Design and visualization of synthetic holograms for security applications

M Škereň, M Nývlt and J Svoboda
Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Břehová 7, 115 19 Prague 1, Czech Republic
E-mail: marek.skeren@fjfi.cvut.cz

Abstract. In this paper we present a software for the design and visualization of holographic elements containing full scale of visual effects. It enables to simulate an observation of the holographic elements under general conditions including different light sources with various spectral and coherence properties and various geometries of reconstruction. Furthermore, recent technologies offer interesting possibilities for the 3D visualization such as the 3D techniques based on shutter or polarization glasses, anaglyphs, etc. The presented software is compatible with the mentioned techniques and enables an application of the 3D hardware tools for visualization. The software package can be used not only for visualization of the existing designs, but also for a fine tuning of the spatial, kinetic, and color properties of the hologram. Moreover, the holograms containing all types of the 3D effects, general color mixing, kinetic behavior, diffractive cryptograms, etc. can be translated using the software directly to a high resolution micro-structure.

1. Introduction
Today, the synthetic holograms are widely used in optical document security, where various visual effects are utilized for an evaluation of originality of the security elements. The security function is based on a very fine micro-structure with the details of order of hundreds of nanometers. It diffracts the light and creates macroscopic visual effects. The holographic security elements have been successfully used for anti-counterfeiting applications since early eighties of the twentieth century [1]. From a technical point of view, these structures are usually created as the thin diffractive relief elements in plastic foil. They are mastered in photo-resist and finally transferred to a plastic foil using the electro-forming and embossing technologies [2]. The elements are attached to the secured products either as conventional stickers or using the hot-stamping technique. Volume holograms are also used for security applications. Then they are usually recorded in a photo-polymer material.

A very important property of the holographic security element is a possibility of an easy evaluation of the originality by a common observer without any sophisticated knowledge of the optical principles and usually also without any additional inspection tools. Today, there are many different techniques capable of evaluating the originality with very high reliability (for example some spectroscopic techniques or others), but most of them require relatively sophisticated inspection equipment and trained operators. A macroscopic visual behaviour of the holograms based on a very fine micro-structure enables to avoid the complicated inspection process and to move the process of the authenticity inspection to the public. Thus the visual
design plays an important role not only from an artistic point of view, but also from a point of view of the security function of the element. When the designed element contains many different visual effects, it is often difficult for the designer to simulate the complex behavior of the hologram only using conventional graphic tools and approaches. Moreover, it is almost impossible to present the hologram properties to most customers, who are not familiar with the holography at all. On the other hand, the modern computer graphics offers several interesting tools for visualization of the dynamic and three-dimensional effects created by the holographic micro-structures. A proper presentation of the visual effect can also significantly help to evaluate the security features and to reveal the potential counterfeits.

In the following sections, the most important visual effects and other security features are described, which are typically present in majority of current security holograms. Elementary physical principles of most effects are briefly discussed in order to explain the basic requirements on visualization of the designs and consecutive fabrication of the micro-structures.

2. Design and fabrication of holographic security elements

Wide variety of different holographic elements is used for security applications. Many of them are based on common holographic principles and have a similar visual behaviour [3, 4]. For most security holograms an elementary functional unit is a diffraction micro-grating [5]. Light from an illumination source (usually a white light source with some degree of spatial coherence) is diffracted from the grating and sends an information about the particular image point to a well-defined direction (see figure 1).

![Figure 1. Common geometry of reconstruction of the thin rainbow holograms for two different micro-gratings ((a) horizontal grating, (b) tilted grating). The color and angular behaviour are given by the position, periodicity, and orientation of the grating.](image)

Usually, the thin gratings are used and thus a whole spectrum of wavelengths is diffracted, each color to a slightly different direction. By changing the grating frequency and orientation of grating lines, each direction in the half-space can be addressed with an image information. The dimensions of micro-gratings can be chosen according to the needs of a particular design, however the grating must contain at least several periods if it should diffract the light effectively. Considering the common observation geometry and the range of visible wavelengths, the grating dimension must be at least several micrometers. On the other hand, when the resolution of the observation system is not better than 0.1 mm, hundreds of different gratings can be placed next to each other within a resolvable point. It means that hundreds of different signals can be included within a single image point. This effect is the base for most of the unique visual
effects of the synthetic image holograms, which use the spatial multiplexing of the images and the limited spatial resolution of the observing system. The holographic element can multiplex various images also using overlapping micro-structures, but this approach is rarely used for preparation of the synthetic embossed holograms.

2.1. Encoding of the design

The design of holographic elements differs from any other graphical artworks in the necessity to define additional parameters for description of the visual behaviour. In contrast to common graphical designs, where each point is usually defined only by color coordinates, the holographic elements can change their visual appearance depending on the geometry of reconstruction (usually the observed view depends on the direction of observation and also on the direction from which the incident light illuminates the hologram).

