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Effects of image compression on digital specklegrams

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Abstract

In order to solve storage problem in real-time optical metrology, storing digital specklegrams by using a lossy-joint photographic experts group image compression is studied. A spatial distribution of a correlation signal calculated from the compressed specklegrams is used as a criterion for evaluating quality of information content of the specklegrams. The results show that high quality of displacement information is retrievable from the compressed specklegrams. © 2002 Elsevier Science Ltd. All rights reserved.

In the field of optical metrology, laser speckle and holography have been found to be very useful method for non-destructive testing and inspections [1]. Recently, with maturation of technology of detector arrays such as charge-coupled device (CCD) image sensors, real-time optical testing and inspections are indeed feasible. In these systems, the CCD sensors are used to capture either speckle or holographic interference patterns [2,3]. The captured patterns are then stored in memory of computer systems as electronic files in order to be further processed. However, in many real-world applications such as measurements of vibration of body and engine in automotive industries [4], we may deal with a huge number of measurements. In this case we may have storage problem, especially if the files must be kept for a long period of time. In order to solve this storage problem, a use of either huge storage capacity of memory system or data compression could be done. The first solution must be compensated at the expense of complex and expensive systems [5], while the second one is immediately applicable to current computer systems and low cost, because no additional hardware is required [6].

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For these reasons, our work is focused on a study of effects of lossy-image compression on double exposed speckle photographs or specklegrams. We evaluate quantitatively whether information content of the specklegram will be effected by the compression. If so, how small the specklegram could be compressed without causing significant degradation. In this study, a use of a lossy-joint photographic experts group (JPEG) compression algorithm is of principal interest because first the lossy algorithm produces a higher compression ratio, defined as the ratio of the size of the uncompressed file to the compressed file, than the loss less compression [6]. Therefore, it gives smaller file size. Second, digital cameras have changed the role of photography in scientific and industrial areas [7]. This is due to several advantages of digital cameras over conventional ones such as the quality is finally competitive than traditional photographic film-based cameras, digital cameras having built-in image compressor could take more pictures without worrying about the cost of film.

There are four step-processes performed in our study: first, the digitized specklegrams are optically generated from a specimen being displaced. Second, the generated specklegrams are compressed by compression software for given compression qualities. In the third step, a spatial correlation of the compressed specklegrams is digitally computed. The final step is to use a spatial distribution of a correlation signal as a criterion for evaluating quality of information content of the compressed specklegrams.

The generation of the specklegrams was done by using a 4f optical setup shown in Fig. 1 with an aperture placed at the Fourier plane used for controlling a speckle size. A speckle pattern was generated from a piece of ground glass illuminated by a He–Ne laser operating at a wavelength of 632.8 nm. The average size of the generated speckle was $\sim 25\,\mu m$. The image speckle patterns of the undisplaced and displaced ground glasses were captured by the CCD camera (Pulnix TM200) which consists of 768×494 pixels array. They were stored into a hard disk in a bitmap file format. By adding digitally two corresponding bitmap files, 370 kbyte digital specklegram was produced. In this work, two specklegrams having the displacement d of 40 and $80\,\mu m$ were generated and studied.

The second step is to compress the generated specklegrams into the lossy-JPEG file format by using the compression software Image Alchemy (Handmade Software, Inc.) [8]. In general, the lossy compression is achieved by quantizing high spatial-frequency components of image data in larger sampling intervals than lower frequencies [6]. In the Image Alchemy, the compression quality could be varied from

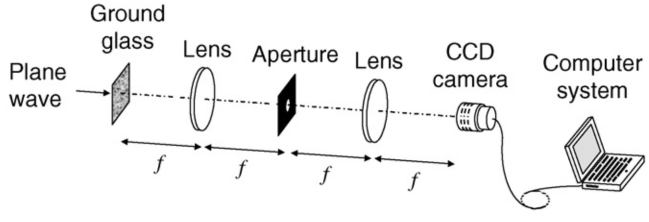

Fig. 1. Schematic diagram of the optical setup for generating specklegrams.

