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# JPEG Compression Scheme in Dynamic Speckle Imaging

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**Abstract:** Application of the JPEG compression scheme to dynamic speckle patterns captured for visualization of faster or slower changes in 3D objects is analyzed. Compression efficiency is proven by simulation and experiment. © 2021 The Authors.

## 1. Introduction

Dynamic speckle imaging (DSI) enables visualization of areas with different speed of changes in micro-topography of a 3D object surface. This allows monitoring of industrial or biological activity. In the intensity-based pointwise implementation of the method [1], a measure of temporal correlation is built from the time sequence of intensity values at a given surface point. A 2D activity map is composed, that shows the areas of faster or slower temporal variations across the 3D object. Dynamic speckle on the object surface is a signal and noise simultaneously, and a large number of correlated in time speckle patterns are required to obtain a single map.

For the correlation-based DSI, correlation in time is important while correlation in space and the absolute intensity values are irrelevant. This justifies data compression, especially for monitoring of processes when many activity maps are built at consecutive instants. Recently, we proposed compression in the DSI by coarse quantization of intensity [2] and by binarization of the speckle patterns with a preset threshold [3]. In this work, we continue analysis of compression options in the DSI by checking applicability of the JPEG compression scheme.

## 2. JPEG compression of dynamic speckle data

The activity map in the DSI represents areas of faster or slower variations of intensity. Different algorithms can be used to build a map. For example, a 2D distribution of the estimate of the modified structure function (MSF) $S_M(i,k,m)=N^{-1}\sum_{l=1}^{N}\left|I_{ik,l}-I_{ik,l+m}\right|$ is determined from $N$ 8-bit encoded bitmap images, where $I_{ik,l}$ is the intensity at pixel $(i,k)$ of the optical sensor at instant $l\Delta t$; $1/\Delta t$ is the capture frame rate. To analyze JPEG compression, we simulated capture of a correlated sequence of speckle patterns for an object with two rapidly changing areas in the form of abbreviations “IOMT” and “ETRI” of the two institutions involved in this study; the logos were surrounded by slowly varying background (Fig.1a). Correlation in time is given by the normalized temporal correlation function, $\rho(\tau)=\exp(-\tau/\tau_c)$, where the time lag $\tau$ and the temporal radius $\tau_c$ are measured in units $\Delta t$. We used $\tau_{c1}=10\Delta t$ and $\tau_{c2}=100\Delta t$ to study the possible distortions introduced by the JPEG compression at high and low activity. The captured patterns of size 256 by 256 pixels at a wavelength $\lambda$ are obtained by Fresnel propagation of a light field diffracted from delta-correlated in space phase distributions, which are correlated in time. The averaging effect produced by the finite size of the camera pixels is also included in the simulation. A speckle pattern formed on the object surface under uniform illumination is shown in Fig.1b in bmp and jpeg formats. The logos are entirely obscured by the speckle fluctuations. The JPEG compression partition the simulated gray-scale speckle images into blocks of 8 by 8 pixels and changes spatial correlations of data within these blocks. This inevitably affects the activity map. However, the absolute values of the map entries are not important. Due to the speckle nature of the acquired data, the map exhibits strong fluctuations from point to point. For effective DSI, these fluctuations must have non-overlapping histograms of the MSF estimates at different activities. If this requirement is fulfilled after the JPEG compression, the latter is fully applicable in the DSI. We checked this issue for the object in Fig.1a at quality of the compressed jpeg images varying from Q = 5 to Q = 90. For comparison, we give in Fig.1c the activity map obtained at $\tau=10\Delta t$ from bmp images. The MSF correctly extracts the high activity areas. The MSF maps obtained from jpeg images at Q = 50 and Q = 5 are shown in Fig.1d and Fig.1e. The ratio $S_{bmp}/S_{jpg}$ between the sizes of the bmp image and the jpeg images exceeds 3 and 8 respectively. The areas of high and low activity are reliably separated in both case but the activity map at Q = 5 is covered with a regular grid of slightly higher values. This artifact is especially clearly visible in the background area and is obviously related to quantization of the coefficients of the discrete cosine transform within the blocks of 8 by 8 pixels. We built the structural similarity index map (SSIM) as a local metric to detect structural changes in the activity maps calculated from the jpeg images (Fig.1 – bottom). The maps are compared to the bmp-based map. For the purpose, the same sequence of generated speckle patterns is recorded both as bmp and jpeg images. The mean structural similarity index (MSSIM), which is found as the mean value of the obtained SSIM distributions, is shown in Fig.1f for Q decreasing from 90 to 5.