In fact, most holographic effects such as the dynamic behaviour, 3D properties, and variable colors are based on the ability of the holographic element to send a completely different information to the different directions from a single area of the elementary resolvable image point. Thus for each point on the surface of the holographic element, the behaviour must be defined for all possible geometries of reconstruction. A simple color image is not sufficient for such a complex description. Very often, the angle of incidence between the illuminating beam and the plane of the hologram is fixed and only the observation angle can vary. There are several approaches how to encode the image data of this kind. In our design software two image maps were chosen, one containing the information about color coordinates and the second describing the observation angle from which the particular point can be observed. When the resolution of such image maps corresponds to the elementary micro-grating dimensions, all desired effects can be represented by these two images. In figure 2, there are examples of such image maps. The color map is usually an RGB mixed image, the map describing the angular properties of the hologram is often a grayscale image (when 8-bit encoding is used, 255 different angles can be encoded).

![Figure 2. Simple example of the encoding of the holographic design using two raster images. The color image defines the color properties of each image point (periodicity of the corresponding micro-grating), the grayscale image carries the information about the direction of observation for each point (orientation of the grating lines).](image)

The visualization of the design consists of simulating the different spatial views of the hologram for various light sources, observation conditions, etc., based on the prepared design image files. The design itself can be created in any graphic software which is capable of exporting the raster design images with sufficient resolution. More complicated designs can require several
sets of color and grayscale images, each describing different properties of the same holographic element. All this data will be finally merged into a single pair of the design maps.

2.2. Visual effects and hidden features
Current security elements are based on two main groups of optical effects. The first group contains visual effects which can be easily observed by a naked eye under common lighting conditions with little requirements on the light source used. The security function is realized through the diffraction process which can create unique macroscopic visual behaviour based on tiny details of the micro-structure with dimensions of hundreds of nanometers or even smaller. These visual effects can serve as the most important group of security features dedicated to the first-line inspection. The typical effect from this group must create a visual perception, which is easily recognizable by a human observer and which cannot be reproduced by common printing technologies. The simplest representatives of this group are basic rainbow diffraction effects, images with a kinetic behaviour, 2D/3D effects, flip-flop effects, full 3D effects and some others. All of them are based on the ability of a holographic structure to spatially multiplex the image information [1, 5, 6].

Although the visual effects are essential for the first-line inspection of originality, it is desirable to combine them with additional security features which are hidden for a common observer. Thus the second group of the security features contains the approaches based on an encryption of some texts or images in the micro-structure. This information can be revealed either using a special geometry of observation, or by application of a specific light source (laser light, polarized light, etc.) [2, 7, 8]. The most commonly used structures of this type are the diffractive cryptograms and micro-texts. While micro-text is just an extremely miniaturized text or image, which can be observed using an optical microscope, the diffractive cryptogram is a holographic element, which forms the reconstruction of the hidden information out of the plane of the security element on the base of the diffraction of coherent light. The diffractive cryptograms are usually aperiodic, but they can be also assembled from similar micro-gratings as the visual effects.

2.3. Mastering techniques
The mastering technique strongly influences the effects, which can be used within the prepared hologram and it also influences the method how the design is prepared and encoded. Today, there are three main approaches to the mastering of the security elements. The first one is based on a classical holographic exposure of the elements, where the desired micro-structure is exposed using a natural interference process in a holographic setup. Relatively large areas are exposed at once and multiple exposures can be used to achieve various visual effects. Particular exposures can overlap or they can be separated using a system of exposure masks. The main advantage of this approach is a relative simplicity of the recording process and a possibility to expose larger holograms comparing to the direct writing approaches. On the other hand, the created color, dynamic, and three-dimensional effects are very limited. The two other approaches are both based on high-resolution direct-writing techniques which can record the details with sub-micrometer dimensions over the hologram area. Because the writing resolution is significantly higher than the resolution of the observing system (the human eye), multiplexing of large amount of image information can be achieved. If the elementary area (usually a regular micro-grating) has the dimension of only several micrometers, several hundreds of different signals can be recorded within a single point resolved by an observer. Such an approach offers huge flexibility in creating new features and enables almost any combination of effects within a single hologram. When designing complicated structures, a proper visualization of the design can be very helpful.
3. Visualization of the security elements

The problem of visualization of the holographic elements was solved using a computer simulation of the visual behaviour of the element based on a simple design data. The most important parameters, which influence visual perception of the hologram are the geometry of reconstruction and the coherence properties of the light source. In a case of an ideal spatial coherence of the source, the rainbow effect is observed and the visualization can be relatively simple. When the source is only partially coherent (which is the case of most real sources), the visual behaviour is more complicated. Application of a partially coherent light can be described by using the convolution of the image data with a coherence function of the source.