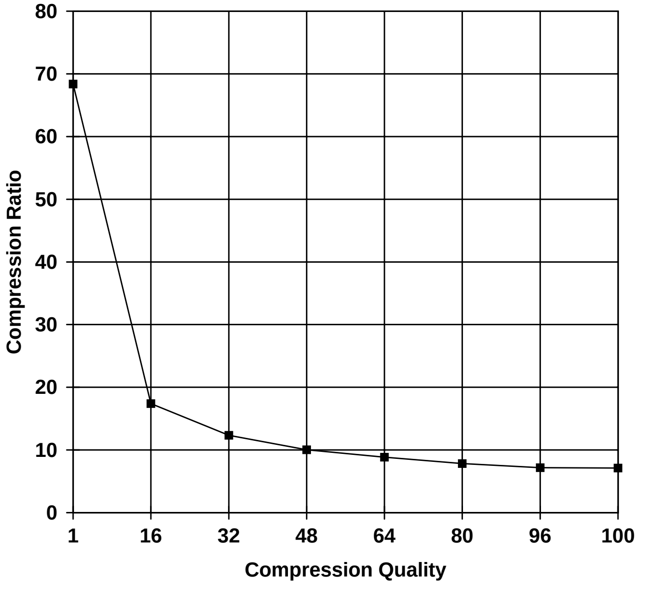

Fig. 2. Variation of the compression ratio as a function of the compression quality.

1 to 100, where a larger number of compression quality generates a slight loss or a higher image quality. In this case, the compression quality of the Image Alchemy is inversely proportional to the sampling interval of the quantization. Fig. 2 shows the inverse relationship between the compression ratio and the compression quality applied to our specklegrams. Higher number of the compression quality gives smaller compression ratio and it's vice versa. Figs. 3(a) and (b), for examples, show the original and the resultant compressed specklegrams having compression quality of 50, respectively. Although the compression ratio could be varied from about 7 to 70 times, it is obvious that a qualitative evaluation of these compressed specklegrams could not give any information of the image quality. Therefore, the specklegrams must be quantitatively analyzed instead.

In order to analyze quantitatively the information content of the compressed specklegram, a spatial correlation technique was employed. Although the desired information, such as magnitude and orientation of displacement, could be determined from the fringes generated from the specklegrams, the fringes are usually modulated by speckle noise. In order to obviate the noise problem, several algorithms discard some information of the specklegrams either by only analyzing a subset of the data or by reducing the image data using filtering operation [9,10]. On the contrary, the correlation technique employs whole image data in order to extract the information. Therefore, it is known to be the most accurate method for analyzing specklegrams [10]. In this work, the correlation was computed by first generating the fringes from the digital specklegrams. The fringes were then digitally Fourier transformed. Since the fringes were a power spectrum of the specklegram, this Fourier transformation gave autocorrelation. All computations were carried out by

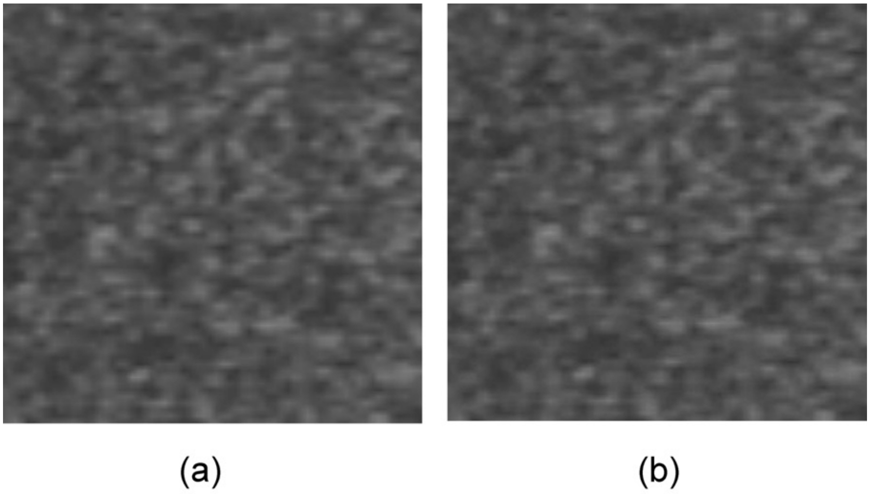

Fig. 3. Photographs of (a) uncompressed specklegram and (b) compressed specklegrams having the compression quality of 50.

