Quantum Electronics **50** (2) 195 – 196 (2020)

OPTICAL ENCRYPTION

https://doi.org/10.1070/QEL17139

QR-code optical encryption in the scheme with spatially incoherent illumination based on two micromirror light modulators

N.N. Evtikhiev, V.V. Krasnov, I.D. Kuzmin, D.Yu. Molodtsov, V.G. Rodin, R.S. Starikov, P.A. Cheremkhin

Abstract. **An optical encryption scheme with spatially incoherent illumination based on two micromirror light modulators has been experimentally implemented for the first time. Currently, such modulators are the fastest tools for spatio-temporal light modulation; their high frame rates provide possibilities for developing optical encryption systems with a bandwidth of several gigabites per second.**

Keywords: *optical encryption, spatially incoherent illumination, micromirror light modulator, optical/digital system, QR code, hologram.*

1. Introduction

The attractiveness of optical encryption methods is due to the high cryptographic security and operating speed, which are provided by parallel operation of optical systems [1 – 11]. Many known optical encryption systems [1 – 4] are based on encryption by two random phase masks; this approach calls for completely coherent illumination. The main problem of such schemes is their low output signal-to-noise ratio [5] because of the presence of speckle noise (inherent in coherent optical systems). In addition, holographic methods are applied in such systems to record the phase distribution; as a result, the optical scheme is significantly complicated. Several encryption methods based on the use of spatially incoherent illumination have been proposed previously [5 – 7] to eliminate the drawbacks of encryption systems with coherent illumination. In this case, holographic detection is not required, and speckle noise is absent. The inapplicability of phase masks, which deteriorates cryptographic security [8], can be partly compensated for using additional amplitude masks [9]. The use of the fastest modern micromirror spatial light modulators (MM SLMs) in encryption schemes may provide a possibility of encrypting data flows at a level of several gigabits per second [10]. In view of the aforesaid, the purpose of our study was to implement experimentally an optical encryption scheme with spatially incoherent illumination based on MM SLMs.

N.N. Evtikhiev, V.V. Krasnov, I.D. Kuzmin, D.Yu. Molodtsov, V.G. Rodin, R.S. Starikov, P.A. Cheremkhin National Research Nuclear University MEPhI, Kashirskoe shosse 31, 115409 Moscow, Russia; e-mail: vitaly.krasnov@mail.ru

Received 23 September 2019; revision received 20 October 2019
Kvantovaya Elektronika **50** (2) 195 – 196 (2020)
Translated by Yu.P. Sin'kov

2. Specific features of MM SLM application

MM SLMs provide high (unattainable for SLMs of other types) input rates (frame rate of 32 kHz at a resolution of 1920 × 1080 pixels) but carry out only binary amplitude modulation. When encrypted information is presented in the form of binary data pages, this limitation of the MM SLM modulation range is rather an advantage from the point of view of input data. In this study the input data were presented using a standard QR code, which is convenient for reading and contains a built-in error correction code [5, 11] (however, any convenient binary data container can be applied). To form an encrypting response of a system with the aid of MM SLMs, one can use only binary amplitude diffraction optical elements; this circumstance imposes well-known limitations as compared with, e.g., kinoform [5]. In this study we applied computer-synthesised (using standard methods) binarised Fourier holograms to form an encrypting response.

3. Experimental setup

A schematic of the experimental setup is presented in Fig. 1. A 532-nm neodymium laser with a power of 200 mW is used as a monochromatic light source. Its radiation is collimated and filtered using lenses L1 and L2 and a microdiaphragm. Spatial coherence is destroyed using a rotating diffuser (RD). The encryption scheme is based on the 'classical' 4*f* architecture. Data input is performed using MM SLM1, which is located in the front focal plane of lens L3. MM SLM2, which serves to display the holograms forming the encrypting response of the system, is installed in the rear focal plane of lens L3 and in the front focal plane of lens L4. The MM SLMs

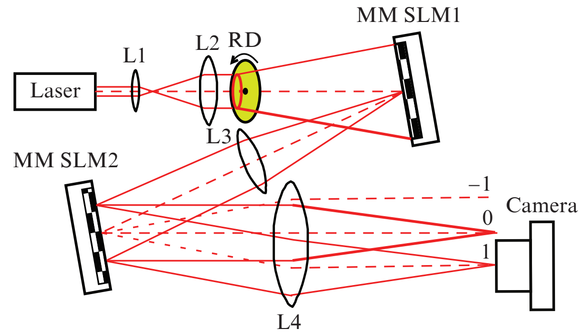
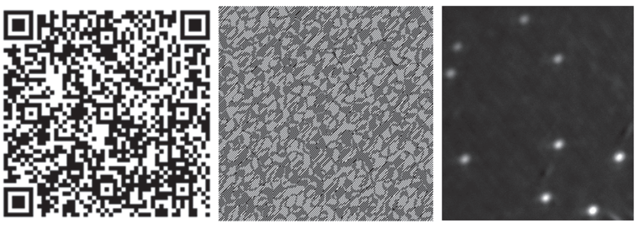


Figure 1. Schematic of the experimental setup.

