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Optical-electronic System and Software Complex for Research and Identification of Macro- and Micro-optical Elements of Security Holograms

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Abstract

The paper presents an automated optical-electronic software and hardware complex for carrying out activities to identify and control the authenticity of diffraction and holographic optical security elements. The developed complex makes it possible to significantly simplify the work of the expert in conducting forensic studies of objects marked with security holograms.

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Received: 28 January 2018
Accepted: 15 March 2018
Published: 25 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the PhIO Conference Committee.

1. INTRODUCTION

One of the most effective methods of protecting documents from forgery is the use of security holograms. However, nowadays the quality of fake holograms has reached the certain level, at which the consumer lacks the ability to distinguish the original diffraction or holographic security element from the counterfeit accurately, regardless of qualification level. The presence of this problem dictates the need to create devices that simplify the process of controlling the authenticity of the security elements mentioned above.

There are devices capable of controlling a wide range of security features embedded in documents; for instance, VSC8000 manufactured by Foster & Freeman Ltd [1] and visualizer of holographic images "Regula" 2303 produced by Regula Ltd [2]. However, the aforementioned devices have disadvantages, which include: 1) the limited illumination angles of security hologram samples; 2) absence of built-in precise positioning rotation and three-axial movement system for the sample; 3) lack of capability to register images and investigate separate areas of security holograms with subsequent further "stitching"; 4) inability to register hidden holographic images. The visualizer "Regula" 2303 has the latter drawback compensated by the availability of a separate device for visualization of hidden images. But the standalone nature of the solution can be considered being a drawback, due to the fact of the system automation level being lowered.

This paper is dedicated to the description of the developed complex, which includes an optical-electronic system and software designed to solve the identified shortcomings of existing systems for control and verification of documents marked with diffraction and holographic optical security elements.

2. TECHNICAL SOLUTION

Expert control of the authenticity of security holograms based on analysis and comparison of controlled security hologram sample images with corresponding images of reference holograms is carried out with the use of a series of holographic images recorded at different angles of illumination [3]. Information on the microstructure of the hologram can be extracted from this series. In addition to the aforementioned approach, the control of the authenticity of security holograms can be carried out by comparing hidden images or diffraction distributions registered when the reference and sample holograms are illuminated by coherent light [4].

The integral representation of the set of the diffraction parameters distribution $D_{i,j}$ is defined as the normalized integral of the power spectrum in the half-plane sector for spatial frequencies form $\nu_i - \frac{\Delta\nu}{2}$ to $\nu_i + \frac{\Delta\nu}{2}$ and the range of angles from $\phi_j - \frac{\Delta\phi}{2}$ to $\phi_j + \frac{\Delta\phi}{2}$ (as presented in Fig. 1) whose magnitude is proportional to the amount of energy in the square sector of the spatial-frequency spectrum

$$D_{i,j} = \int_{\phi_j - \frac{\Delta\phi}{2}}^{\phi_j + \frac{\Delta\phi}{2}} \int_{\nu_i - \frac{\Delta\nu}{2}}^{\nu_i + \frac{\Delta\nu}{2}} A(\nu, \phi)\, \nu d\nu d\phi / \int_0^{\pi} \int_{\nu_{\min}}^{\nu_{\max}} A(\nu, \phi)\, \nu d\nu d\phi$$

Thus, the spatial frequency spectrum of the input and reference diffraction distribution reconstructed from the input and reference holograms can be characterized by an array of numbers in the form of integral frequency $\{F_i^{\nu}\}$, angular $\left\{S_j^{\phi}\right\}$ and sector parameters $\{D_{i,j}\}$ in certain, pre-selected sectors (i, j), as well as average parameters such as $\phi_{A@}$. For the task of describing the spatial-frequency spectrum of hidden images reconstructed from holograms, an array of integral parameters $\{D_{i,j}\}_{N_\nu, N_\phi}$ for

