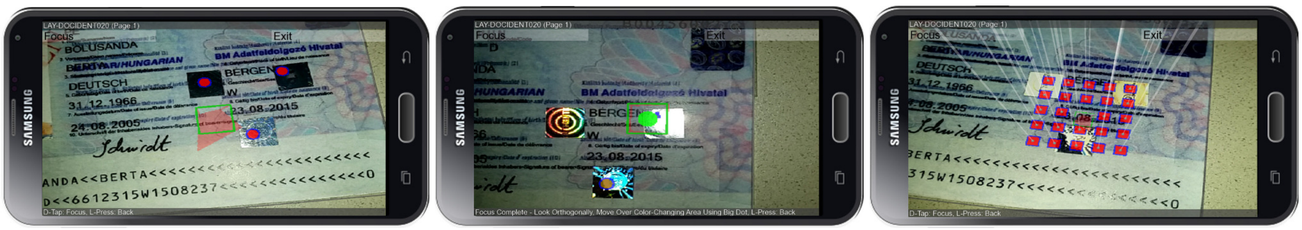
Towards Mobile Recognition and Verification of Holograms using Orthogonal Sampling

Andreas Daniel Hartl * Werner Alexander Isop † Clemens Arth ‡ Dieter Schmalstieg §

Institute for Computer Graphics and Vision
Graz University of Technology, Austria



(a) (b) (c)

Figure 1: Mobile application for hologram verification during orthogonal sampling. The user interface provides guidance during orthogonal image capture within a constrained space around each reference view (a),(b). The application can also be used to sample reference data using an augmented grid (c). At each position, several measurements are taken to account for expected inaccuracies during inspection.

ABSTRACT

Although holograms provide a reasonable level of security, for lay-people, the inspection is difficult due to the inherent lack of knowledge. Mobile AR setups using off-the-shelf smartphones can provide this information and support the verification process. However, current approaches lack in accuracy or are difficult to instruct to the user. We propose a series of designs for holograms suitable for mobile verification. They support the orthogonal sampling of elements within a constrained space along with an assessment of the capture conditions. We evaluated these designs regarding their verification performance and task completion time. The associated study revealed encouraging results for robust and efficient hologram verification on mobiles using a specially designed security element.

Index Terms:

H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User interfaces—Input interaction styles; H.4.9 [Image Processing and Computer Vision]: Applications—; I.7.m [Document and Text Processing]: Miscellaneous—.

1 INTRODUCTION

Optically variable devices (loosely referred to as holograms) are used on various documents or goods as a means of protecting the originality of the item. They change their appearance depending on the viewing angle and the presence of light sources in the environment, which makes them hard to forge, but also hard to inspect. In particular, they cannot be reproduced using color scanners and printers, which are available to the public.

*e-mail:hartl@icg.tugraz.at
†e-mail:isop@icg.tugraz.at
‡e-mail:arth@icg.tugraz.at
§e-mail:schmalstieg@tugraz.at

In general, inspection is carried out by looking for a series of reference patterns visible within the element, while changing the pose of the document or the view. Since such behavior is difficult to reproduce, often substitutes are used instead of the original elements. This is a problem in the absence of reference information, since people do not know what to look for, and the presence of specular highlights is not enough for verification of anything else than a color copy. Specific knowledge regarding security features is required to reason about the validity of a hologram or the associated document as a whole.

Mobile devices such as smartphones or tablets can provide information relevant to inspection and also augment it in place on the document. In addition, the verification procedure can also be supported. Although it is possible to record suitable data for the verification of holograms using an off-the-shelf mobile device [5], the involved movement on the surface of a hemisphere over the document is difficult for the user [4]. Besides, the built-in flashlight of the device must remain the dominant light-source during the whole procedure. Consequently, it is desirable to design holograms with support for efficient and robust verification using mobiles in mind.