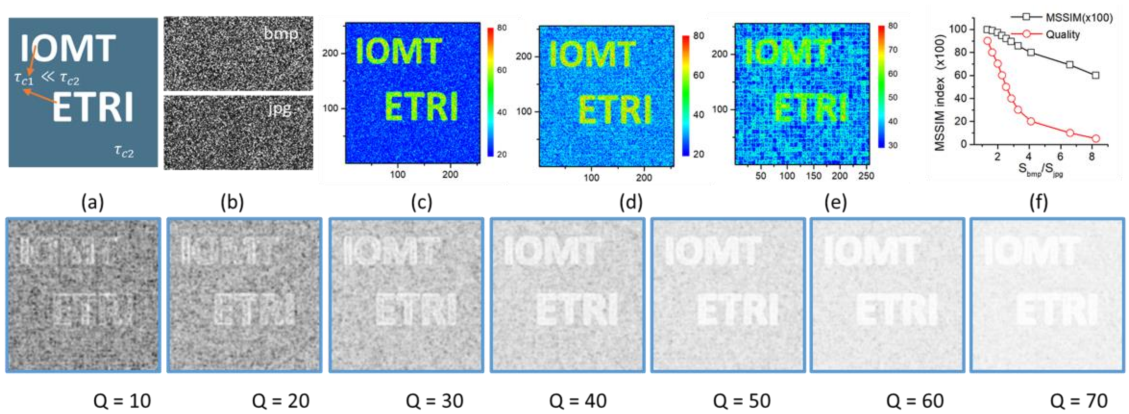


Fig. 1. Top: areas of activity in the simulated object (a), speckle pattern of the object in bmp and jpeg formats (b), maps of the MSF estimate calculated from the bmp images (c), jpeg images with quality 50 (d) and 5 (e) and MSSIM index for maps obtained from jpeg images of decreasing quality (f). Bottom: structural similarity distributions at JPEG compression with decreasing quality; time lag $\tau = 10\ \Delta t$, $N = 256$, $\lambda = 532$ nm.

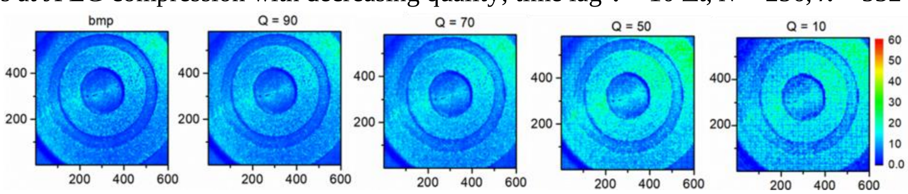


Fig. 2. Activity maps for a circular metal object covered with paint in case of the speckle patterns in the bmp format and after JPEG compression with different quality of images; time lag $\tau = 15\ \Delta t$, $N = 256$, $\lambda = 632.8$ nm.

We made experiments for a circular metal object covered with paint. The object contained two hollow regions of the same depth that were obscured on the acquired images by speckle formed under He-Ne laser illumination. Evaporation of the paint on the flat object surface and within the hollow regions leads to observation of dynamic speckle with different temporal behavior. The patterns were recorded as 8-bit encoded bmp images by the color camera X06c-s (manufactured by Baumer) with 780×582 pixels and pixel pitch 8.3 μm. The MSF algorithm visualizes the hollow regions due to different activity. We applied JPEG compression to the captured images at different quality of jpeg images. The results of MSF processing are shown in Fig.2. The size of the captured bmp images is 1.29 MB; the size of the compressed jpeg images is 182 kB (Q = 90), 103 kB (Q = 70), 77 kB (Q = 50) and 25 kB (Q = 10). In conclusion, simulation and experiment show that quality of the activity maps is rather good at $Q \geq 70$. At $Q \leq 50$, a regular grid is clearly visible on the calculated maps but it does not interfere with the characterization of the activity areas.

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