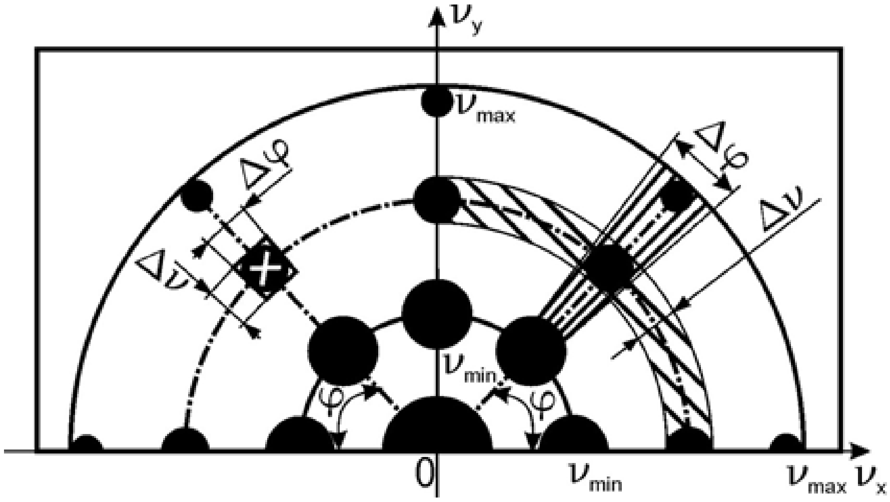

Figure 1: The domains of integration of the diffraction distribution parameter.

all $i = 1 \ldots N_\nu$ and $j = 1 \ldots N_\phi$ can be sufficient, and can be written in the form of a matrix

$$\begin{bmatrix} D_{1,1} & D_{1,2} \cdots & D_{1,N_\phi} \\ \vdots & & \\ D_{N_\nu,1} & D_{N_\nu,2} \ldots & D_{N_\nu,N_\phi} \end{bmatrix}.$$

This array actually represents a spatial frequency spectrum, digitized by a matrix with counts at points $N_\nu \times N_\phi$. For sufficiently small $\Delta\nu$ and $\Delta\phi$, the digitization function produces directly a matrix radiation receiver with the required number of elements.

The identification rule, which makes it possible to establish the identity of the input and reference diffraction distributions, can be represented by a correlation functional. Taking into account the stationary connection of the vectors of the characteristics of the reference $D^{-"} = \left\{D_{i,j}^{-"}\right\}_{N_\nu,N_\phi}$ and input $D^{\%} = \left\{D_{i,j}^{\%}\right\}_{N_\nu,N_\phi}$ diffraction distributions as realizations of random fields (ν,ϕ)in the plane (or input plane (x,y)) with the normal distribution law, the correlation functional of the identifying rule can be written in the form

$$R(\xi,\eta) = \iint D_{\%}(x,y)\, D_{-"}(x-\xi, y-\eta)\, dxdy.$$

The identification rule consists in maximizing the functional for different values of the spatial displacement parameters of the analyzed objects. To effectively apply the correlation analysis, it is necessary to ensure the identity of recording conditions for diffraction patterns of the corresponding protective holograms.

Correlation functional with normalization takes the form

$$R(\xi,\eta) = \frac{\iint D_{\%}(x,y)\, D_{-"}(x-\xi, y-\eta)\, dxdy}{\sqrt{\iint D_{\%}^2(x,y)\, dxdy}\sqrt{\iint D_{-"}^2(x,y)\, dxdy}}.$$

The decision to identify the security hologram is accepted if the rule holds true

$$R\left(D^{-"}, D^{\%}\right) > h_{nop}$$

where h_{thr} is the threshold level determined by the Neumann-Pearson detection criterion.

The hologram authentication procedure compares the values of each of the parameters in each pixel from the corresponding values of the reference security hologram that are stored in the database. When deciding on the authenticity of a sample, it is possible to set the threshold from the values of each of the parameters of the diffraction grating, namely, period, orientation, angular selectivity, and diffraction efficiency.

To realize this functionality, the digital camera with zoom-lens was used as the digital image recording unit.

3. DESIGN SOLUTION

Structural schematic, functional schematic and overall design of the system were developed, based on the results of methods' research for security hologram image and hidden diffraction image analysis.

The complex consists of two structural units: the subsystem "Macro" (the Macro image unit) and the subsystem "Micro" (the Micro image unit). The analysis and authentication of protective holograms is performed in automated mode under the control of a computer with developed software.