We propose several designs of security elements suitable for inspection using an off-the-shelf mobile device. They consist of multiple holographic elements, which can be inspected simultaneously and act as indicators for the dominance of the built-in flashlight. Another contribution of this work is a novel user guidance approach for recording and checking these elements by performing movements within a constrained orthogonal space. We constructed a series of physical samples along with a mobile prototype (see Figure 1) in order to reason about the feasibility of the proposed approach for hologram verification within matching experiments and a subsequent user study involving originals and fakes.

2 RELATED WORK

Prior art relevant to the proposed approach can be divided into two categories. We elaborate on work dealing with the recording and inspection of holograms by means of computer vision, but we also discuss related work regarding guidance of the user in a small workspace (*i.e*., table-sized environments).

Recording and Inspection While the recording and reconstruction of holograms generally involves a coherent light-source, in the following, we only consider recording approaches using ordinary means of lighting, since the goal of this paper is to use standard devices for capture and inspection.

Pramila *et al*. [12] use a uniform light source and a camera for recording the watermark of a dual-layer hologram situated on a tiltable plane. This is a stationary setup, where the result is very sensitive to the angle of the plane. Holographic patterns can be identified from a printed page using a Wavelet approximation of the intensity distribution of the hologram [10]. A Wiener filter is used to eliminate the influence of non-uniform background, making this setup also suitable for quality estimation of a holographic device.

Automatic inspection systems for holograms can use sets of patterns illuminated with multiple IR LEDs on a hemisphere [11]. Images are captured with a CCD camera at controlled illumination angle, and correlation-based matching is carried out in the frequency domain. The system also performs a correction of rotation and was evaluated with Korean banknotes. Soukup *et al*. [15] sample a diffractive optically variable image device using photometric stereo and light-field-based methods. For this purpose, they propose a tailored feature descriptor, which is robust, but still specific enough for the given task. They demonstrate their approach with the automated discrimination between genuine and counterfeited elements on banknotes.

Hartl *et al*. [3] detect holograms on arbitrary documents using a mobile AR setup. They analyze a registered stack of images obtained during the process, not requiring prior knowledge about document location or content and being suitable for real-time operation. They also showed the feasibility of hologram verification in a mobile AR setting using an off-the-shelf mobile device [5]. By using the built-in flashlight of the device as a dominant light-source, the appearance of reference patches can be reproduced in a mobile context for manual matching by the user.

User Guidance Tackling hologram verification in a mobile context using off-the-shelf devices requires guidance of the user, since only a single camera and light-source are available for use during inspection, which is a completely different situation compared to stationary setups.

One possibility is to guide the user towards a reference viewing direction by visualization of the associated view alignment error. In previous work on mobile hologram verification [5], the user is guided towards the required poses using a complex alignment-based user interface, where most parts are augmented onto the target. This is a lengthy procedure causing heavy physical and cognitive load for the operator, being much slower than look-up in a manual. A visualization of the alignment error can also be achieved by colored augmented coordinate systems [2], pyramidal frustums [14], [17] or an *Omnidirectional Funnel* [1]. Heger *et al*. [8] use a 2D-indicator to provide visual feedback about the deviation from the surface normal during alignment of an ultrasound transducer.

The user can also be guided to move within a constrained navigation space in order to cover relevant poses. Following this concept, the efficiency of mobile hologram verification was improved upon by automatic image capture and matching along with an efficient user interface involving sampling in certain areas of a 2D orientation map [4]. However, this approach does not perform on par with human inspection and was found to be again rather complicated and tedious. Still, a preference regarding a constrained navigation setup was observed. Consequently, relevant work in this context shall be mentioned here. Shingu *et al*. [13] create AR visualizations for rephotography tasks. They use a sphere as a pointing indicator along with a half-transparent cone having its apex at the sphere as an indicator of viewing direction. Once the viewpoint is inside the cone, it is not visible anymore. The sphere changes its color, when it is fully visible, corresponding to a valid recording position. Sukan *et al*. [16] propose a wider range of look-from and look-at volumes for guiding the user to a constrained set of viewing positions and orientations, not counting roll *(ParaFrustum)*. This can be realized as an in-situ visualization or via non-augmented gauges. In the in-situ variant, the transparency of volumes is modulated depending on the distance and orientation of the current pose. In addition, the general representation of the look-at volume is also changed.

