รายงานการวิจัย

การศึกษาการบันทึกแบบดิจิตอลของออปติคอลซิกแนล:
ตอนที่1 ใช้คอมเพรสสเปคเคิลแกรม
Study of Digital Recording of Optical Signals:
Part I. Compressed Specklegram

ผู้วิจัย

หัวหน้าโครงการ

Assoc. Prof. Dr. Joewono Widjaja
สาขาวิชาเทคโนโลยีเลเซอร์และโฟตอนนิกส์
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สิงหาคม 2545

Acknowledgement

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บทคัดย่อ

เพื่อที่จะแก้ปัญหาในเรื่องพื้นที่จัดเก็บสำหรับมาตรวิทยาทางแสงแบบเวลาจริง จึงได้มีการศึกษาการ
จัดเก็บสเป็คเคิลแกรมเชิงเลขด้วยวิธีการบีบอัดภาพแบบสูญเสียขึ้น ในโครงการนี้สเป็คเคิลแกรมถูกสร้างขึ้น
ในเชิงแสงจากวัตถุตัวอย่างซึ่งมีการเคลื่อนไปจากตำแหน่งเดิม สเป็คเคิลแกรมนี้จะถูกจับภาพไว้โดยอุปกรณ์
ตรวจจับแบบถ่ายเทประจุ และถูกบีบอัดด้วยโปรแกรมบีบอัดตามค่าตัวประกอบคุณภาพที่กำหนด ลำดับต่อ
มาจึงคำนวณสหสัมพันธ์เชิงตำแหน่งของสเป็คเคิลแกรมซึ่งถูกบีบอัด ลำดับสุดท้ายการกระจายเชิงตำแหน่ง
ของสัญญาณสหสัมพันธ์ซึ่งถูกคำนวณจากสเป็คเคิลแกรมที่ถูกบีบอัดจะถูกใช้เป็นบรรทัดฐานในการ
ประเมินคุณภาพเชิงปริมาณข้อมูลสำคัญของสเป็คเคิลแกรมผลที่ได้แสดงให้เห็นว่าข้อมูลการกระจัดคุณภาพ
สูงยังคงกู้กลับมาได้จากสเป็คเคิลแกรมที่ถูกบีบอัด

Abstract

In order to solve storage problem in real-time optical metrology, storing digital specklegrams by using lossy-image compression is studied. In this project, the specklegrams are optically generated from a specimen being displaced. The generated speklegrams are captured by a charge-coupled device sensor and compressed by compression software for given compression quality. Next, a spatial correlation of the compressed specklegrams is digitally computed. Finally, a spatial distribution of a correlation signal calculated from the compressed specklegrams is used as a criterion for evaluating quantitatively quality of information content of the specklegrams. The results show that high quality of displacement information is retrievable from the compressed specklegrams.

Contents

Chapter 1

Introduction

1.1 Background and Significance

Laser speckle photography has been widely investigated in order to measure very small in-plane displacements and deformations of objects. In conventional speckle photography, a single photographic film is used for recording speckle patterns generated before and after displacements from a specimen being studied. Although photographic films have been widely used as a recording media, access time delay in developing process always becomes troublesome in many real-time optical systems. In order to overcome this problem, several interesting hybrid digital-optical architectures for implementing real-time analysis of speckle photography have been suggested. In these architectures, the speckle patterns were captured by using either a charge-coupled-device (CCD) camera or an optic random-access-memory detector. The captured speckle patterns generated before and after displacement were digitally added and then stored into a memory of a computer system for further processing. In real world applications, however, we may deal with a huge number of digital specklegrams that causes storage capacity problem. In order to solve this problem, use of either a huge storage capacity of memory system or a data compression could be done. The first solution must be compensated at the expense of complex and expensive systems, while the second one is low cost and is immediately applicable to current computer technology. For this reason, we consider the use of the data compression for solving the storage problem. In this project, we study quantitatively effects of data compression on information quality of the digital specklegrams.

1.2 Objective:

1. To study quantitatively effects of compression on digital specklegrams

2. To determine the smallest compression that can be done without causing significant degradation of information content

1.3 Scope

In this study, digital specklegrams having different displacement information are generated from a ground glass. The compression of the digital specklegrams is done by using a lossy-JPEG algorithm, because it produces a higher compression ratio than the lossless compression. A spatial distribution of a correlation signal calculated from the compressed specklegrams is used as a criterion for evaluating information content of the specklegrams.

1.4 Expected Benefit

The result obtained from this research project will significantly reduce practical and technical problems of application of laser speckle metrology in industries.

Chapter 2

Analysis

The correlation computations were carried out by Matlab 5.0 run on a personal computer. We used the maximum peak and the full-area at half-maximum (FAHM) 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 (See Appendix A).

Chapter 3

Conclusions

The results show that regardless the value of the displacements accurate displacement information could still be obtained from the lossy-compressed specklegrams. From our evaluating criteria, the specklegram could be compressed about 12 times smaller without distorting significantly the displacement information. Therefore, this may solve the storage problem of the real-time optical testing and inspections.

