Chapter 14
Using Anti-aliasing Camera Filters for DIC: Does It Make a Difference?

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Abstract Aliased speckle patterns are a known problem for digital image correlation (DIC). By definition, aliased speckles are smaller than the resolution limit of the camera and add "noise" to images via the spatially-aliased frequency content. Aliased speckles occur quite frequently in practical DIC applications, especially when using spray paint to speckle a surface, where control of the speckle size is difficult at best. This paper compares DIC results from aliased speckle patterns imaged with typical machine cameras with and without physical anti-aliasing filters applied to the camera detectors. Additionally, physical anti-aliasing filters are compared with post-processing, digital low-pass filters of aliased images to quantify the influence of the two types of filters on the quality of DIC results. A key result from this work is that the loss of contrast associated with the addition of physical anti-aliasing filters is generally more detrimental to DIC results than the noise resulting from aliased speckles.

Keywords Digital Image Correlation (DIC) • Full-field • Optical methods • Uncertainty quantification (UQ) • Aliasing

14.1 Introduction

Digital image correlation (DIC) is a full-field displacement and strain measurement technique that uses a digital image of a "speckle" pattern for tracking the underlying motion [1]. The quality of the results relies on the quality of the acquired images, namely the contrast provided by the speckle pattern. This speckle pattern is often applied using a spray paint can and lightly misting the surface. This can create a nice contrasting surface; however, controlling the speckle size is often difficult, and speckles that are too small often result. Additionally, in attempts to increase the spatial resolution of the measurement, speckles are often created that are at the digital sampling limit of two pixels. In both situations, speckles that are smaller than the minimum of two-pixels occur causing the image to be aliased. There is theoretical work on the influence of aliased and undersized speckles on the interpolant and the corresponding bias errors [2]; however, there has been little or no experimental work on this topic. This brief paper looks at an experimental setup that includes three machine vision cameras with two levels of antialiasing filters and an unfiltered camera to investigate the influence of aliased speckles on the DIC results.

14.2 Experimental Setup

The experiment consisted of three PointGrey 5-Megapixel cameras with identical Schneider 35-mm lenses. Camera 1 had no antialiasing filters, Camera 2 had a 2-pixel (2Lambda) birefringent blur filter mounted in front of the detector, and Camera 3 had a 4-pixel (4Lambda) blur filter. These filters were designed for the 3.45-μm pixel size of the machine vision camera. To confirm the relative filtering of the antialiasing plates, an Airforce target was used to measure the modulation transfer function (MTF) of the camera and lens system. Figure 14.1 is the MTF of the three systems showing that the resolution of the unfiltered camera is approximately 7.2 line pairs/mm (lp/mm), and the other two are 5.6 and 3.6 lp/mm respectively. The resolution represents the resolving power of the optical system with speckles that are smaller than the resolving limit being filtered out of the image. The cameras were setup to observe a 100-mm field-of-view (FOV) with three different speckle patterns that are observed simultaneously by all three cameras. One pattern was printed with a speckle size of 354 μm or approximately 6-pixels across the speckle to be fully resolved by all three cameras. The aliased pattern was printed with

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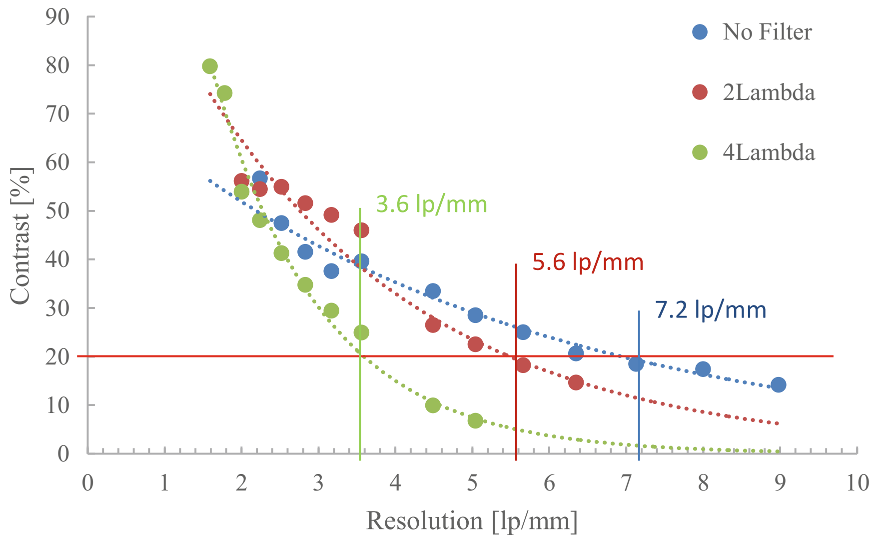