While the general pipeline used in this work is based on previous experiments regarding efficient automatic hologram verification on mobiles [4], the closest prior art originates from a commercial background. Authentic Vision[1] sell special QR-codes with an embedded hologram for product protection. They claim to use both a unique encrypted code and a hologram. In the sample application (*Check If Real*), they guide the user to sample the hologram orthogonally by placing a rectangular area on various places on the screen, in which the actual element needs to be fitted in. However, they do not give instant feedback to the user, since no tracking is performed, and rely on discrete sampling positions instead of constrained navigation. The design of the element and the recording approach do not allow to assess the capture conditions regarding flashlight dominance.

3 Element Design

In the following, we elaborate on requirements regarding security elements with the inspection using mobile devices in mind. We then propose a series of designs, following certain requirements with the goal to allow practical application.

3.1 General Considerations

First and foremost, security elements must serve the purpose of protecting the associated document from copying. Regarding holograms, several distinct patterns should be shown. Optionally, unique or personalized information can be incorporated into the element, but this may be prohibitive due to higher manufacturing cost. It must be possible to reliably reason on authenticity, despite changes in appearance due to aging effects or unexpected behavior of the user during inspection. It is important that the process is easy to learn and to memorize and that there is still a possibility for pure visual inspection by the user.

The mobile inspection of security elements requires a dominant light-source in order to trigger the desired appearances of the element. While a rough estimate on the conditions can be done by fixing the exposure and quantifying the effect of the used light source on the saturation of the image, special elements for mobile inspection should provide a means of checking the dominance of the light source throughout the process.

3.2 Proposed Designs

We propose arrangements of spatially distributed holographic elements as security features suitable for inspection with mobile devices. This is motivated by previous experiments in this context, which required tilting the document or the device during inspection [5][4]. In order to reduce the demand for the user, we require the arrangement to show all relevant patterns for inspection when performing a purely translational movement over the document. When pointing orthogonally at an individual holographic element, the image capture conditions (*i.e*., dominance of the flashlight) can be assessed for each viewing direction relevant to verification, while the remaining elements can be matched.

There are several ways in which holographic elements can be distributed, but the minimum amount of elements is two (see Figure 2). In this case, there are two interesting poses, and each element just needs to show one pattern. With n elements, $(n-1)$ patterns need to be shown by each element, which can be triggered by lighting up each individual part. However, the amount of elements is

[1] `http://www.authenticvision.com`

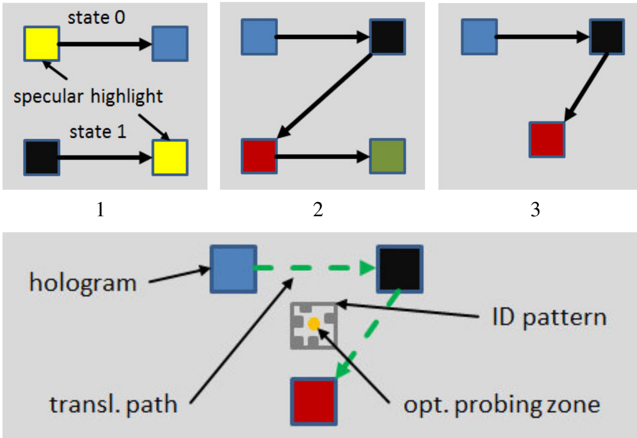


Figure 2: Proposed designs of holograms suitable for orthogonal sampling (1-3). They consist of spatially distributed sub-elements. Inspection can be carried out by lighting up each individual element and measuring the response of the remaining ones, also acting as an indicator for flashlight dominance. We also propose a standalone multi-part hologram with an optional ID pattern, which can be tracked and includes a zone for initial probing of capture conditions (bottom).