Subsystem "Macro" working area houses a steel sample table with a diameter of 300 mm, as seen in Fig. 2. It allows for the open passport to be studied in one session. The object table is located on four precision translators, which allow for the sample table to perform three-axial linear movement and rotation around the vertical axis. The use of such a design provides a wide range of positions of the sample with respect to the light sources and digital camera.

Developed "Macro" subsystem solution is capable of registering hidden images, which can be visualized using a hidden image display system and illumination of the certain regions of the sample hologram with coherent light.

The images of the samples are registered with a digital camera with a zoom-lens, integrated in the "Macro" subsystem.

The illumination system consists of the mobile incoherent illuminator of the mobile coherent illuminator. The incoherent illuminator consists of a four color 20 W RGBW LED with wavelength range of 350-750 nm. The emitted light cone is regulated by means of a special lens. A coherent illuminator is a 5 mW laser module and a wavelength of 650 nm.

The moving system of coherent and incoherent illuminators provides positions of illuminators in the range of angles from 10 ° to 170 ° to the horizon.

The operation of the subsystem "Macro" is presented in Fig. 3. The operator fixes the sample security hologram in place on the object table. The camera displays the real-time image of the object table and the sample attached to the table on the computer monitor. The operator moves the fragment of the sample hologram into the field of view of the camera by moving the object table and orientates it at the desired angle by rotating around the vertical axis. The incoherent illuminator is used as the source of light during the study of visual features. The operator is aided by the computer to get the required angle of illumination, color of illumination and its power. The image of the hologram is taken and then the information is processed into the database after the specific commands are issued by the operator. When investigating hidden holographic images, a laser module is used as the light source, as presented in Fig. 4. The operator adjusts output power using the software. In this case, the laser beam is aimed at the area containing the hidden image with the help of the object table positioning system. The hidden image display system is introduced into the field of view of the camera. Using the rotation of the object table and the angle of laser diode illumination, the operator finds a position where a hidden image is visualized on the introduced system. After the aforementioned adjustment procedure, the image is recorded as visualized on the ground glass of the introduced system and then the information is entered into the database.

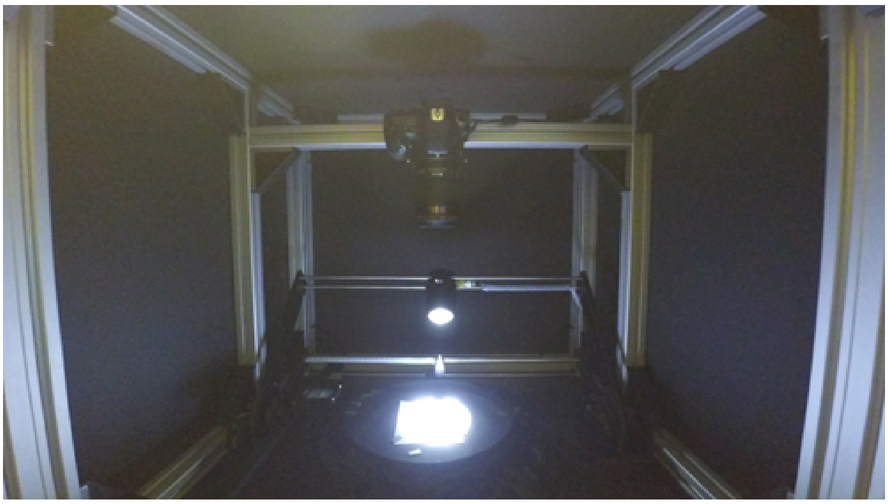

Figure 2: Working area of the complex.