Fig. 14.1 Modulation transfer function (MTF) of the three camera systems

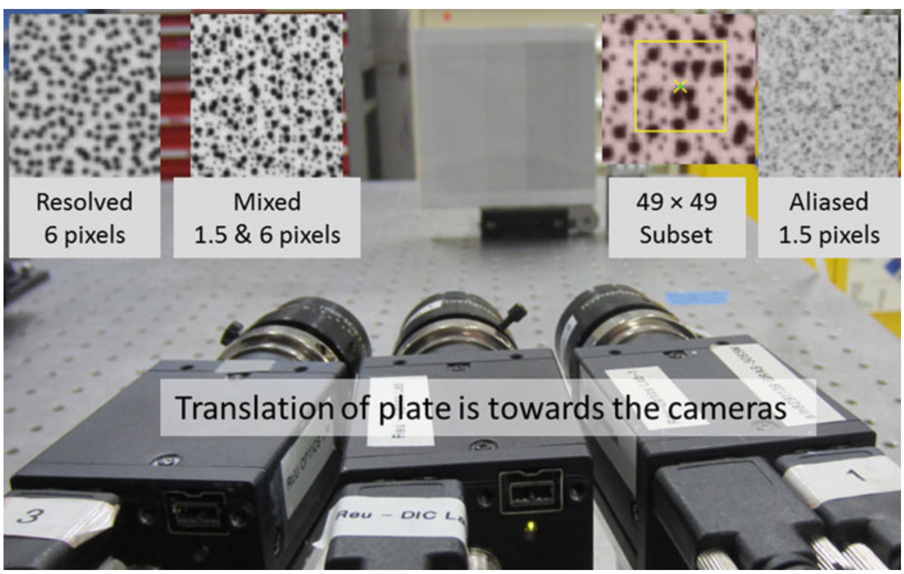

Fig. 14.2 Experimental setup showing three cameras observing a 100-mm FOV with three different speckle patterns as illustrated in the insert. The DIC subset size is shown overlaid on the mixed speckle pattern a close-up

a 78 μm speckle or 1.5-pixel diameter speckle. The third pattern was a combination of the large and small speckles into a single pattern to represent a situation where there are both aliased and non-aliased speckles, a situation that often occurs when spray painting speckle patterns. The three speckle patterns and the experimental setup are shown in Fig. 14.2. The three speckle patterns were then translated towards the cameras using a linear stage and precision micrometer to create a uniform stretch of the image in the *x*- and *y*-directions. This uniform stretch allows one to easily observe the influence of the interpolation bias error on the results and also provides a uniform displacement and strain field for analysis without the need of expensive precision translation stages.

14.3 Results

The images for the three cameras were analyzed using standard subset based commercial DIC codes. The subset size was 49 pixels, the step size was 10 pixels, the strain window was 15 data points yielding a virtual strain gage size of 189 pixels. An affine shape function was used with two different interpolation functions, a bi-linear interpolant and an optimized interpolant. The bi-linear interpolant was chosen because of its poor performance with respect to aliased images. The optimized interpolant was used to show how a more typical (and better) interpolant interacted with the speckle patterns and the three camera images.

Figure 14.3 shows the strain bias errors for the linear interpolant for all three cameras and all three speckle patterns as labeled in the image. The scales are identical showing the relative bias errors between the different patterns and the effect of the anti-aliasing filtering on the results. The tabulated results for the linear interpolant are shown in Table 14.1 and are the peak-to-valley bias error from a line cut in each region of the image. The aliased speckle pattern is clearly the worst for linear interpolants for all three cameras. However, the anti-aliasing filter does not improve the results as may be expected. This is because the loss of contrast from the filtering of the under-resolved speckles has a more dramatic influence on the results than the deleterious influence of the aliased speckle information.