limited by the range of the flashlight. Through hands-on testing, we found that it is not practical to put patterns more than three centimeters away from each other and that the extension of each individual part should be around one cm. Consequently, a 2x2 layout is the most advanced we found to be useful, but this poses most effort. As a compromise regarding security and usability, it seems reasonable to use an element following a triangular shape (case three in Figure 2). In this case, each element needs to show two different patterns. Not considering the case of specular highlights, this is the minimum amount of views, which a hologram should have.

It is also be possible to just go with two elements (case one) and to extend the amount of reference positions (*e.g.*, add top and bottom area of the path between the elements), but in this case, the check for flashlight dominance cannot be made within each reference position anymore.

3.3 Standalone Elements

Alternatively, it is possible to detect and track a security element directly without considering the actual document as the context. This allows the element to act as a secure label, which can be attached to various goods or machinery. However, this would require to come up with an identifier based on measurements from the image in order to retrieve reference information required for verification. This can for example be achieved by placing a bar code in the middle of the document, which is also useful for pose estimation. An additional shiny surface element could allow to assess capture conditions right at the time of bar code detection (see Figure 2). Alternatively, the code could be integrated into the sub-elements themselves, omitting the need to cover additional space on the document. Due to the use of several holographic elements, providing the capability of monitoring capture conditions and also continuous user guidance, we consider this to be a considerably more advanced setup than the state-of-the-art.

3.4 Capture and Matching using Mobile AR

Our recognition approach is separated in two major parts as follows.

Mobile AR System for Document Inspection To verify the proposed designs, we apply a pipeline for document inspection. We constructed a prototype performing document classification [7], tracking [18] and augmentation, which is able to process documents with arbitrary personal information using an initial detection and rectification step [6]. Due to the determined document class, information relevant for verification (layout, patches) can be loaded on demand. The latter is prepared using a proprietary editor and is put onto the flash memory of the mobile device or queried from a server. It must be noted that all processing involving information captured from the current document is kept locally for reasons of privacy.

Capture and Matching of Multi-Part Holograms Due to the available layout and real-time pose information, the hologram region can be rectified and matched to loaded reference information on the device. Since the minimum bounding rectangle includes also non-holographic space, a mask is provided to the system for considering only relevant parts of a region for matching using the structural similarity index (SSIM) [19]. In order to save computation time and to account for inaccuracies in positioning, an initial alignment is found by windowed matching using the sum of absolute differences regarding the reference patch. However, also other measures can be used [9]. During inspection, the coverage of a sub-element by a specular highlight can serve as an indicator for the dominance of the flashlight.

The computation of the matching result is done for each reference view according to thresholds, giving a decision per patch (not valid, not sure, valid), which is mapped to a range of [0...1]. The aggregated scores are subject to a final threshold, giving the overall system decision.

We also experimented with using machine learning to reason about the validity of patches, which scales better with a larger amount of information incorporating invariance regarding the environment and the recording device. However, the lack of representative training samples currently impedes such an approach. Thus, we found it more suitable to stick with the previous approach.

It must be noted that a suitable spatial position for assessment of per-element flashlight dominance (saturation check) can be identified just by watching the pose information of the tracking system and considering the layout of the arrangement.

Due to the special setup of off-the-shelf mobile devices during hologram inspection, a user guidance component is required in order to support the user towards an initial alignment of orientation and to keep a reasonable working distance throughout the process.

4 User Interface

An exact alignment with reference viewing directions is slow and not desired by users [5]. In contrast, a constrained navigation approach was found to receive considerably more user consent [4]. However, the associated sampling on a hemisphere is difficult to instruct, which is problematic, when the application is downloaded to be used instantly. We believe that user acceptance can be improved by using a less complicated movement pattern during inspection.

