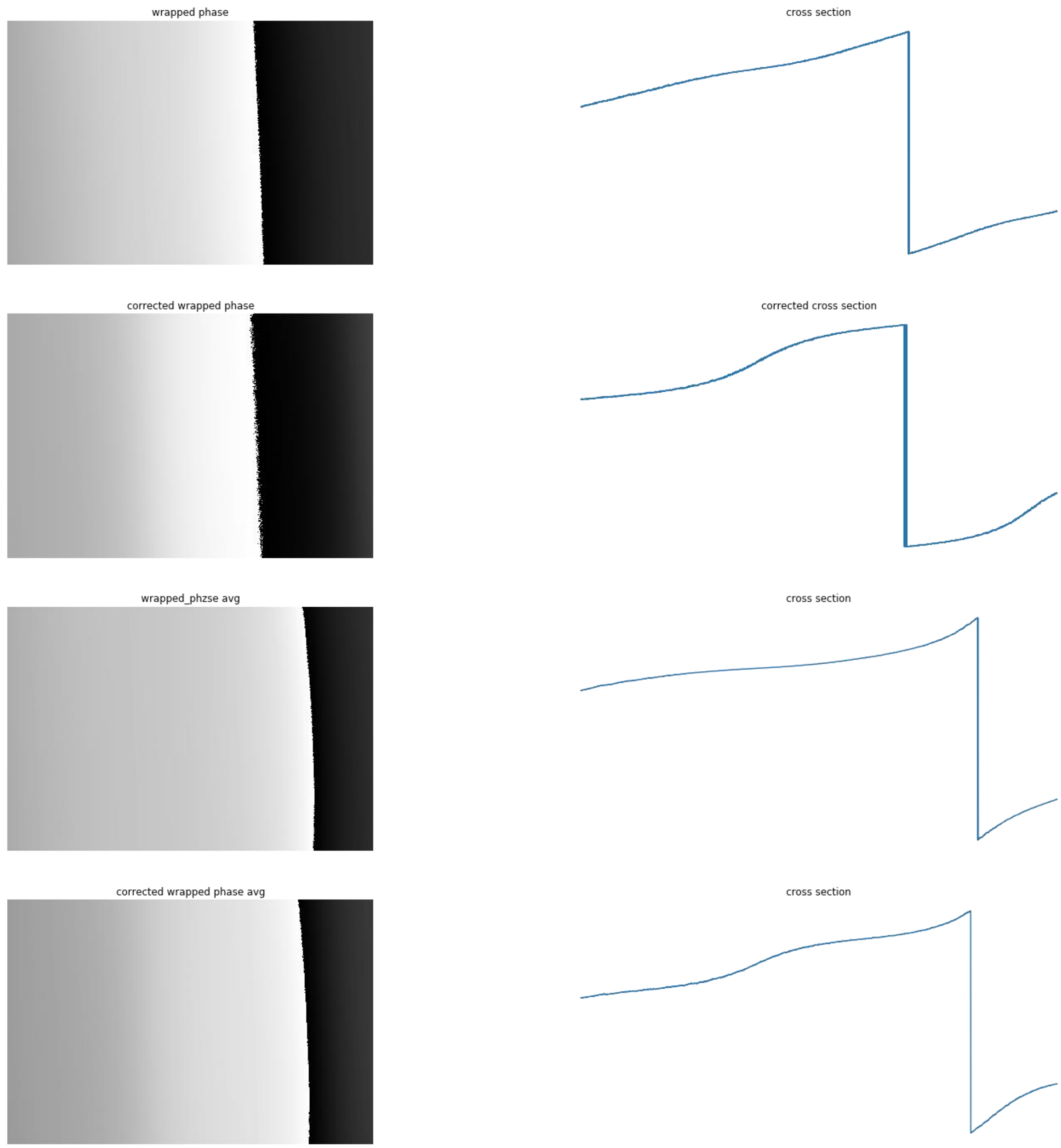
Top: Ideal sinusoid, Bottom: Projector-calibrated and camera captured sinusoid

3. Ideally, sinusoidal fringes can also be created by blurring a square wave to get a smooth sinusoid. This did not have much effect for our setup.