A software tool has been built for visualization of existing designs containing wide variety of effects. In figure 3 there is a graphical interface of the HoloDesigner software. The code was written in Python language and optimized for Linux operating system. The software can generate various views of the designed hologram in real time with a possibility to interactively change full range of parameters. All kinds of designs can be loaded and also partially edited by the software.

A two dimensional preview of the holographic elements can be used for presentation of the designs in most cases, especially when the important parameters such as the viewing angle and coherence of the light source can be easily changed in the computer. However, for real three dimensional images it would by much easier to visualize the design using some of the 3D projection techniques. A combination of the interactive graphical interface with a three dimensional visualization can bring new dimension to the processes of the design and presentation of the holograms. Such a tool can be very helpful not only for previewing the future hologram prior to the expensive fabrication process, but also for evaluation of the originality of existing elements. Today, there are several techniques commonly used for the 3D visualization in the entertainment industry. For our application, two different approaches have been chosen. For
a high-quality 3D visualization the two channel stereo with a temporal multiplexing of two spatial channels was used. Different hardware devices can be used for such an imaging, the output of the HoloDesigner package was optimized for application of the NVIDIA 3D Vision technology with synchronized shutter glasses. The device is based on a fast temporal switching of two spatial viewing channels with a refresh frequency 120Hz (60 Hz per channel) using a projection device such as a computer monitor or a projector with an appropriate switching frequency. The separation of spatial channels for observer is done using the synchronized shutter glasses based on the liquid crystals. The image data consists of a set of 2D views from two different observation directions. The HoloDesigner can export video preview of any holographic design in such a format. The exported data can be viewed also using another similar 3D projection systems.

The second option for the three dimensional visualization included in the software is a conventional anaglyph projection with two channels multiplexed using the pre-defined color shifts of the channels. Although this technique influences negatively the color perception of the holographic image, its main advantages are a wide availability, simplicity, and little hardware requirements (except for the passive color anaglyph glasses). In figure 4, there is an example of the anaglyph output within the main window.

![Figure 4. HoloDesigner with three-dimensional design in anaglyph mode. The view can be fully adjusted from a point of view of observation distance, position of an observer, anaglyph type, etc.](image)

The 3D preview can be used not only for the designs containing some three dimensional objects or spatial planes in the 2D/3D design, but also for a three dimensional observation of two dimensional holograms. In figure 3 there is an example of a two dimensional design tilted in the 3D space which corresponds to the common geometry of reconstruction when the security elements are visually inspected. Such a three dimensional observation can be performed in the perspective projection mode, the anaglyph mode, and the real 3D Vision mode.
4. Processing of the design
The described software HoloDesigner can be used also as a tool for translation of a visual design to a high-resolution micro-structure. After finishing the composition, setting the 3D spatial parameters of particular objects and loading the data for the recording device, the software can merge all information to a single set of the design maps similar to those from figure 2. All viewing channels for the 2D/3D and full 3D objects are spatially multiplexed at the hologram plane, the color mixing is performed for the areas with the mixed colors, and finally the hidden features such as the micro-texts and cryptograms are included. In figure 5 there is an example of a small part of the resulting micro-structure represented as the raster image. Particular micro-gratings are clearly visible. Several micro-gratings are further segmented due to the multi-channel color mixing. The software uses 6 basic colors for mixing from which it automatically selects two or three closest colors for particular mix. The software can use gratings with various profiles such as harmonic, binary, and also more general user defined shapes. Different types of profiles can be also easily combined within a single design.

![Figure 5](image_url)

Figure 5. (a) Example of the micro-structure generated by the HoloDesigner in the case of the 3D true color hologram. (b) Microscope image of the micro-structure fabricated using a matrix laser lithography device.

5. Conclusions and acknowledgements
The design and visualization software for synthetic security holograms was presented. The visualization tool has proven its importance in the design and presentation processes. Application of the recent 3D projection systems rapidly improved effectiveness of the visual design and contributed to a significant time and money savings in the holographic mastering process.

This work has been supported by the Grant Agency of Czech Academy of Sciences Project No. KAN401220801.

References
[1] Van Renesse R L 1994 Optical document security 2nd ed (London: Artech House)
[2] Skeren M 2006 CTU Reports 10 1-181
[3] Saxby G 1994 Practical holography 2nd ed (Prentice Hall International)
[4] Hariharan P 1996 Optical holography 2nd ed (Cambridge, Cambridge University Press)
[5] Svoboda J, Skeren M and Fiala P 2011 Advanced holography - metrology and imaging ed Naydenova I (Intech) 209-232
[6] Girnyk V I, Grygoruk V I, Borisov I S and Kostyukevych S A 2003 Proc. SPIE 5290 179-189
[7] Skeren M, Fiala P and Richter I 2006 Appl. Optics 45 27-32
[8] Aggarwal A K, Kaura S K, CHihachhia D P and Sharma A K 2004 J.Opt. A-Pure App. Opt. 6 278-281