4.1 Orthogonal Navigation Space

We propose an aligned constrained navigation space for sampling the hologram during a purely translational movement of the document or the device. First, the orientation and distance need to to be adjusted. For this purpose, we augment a quadrangle onto the document which is transformed according to the current orientation and distance to the document (see Figures 1, 3).

An auto-focus operation is triggered, so that the document is in focus during further interaction. After this initial alignment procedure, the user is required to perform only translational movements for capture. Blinking circles around reference poses indicate interesting areas which can be removed using an augmented eraser device (see Figure 4). This gives the user the freedom to cover the indicated space in her own way, while providing more measurements for matching to the system.

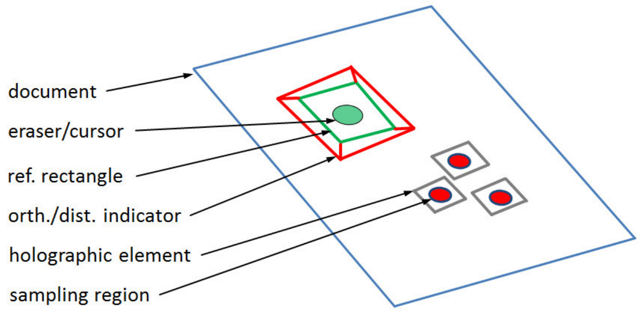


Figure 3: Illustration of the elements involved for guiding the user during orthogonal sampling. A quadrangle is transformed according to the current orientation and distance. If these conditions match, a circular element appears, acting as an eraser for augmented regions.

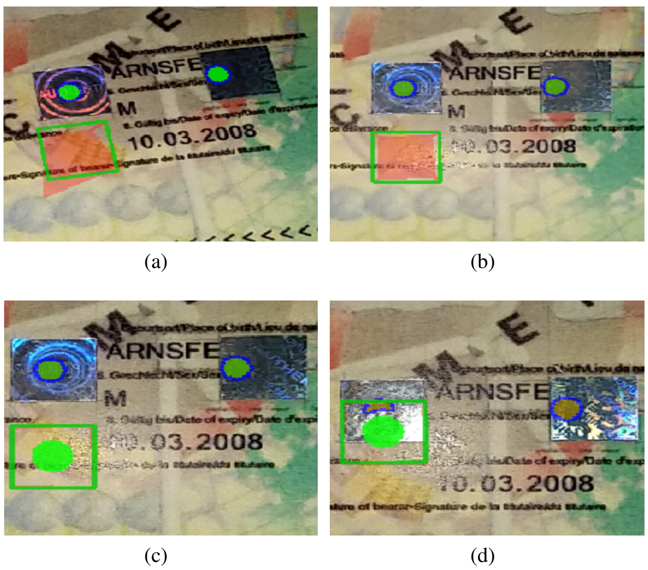


Figure 4: Steps required in sampling the hologram. The alignment status regarding an orthogonal view is communicated through a distorted and scaled rectangle (a). At the correct orientation (b) and distance (c), a pointing device (green dot) can be used to cover interesting space (circles with blue border) (d).

Once all relevant space has been captured, the global system decision is presented to the user in the form of a colored square (green...valid, yellow...not sure, red...not valid). Each reference view is shown side-by-side with the captured information for visual comparison (see Figure 5). So, the user can also use the captured images in order to make a decision on validity for himself.

We constructed a prototype running on off-the-shelf mobile hardware, which is able to record and verify the proposed hologram designs (see Figure 1). It can also be used to record reference information by locally sampling on a grid, and it provides the basis for evaluating the proposed designs and the associated verification process using orthogonal sampling.