DOI 10.18502/ken.v3i3.2067

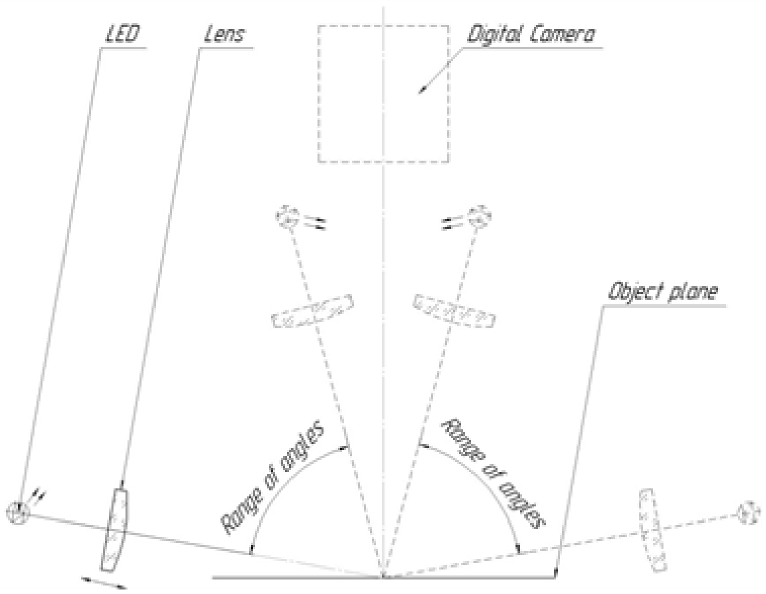

Figure 3: The optical scheme of the complex.

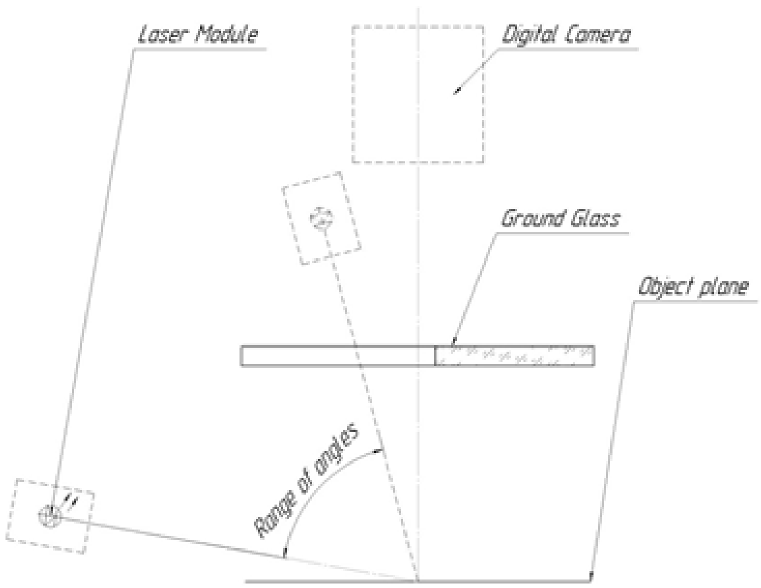

Figure 4: The optical scheme of the complex when registering a hidden image.

The subsystem ”Micro” based on a microscope allows the observation of the sample security hologram, both through eyepieces and with a video camera, to display the image on the computer monitor in real-time using micro-lenses with various magnifications from 5x to 150x. The three coordinate positioning system moves the microscope stage to introduce the required fragment of the sample into the field of view of the microscope and focuses on it for the study of the security elements. The microscope can realize the following methods of investigation and contrasting: light field, dark field, differential-interference contrast and polarization method. After choosing the research method, adjusting the position of the object table by commands from the computer, the microimage of the investigated hologram is recorded and the information is processed into the database.

Both “Macro” and “Micro” subsystems are controlled by a computer through the corresponding control units and controllers connected to the computer via the USB interface. The operator uses the software to determine the required mode of operation and captures the frame with the digital camera in the “Macro” subsystem and digital video-camera in the “Micro” subsystem. The joint operation of all modules and control units is carried out using the developed software.

4. CONCLUSION

Developed automated optical-electronic software and hardware complex for identification and control of authenticity of diffraction and holographic optical security elements, described in this paper, lacks the disadvantages of the existing aforementioned systems. This complex significantly simplifies the work of the expert in conducting forensic studies of objects marked with security holograms.

Acknowledgments

The work was completed in BMSTU with financial support from Russian Ministry of Education as a part of the grantagreement № 14.577.21.0223 (ID PRFMEFI57716X0223).

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