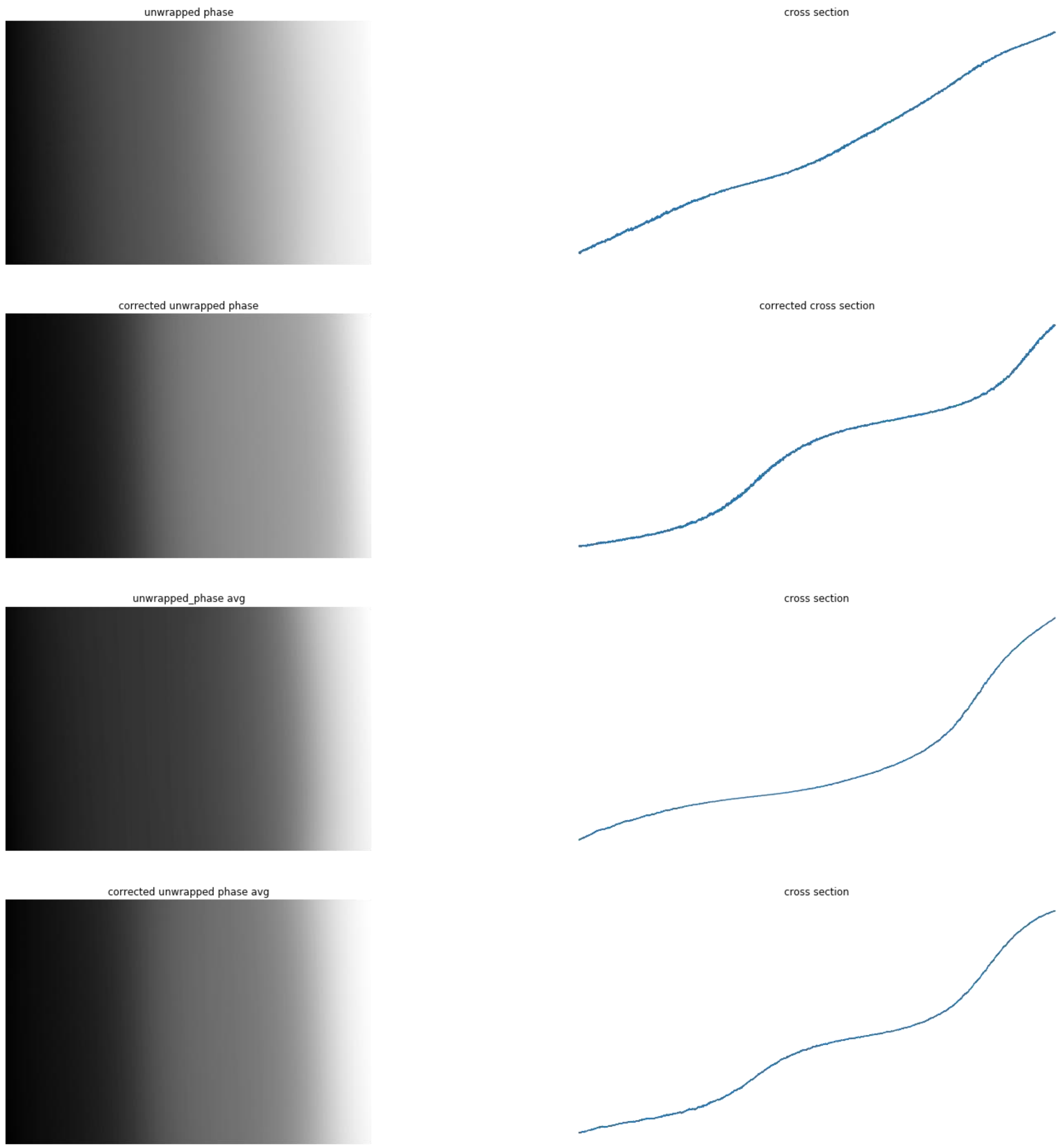


Gradual blurring and projection of square wave to produce sinusoid

4. One more experiment we carried out was to test if the variations are due to the device non-linearity or due to internal and external noise. We captured a set of uncalibrated and projector-calibrated sinusoids and averaged them together. Surprisingly, the variations increased and were more pronounced.