5 Evaluation

We built physical examples for each of the proposed designs for mobile verification using elements extracted from existing holograms. In each case, an original, a substitute and a color copy were created for the purpose of evaluating the feasibility of using them with the proposed approach for orthogonal sampling (see Figure 6). For both the recordings of reference information and the actual ver-

Figure 5: Summary of image capture presented to the user. Reference information is shown left, obeying the layout of sub-elements, while the best match is shown on the right hand side along with local and global ratings of the system indicated as colored squares.

ification procedure, an off-the-shelf smartphone (Samsung Galaxy S6 Edge) was used. A submission video is available online[2].

5.1 Feasibility

We conducted an initial experiment for gaining information regarding the feasibility of the proposed hologram designs w.r.t. practical application. Matching performance and image capture time were evaluated for an instance of each proposed design under typical indoor operating conditions for an original, a substitute and a color copy. For this experiment, we simulated perfect user compliance with the goal to also complete the task in the fastest possible time.

During analysis of data it became evident that originals can be differentiated successfully when using an appropriate threshold (see Figure 7). However, there are considerable differences among designs regarding the average matching score. Although the three-element design scored slightly higher for fakes, the score for the original was best among all designs (approx. 0.7). Taking into account the reasonable capture time of around 8 seconds, this is the most promising candidate for practical application. The four-element design did not show an advantage, but proved to be harder to handle due to occasional tracking issues caused by specular highlights on several parts of the element.

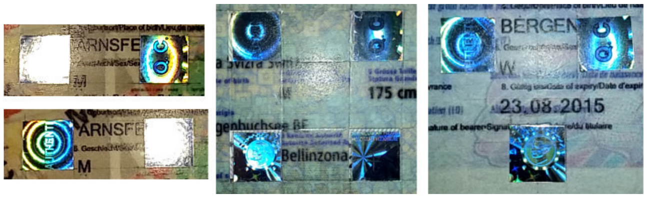
Note that we also experimented with sampling a single hologram from several 2D positions using the proposed approach for orthogonal sampling. However, this setup requires the user to move over larger distances and it does not allow an assessment of flashlight dominance for each sampling region. Still, a special element is required which reacts when performing purely translational movements. Although the elements we had for testing partially exhibit such behavior, we did not find the results to be very robust.

5.2 User Study

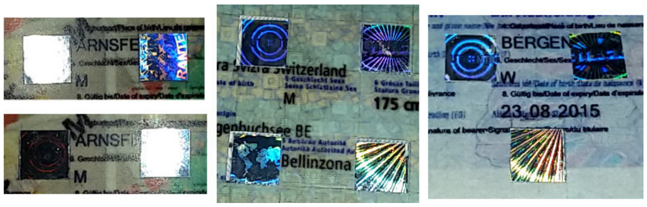
With the obtained information of general feasibility of the proposed designs and the associated approach for user guidance, we conducted a user study using an original and a substitute of the three-element design. The goal was to get an impression regarding the expected accuracy, temporal effort and user acceptance of the proposed security element and the associated checking procedure.

Apparatus and Procedure Users were explained the purpose of the study and invited to agree with a consent form. As a first step, background information (demography, experience and interest in technology, AR and mobile devices) was collected. Then, a training phase was started, involving a fake and an original document not used later in the study. After an introduction to the document detection pipeline and hologram verification process using orthogonal

[2] `https://youtu.be/720moVaLQdA`



(a)



(b)

(c)

Figure 6: Exemplary samples (original (a), substitute (b), color-copy (c)), created for evaluation consisting of 2-4 elements. They are recorded by using the proposed interface to guide the user towards lighting up each individual part, while automatic matching takes place in the background (left).

sampling, users could get used to the system on their own. We used a gaming metaphor to introduce the concept of constrained navigation to the users (*i.e.*, *eating* circular elements), which seemed to work well for all sessions conducted. Once they felt comfortable, the actual runs started. Original and substitute holograms of the three-element design were presented to the user. They were told to come up with their own decision regarding the validity of the sample after looking at the recorded data. This information was then entered into another form, while the system status, timings and decisions were logged directly onto the flash memory. We randomized the order in which the samples were shown, and we also introduced samples of the four-element design to confuse the user. After all runs were conducted, a final questionnaire on the overall experience was presented to the user along with the possibility to give comments regarding the study. Finally a candy bar was handed over to the user to compensate for the effort. On average, the time spent with each participant was about 15 minutes.