(0.7 XGA DLP7000, Texas Instruments) have 1024 × 768 pixels, each 10.8 × 10.8 μm in size. A Canon EOS 400D camera with a sensor composed of 3888 × 2592 pixels (pixel size 5.7 × 5.7 μm), located in the rear focal plane of lens L4, recorded encrypted images (each encrypted image is an optical convolution of an image displayed on SLM1 with the response of the hologram imaged by SLM2.

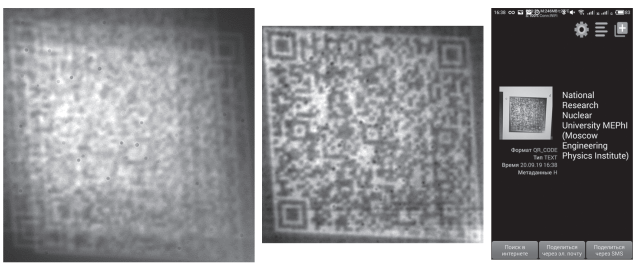
4. Results of the experiment on QR-code optical encryption

As an object to be encrypted, we used a QR code consisting of 51 × 51 elements. It was displayed on SLM1 and is presented in Fig. 2a. A binarised encrypting Fourier hologram, containing 300 × 300 elements, was imaged by MM SLM2; it is shown in Fig. 2b. Figure 2c presents the optically recorded hologram response in the first diffraction order. To record it, a black field with an only white pixel at the centre was displayed on MM SLM1. The encrypted image, recorded by the camera in the green colour channel, is presented in Fig. 3a. Decoding was performed numerically by the inverse filtering method with Tikhonov regularisation [12]. The decrypted image is shown in Fig. 3b; the normalised standard deviation from the original turned out to be 0.17. The result of recognition of a decrypted image by a smartphone with commercial software is demonstrated in Fig. 3c.



a b c

Figure 2. (a) Encryption object (QR code), (b) encrypting amplitude Fourier hologram, and (c) its response in the first diffraction order.



a b c

Figure 3. (a) Encrypted and (b) decrypted images and (c) recognition of a decrypted image with a smartphone.

5. Conclusions

An optical encryption scheme with spatially incoherent illumination based on two micromirror light modulators has been experimentally implemented. The experimental results demonstrate a moderate level of noise: the normalised standard deviation of decrypted image from original is 0.17; the decrypted QR code can be successfully recognised by standard tools. The results show that micromirror light modulators can be used to develop fast optical encryption systems.

Acknowledgements. This work was supported by the Russian Science Foundation (Grant No. 19-19-00498).

References

1. Refregier P., Javidi B. *Opt. Lett*., **20**, 767 (1995).
2. Rajput S., Nishchal N. *Appl. Opt*., **51**, 1446 (2012).
3. Markman A., Wang J., Javidi B. *Optica*, **1**, 332 (2014).
4. Situ G., Zhang J. *Opt. Lett*., **29**, 1584 (2004).
5. Cheremkhin P., Krasnov V., Rodin V., Starikov R. *Las. Phys. Lett*., **14**, 026202 (2017).
6. Krasnov V., Starikov S., Starikov R., Cheremkhin P. *Russ. Phys. J*., **58**, 1394 (2016) [*Izv. Vyssh. Uchebn. Zaved., Ser. Fiz*., **58**, 29 (2016)].
7. Tajahuerce E., Lancis J., Javidi B., Andrés P. *Opt. Lett*., **26**, 678 (2001).
8. Cheremkhin P., Evtikhiev N., Krasnov V., Rodin V., Shifrina A. *Proc. SPIE*, **10433**, 104330B (2017).
9. Evtikhiev N., Krasnov V., Cheremkhin P., Shifrina A. *Komp. Opt*., **41**, 391 (2017).
10. Bondareva A., Cheremkhin P., Krasnov V., Rodin V., Starikov R., Starikov S. *Proc. SPIE*, **9648**, 96480S (2015).
11. Barrera J., Mira A., Torroba R. *Opt. Express*, **21**, 5373 (2013).
12. Tikhonov A., Arsenin V. *Solution of Ill-posed Problems* (Washington: Winston & Sons, 1977).