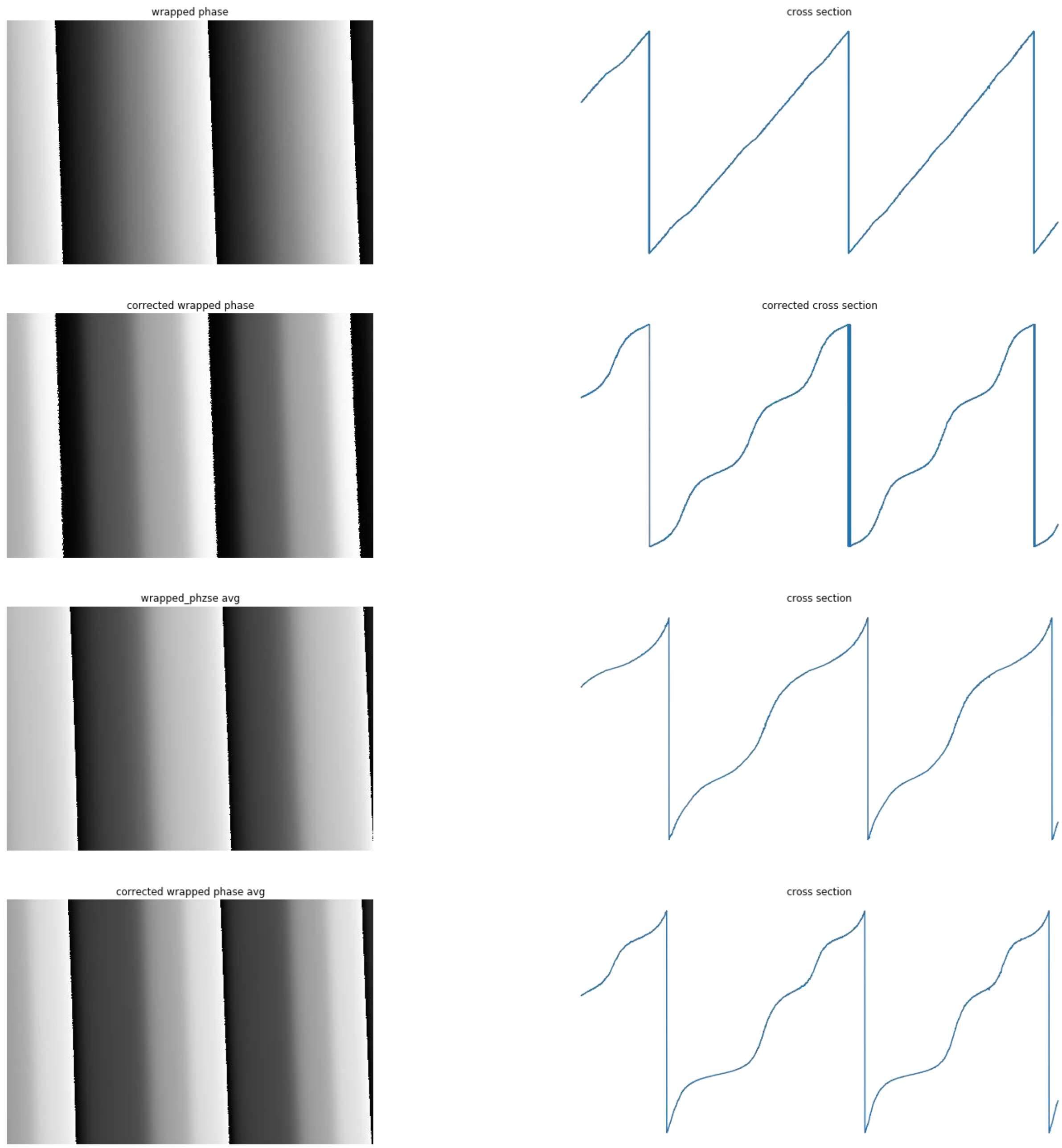


From Top: 1. uncalibrated system wrapped phase, 2. projector-calibrated system wrapped phase, 3. Uncalibrated system average wrapped phase, 4. Projector calibrated system average wrapped phase, and their cross sections



From Top: 1. uncalibrated system unwrapped phase, 2. projector-calibrated system unwrapped phase, 3. Uncalibrated system average unwrapped phase, 4. Projector calibrated system average unwrapped phase, and their cross sections

The system behavior depends on the hardware. To see the effect, we carried same experiment carried Nikon 18-55mm zoom lens. The uncalibrated unwrapped phase looked nicely linear, but the others had more distortions compared to our previous canon setup.