In total, 11 participants (aged M=27, SD=4.91) took part in the study, which were recruited on the university campus. Consequently all of them had a technical background and a general interest in technology, but not necessarily experience with holograms.

Results and Discussion On average, users spent 11 s (M=10.81, SD=3.52) during sampling of the hologram and another 21 s (M=21.18, SD=12.84), while making their decision (see Figure 8). For the evaluated three-element design, all system and user decisions were correct. As the system is able to provide a fully correct decision immediately after image capture, the associated temporal effort for mobile hologram verification of the proposed three-element design corresponds to the same amount. Once such elements are widely adopted, the capture time can be expected to decrease, since people get used to the workflow (see Section 5.1).

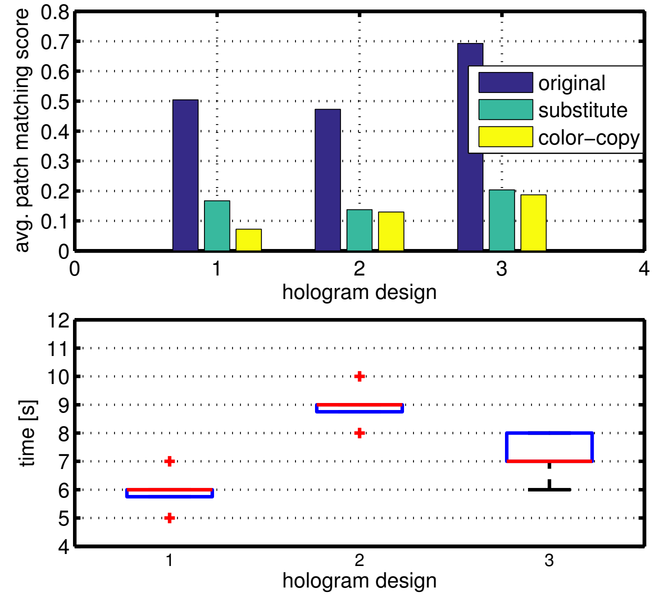


Figure 7: Results of feasibility testing for the proposed hologram designs concerning matching (top) and sampling time (bottom). The three-element design has the best average matching score for originals and poses a reasonable compromise regarding capture time.

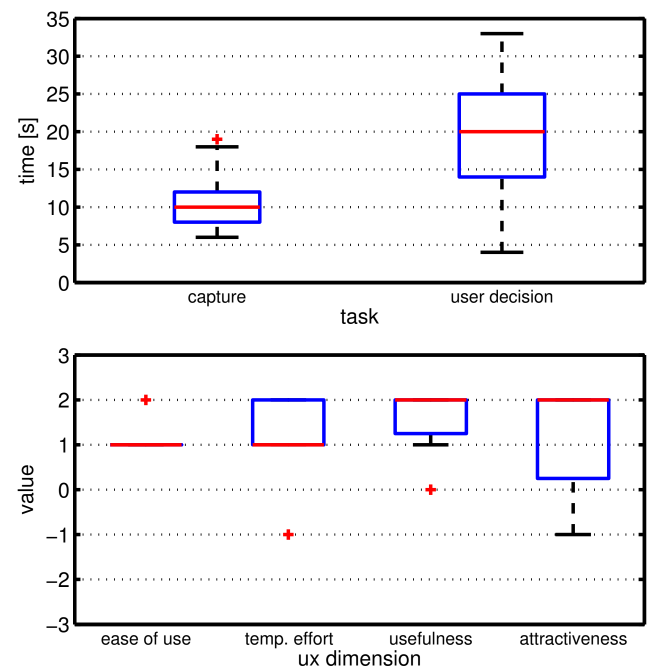


Figure 8: Results of the user study regarding temporal effort and user experience. Holograms can be verified by the system in approx. 11 s, while the user takes another 21 s for coming up with his own decision (top). User experience measures indicate that the interface was easy to use, that the perceived temporal effort was manageable and that people are willing to use the proposed approach for hologram verification (bottom).