Matlab 5.0 run on a personal computer. As the result, two off-axis correlation peaks with a central DC spot were obtained, where the distance between the peaks was proportional to the magnitude of the displacement, while its orientation corresponded to the direction. Note that the important point of the correlation method is that the displacement could be accurately measured provided the correlation peaks are sharp enough to distinguish the adjacent peaks [11]. Therefore as the final step in our study, we use the maximum peak and the full-width at half-maximum (FWHM) of the correlation peaks as our criteria to measure quality of the information from the compressed specklegram.

The maximum value of the correlation peak and the FAHM were then measured as a function of the compression quality, respectively. The results are shown in Fig. 4, where both measurements were normalized by its associated value of the uncompressed specklegram. It can be seen that regardless of the magnitude of the displacement, as the compression quality becomes lower, the quality of the correlation signals of both specklegrams degenerates: The correlation peak decreases, and the FAHM increases. This was caused by the quantization process of the lossy compression that reproduced high spatial-frequency information less accurately than the lower spatial frequencies. Since the high spatial-frequency information determined effectively the sharpness of the correlation signal in comparison to the lower one, the loss of the high frequency information degenerated the shape of the correlation peak. Subsequently, the accuracy of the measurement became lower. It is also obvious that when the compression quality is smaller than 32, the correlation peak decreases by more than 20%, while the FAHM becomes broader by more than 150%. By taking 10% peak reduction and broadening of the FAHM as the limiting criteria, the compression quality of 32 corresponding to the

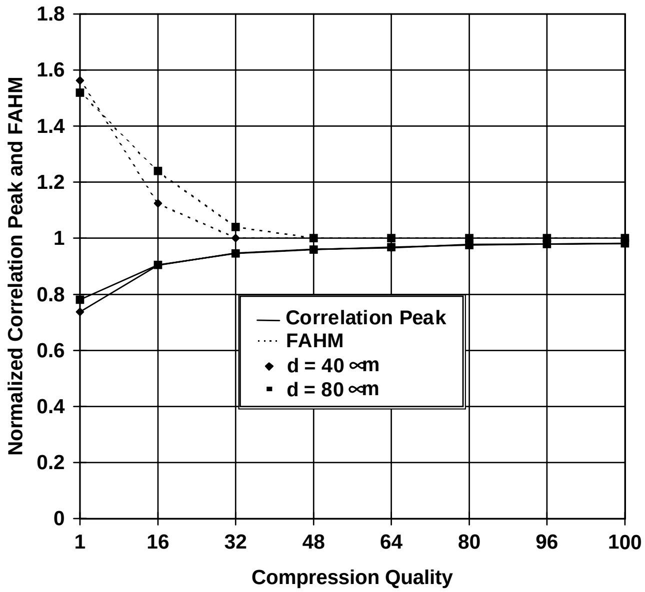

Fig. 4. Variations of the normalized correlation peak and the FAHM as a function of the compression quality.

compression ratio of about 12 may become the lowest applicable compression quality.

In summary, we have investigated quantitatively the effects of compression on information content of the specklegrams. The results show that accurate displacement information could still be obtained from the compressed specklegrams. From our evaluating criteria, the specklegram could be compressed about 12 times smaller without distorting significantly the displacement information. Finally, the results show a feasibility to store digital specklegrams as lossy-compressed files. This may solve the storage problem of the real-time optical testing and inspections.

Acknowledgements

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