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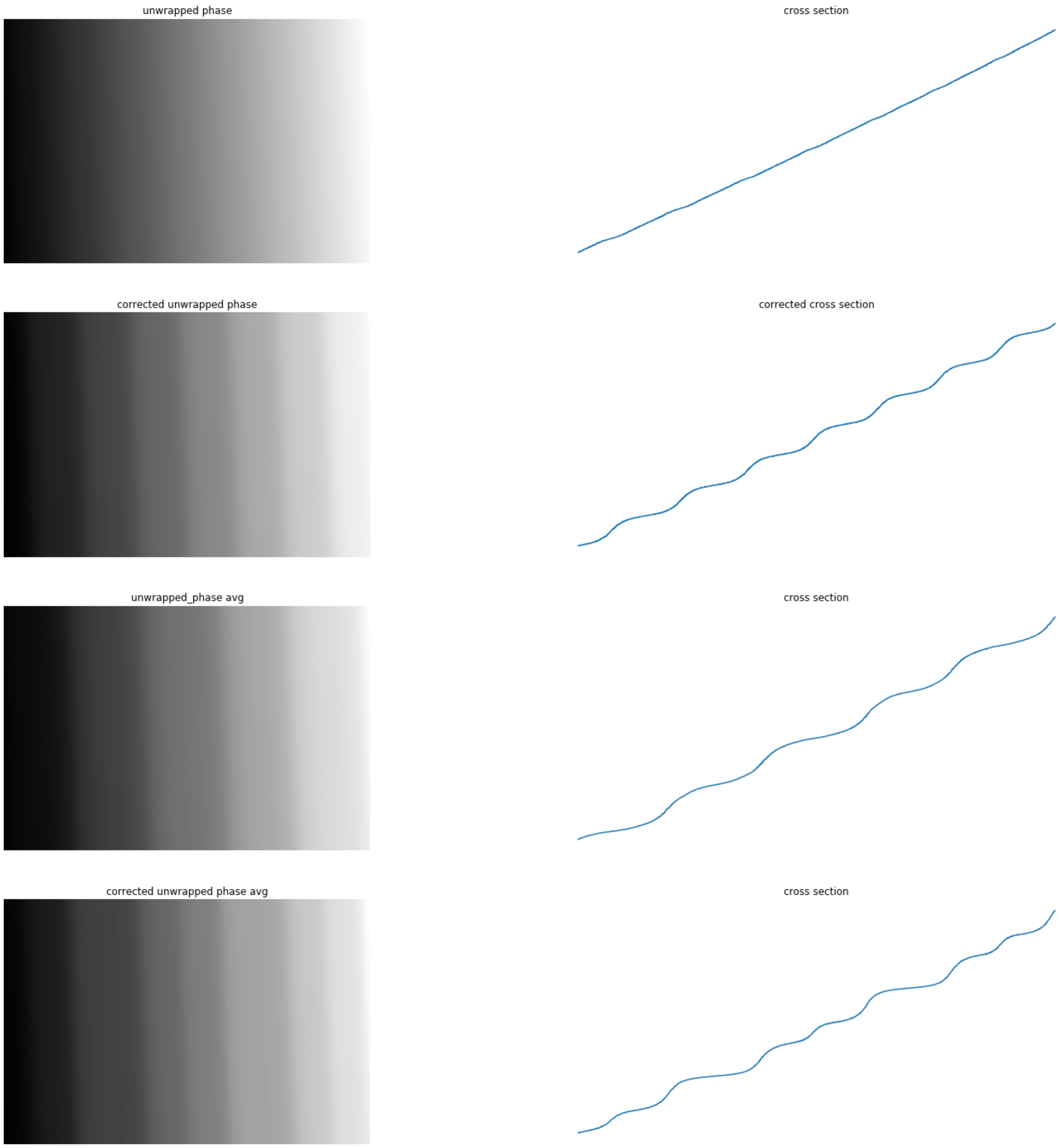

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- Contrast sensitivity – higher frequency fringe reduces the contrast.