An analysis of the collected questionnaires (5-point Likert scales) revealed different results compared to previous work (see

Figure 8). Participants found the prototype easy to use and also rated the involved temporal effort positively. Furthermore, they reported to be willing to use it for the verification of holograms. Although obtained with different samples and using an alternative interface, this is a considerably different result compared to prior art [4]. An analysis of the obtained comments by the users largely supported the result of the questionnaires. Five users pointed out that the interface is intuitive in terms of orthogonal sampling including the reference rectangle and reference circles for guiding the movements. Four users found that, in general, the translational movement in the plane was an easily accessible approach. Only two users mentioned that they had serious problems in terms of interpreting the feedback for orthogonality. They reported to have their personal gaming setups deliberately configured with inverted pitch and, thus, were unable to switch instantly. Consequently, compensation for the error regarding orthogonality was perceived to be quite difficult. Four users added that it would be helpful to emphasize incompletely sampled regions in order to reduce temporal effort for validation.

One user pointed out having problems in terms of double tapping for proceeding to the next step inside the application, because he was simply used to tap and hold interactions. In order to tackle these issues, an additional setup step can be included in the application, allowing the user to invert axes or to customize input commands. In general, the app could be extended to provide support for more user-specific habits. Suggestions for improvement of UI-element design were also stated, especially concerning the placement of buttons for basic interactions like proceeding to the next step or exiting the application. Three users had problems with triggering the buttons placed on the edge of the screen and suggested to increase size and readability or placement to another location on the screen. Similar user feedback was given for important text information located at the edges of the screen, but this could be due to the specific smartphone used for the experiments. Four users were confused regarding the current state of the application. They pointed out that they had problems during the auto-focus operation, not knowing if they could proceed to the next step or not. Two users were questioning the amount of necessary interaction to achieve a final validation with the app. They recommended to add additional elements like a progress bar and to cut unnecessary steps.

Four users requested more background knowledge regarding the criteria for proofing the validity of holograms in general. They also suggested to increase the size of the image presented for patch comparisons in the summary and to highlight the measured differences.

All in all, these results indicate that mobile hologram verification can benefit from a carefully designed security element, in particular regarding user experience and acceptance.

6 Conclusion

We proposed a series of hologram designs suitable for verification using off-the-shelf mobile devices. In contrast to existing holograms, they consist of several elements which can also serve as indicators for local flashlight dominance during inspection. Besides, they are suitable for capture using a purely translational movement over the document. For this task, a novel user interface is presented in order to efficiently guide the user towards hologram verification. An evaluation on the feasibility of the proposed designs gave encouraging results regarding verification performance and task completion time. In particular, a three-element design was selected for further evaluation within a user study involving original and substitute holograms. Results showed that capture can be done in approximately 11 s with perfect accuracy. Moreover, users gave positive feedback regarding the overall usability of the prototype and reported to be willing to use it for hologram verification.

We plan to improve document tracking performance, which generally suffers from specular highlights on individual parts of the security element and to experiment with setting image capture parameters automatically after an assessment of the current distance and sharpness. Alternatively, we consider integrating a marker, providing the basis for tracking, but also a means of identifying reference information for verification. A visualization of the optimal path on the document might further speed up the process. An animation of the eraser device (*i.e*. Pac-Man character) might make it more tempting for the user to fulfill the required movements.

Acknowledgements

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