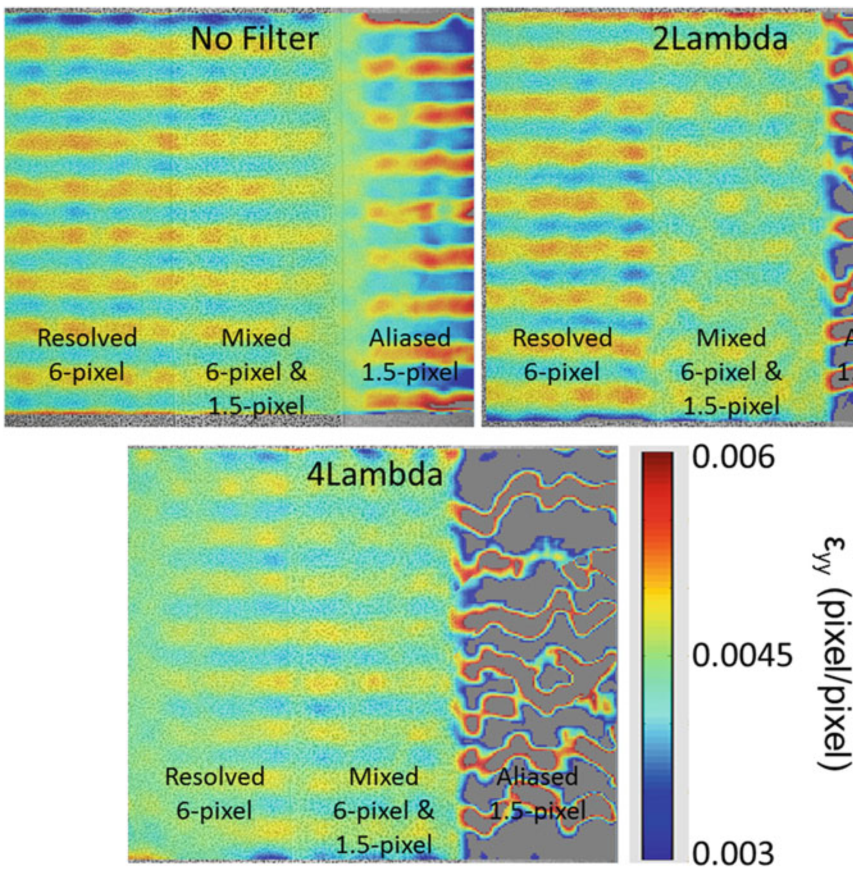

Fig. 14.3 Strain results (ε_{yy}) for all three cameras and all three speckle patterns with a bi-linear interpolant. Scales are identical showing the relative magnitude of the interpolation bias error in the strain field

Table 14.1 Strain bias errors (in microstrain) caused by the aliased images using a bi-linear interpolant. Peak-to-Valley strain error is reported

Filter	Aliased Speckle	Resolved Speckle	Mixed Speckle
None	4520	1309	1388
2Lambda	5393	1182	808
4Lambda	7437	590	589

Table 14.2 Strain variance error using the optimized interpolant

Filter	Aliased Speckle	Resolved Speckle	Mixed Speckle
None	100	49	33
2Lambda	333	56	85
4Lambda	899	41	43

For the fully resolved speckles, the anti-aliasing filter improves the results for the bi-linear interpolant, and has no influence with the optimized interpolant. This is most likely because there is no loss of contrast, because the speckles are fully resolved; however, the edges of the speckles, which in the printed image have hard edges, are filtered and softened. This improves the ability of the interpolant to be able to fit the contrast gradients. Table 14.2 presents the tabulated results of the strain variance in the three speckle regions for the three cameras. There were no noticeable bias errors for the optimized interpolant.

For the mixed speckle patterns, with both aliased and fully-resolved speckles, anti-aliasing does seem to improve the results for the linear interpolants. This is because removing the aliased information helps, while there is less loss of contrast due to the presence of the fully-resolved speckles. For the optimized interpolant, there is no improvement from the anti-aliasing filters.

14.4 Conclusions

It has been known that aliased speckles, and speckle size in general, has an influence in the quality of DIC results. This short study confirms those results. Aliased speckles, for either an optimized or bi-linear interpolant (and presumably all interpolants) negatively impact the DIC results. For bi-linear interpolants, where the bias errors are larger, the results are clearly seen in the greater peak-to-valley errors for the aliased patterns regardless of whether there is an antialiasing filter. For the optimized interpolant, the strain noise is worse for aliased speckles, again regardless of whether there is filtering. However, for the optimized interpolant, adding the antialiasing filter actually made the results much worse than having no filter when aliased speckles were present. This was true of the bi-linear as well but to a much smaller extent. This is because the loss of contrast in the image due to filtering out the small speckles is worse than the influence of the speckle aliasing.

For fully-resolved speckles, filtering has a 2× improvement for the bi-linear interpolants, and a very modest improvement on the optimized interpolants. This was again approximately true for the mixed speckle pattern.

These results were somewhat surprising as it was theorized that removing aliased content would greatly improve the results. This is only true when a "bad" interpolant is used for the analysis. When a good interpolant is used, the gains are relatively modest. This is again because the loss of contrast has a larger influence on the results than the added noise of the aliased information. This study does confirm that having an aliased speckle is much worse (approximately 3×) than having a larger and fully resolved speckle. Therefore, aliased speckles should always be avoided. Finally, with modern DIC software, it seems that adding an anti-aliasing filter to commercial machine vision cameras is not worth the added cost and effort.

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