APPENDIX

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 μm 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
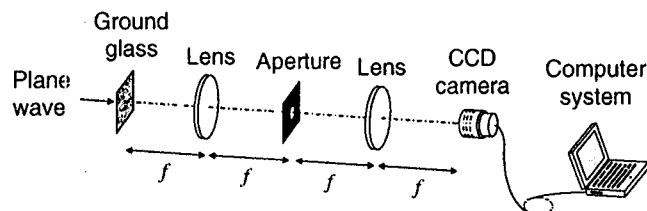

Fig. 1. Schematic diagram of the optical setup for generating specklegrams.
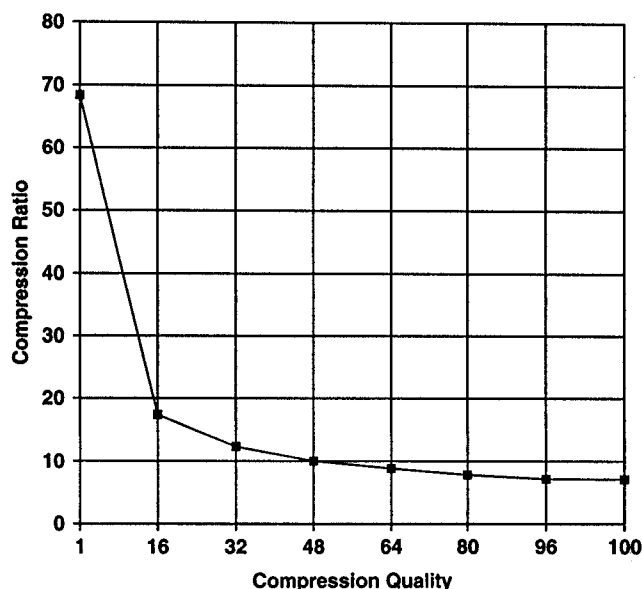
Fig. 2. Variation of the compression ratio as a function of the compression quality.

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
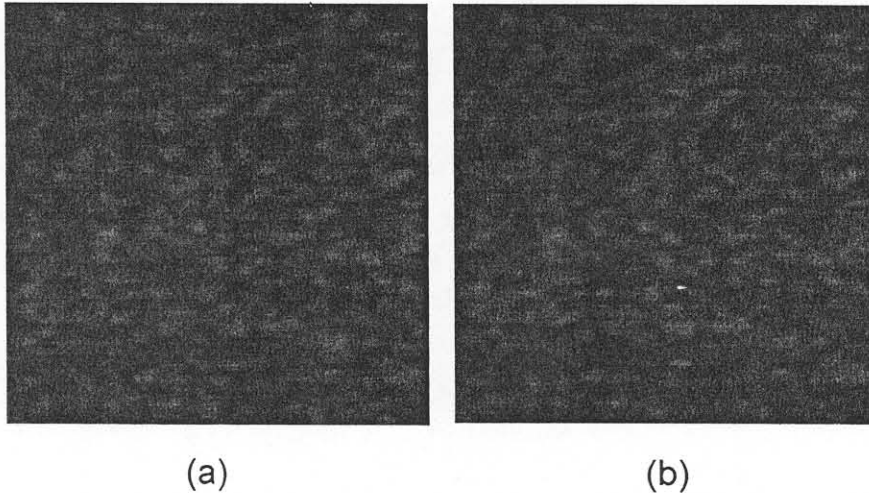
(a)   (b)

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-areas at half-maximum (FAHM) 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
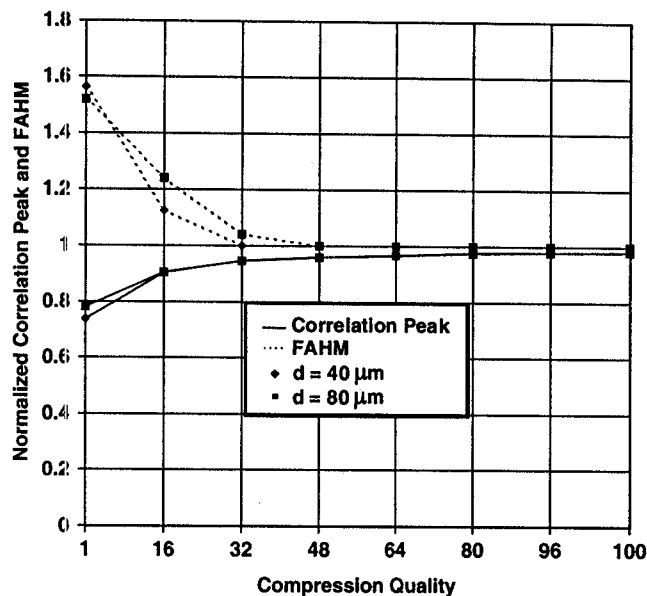
Fig. 4. Variations of the normalized correlation peak and the FAHM as a function of the compression quality.

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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