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Approach to evoking stereovision impressions from images

Abstract. *In this paper we present a new approach, based on a simple 2D to 3D image conversion, to evoke stereovision impressions from images. First, an influence of the red color component shift on the occurrence of a plausible 3D effect is examined. Next, the resulting method for the 2D to 3D image conversion is described. It occurred to be suitable for the real-time realization as it is shown with the presented results of experiments. Among possible applications of the proposed approach are: stereovision post-processing of standard 2D (e.g., archive) photographs and stereovision real-time option for typical 2D monitoring systems.*

Streszczenie. *W artykule zaprezentowano nowe ujęcie problemu konwersji obrazów dwuwymiarowych (2D) do trójwymiarowych (3D) w celu uzyskania wrażeń stereowizyjnych. Badano wpływ przesunięcia składowej czerwonej obrazu na pojawianie się efektu 3D. Przeprowadzone eksperymenty wskazują na efektywność zaproponowanej metody konwersji, która dzięki temu może być realizowana w czasie rzeczywistym. Potencjalne zastosowania zaproponowanego rozwiązania to np.: poprawa jakości standardowych zdjęć 2D i opcja stereowizyjna w typowych systemach monitoringu z obrazowaniem 2D. (**Wywoływanie wrażenia trówymiarowego dla obrazów**)*

Słowa kluczowe: stereowizja, anaglif, konwersja 2D do 3D, postrzeganie efektu 3D.
Keywords: stereovision, anaglyph, 2D to 3D image conversion, 3D effect perception.

Introduction

A three-dimensional scene is a human brain interpretation of two two-dimensional images, which registered by both eyes [1]. A 3D illusion is noticed even if images presented to the eyes are to some extent incorrect, incomplete or inconsistent. In case of a color space like RGB (red, green, and blue), if only one color component e.g. from the left eye view reaches the left eye and two remaining color components from the right eye view reach the right eye, not only a 3D scene is perceived but also quasi-true colors are seen [2, 3]. This effect is used in 2D anaglyph images, which are seen as 3D images when using widely available color (red and cyan) filter glasses [3]. This simple technique has been used in our research for its convenience in performing experiments. In final systems, however, more involved technologies can be used with only straightforward modification of the presented approach, e.g. autostereoscopic screens or synchronous polarization glasses.

A basis to our simple approach to transformation of 2D images into their 3D counterparts is a proper horizontal shift of the red component in appropriate image regions [4]. The influence of the red color component shift parameter on perception of the 3D effect has been examined and circumstances for achieving the best perceived image quality has been studied. In result a new low computational complexity method based on color components shift has been proposed and implemented in an application for real-time 2D to 3D conversion. Such an image processing tool can be applied e.g. as an optional visualization aid for the monitoring operator, helping him/her to stay actively conscious for a sufficiently long time.

The paper is structured as follows. After an introduction in this section, the stereovision impression experiments are presented in Section 2. Section 3 is devoted to the real-time 2D to 3D video conversion and illustration of the prepared application for the presented solution. Final conclusions are formulated in the last section.

Stereovision impression experiments

In order to study the human brain potential to perceive 3D impressions evoked due to the horizontal shift of the red component, a series of experiments has been conducted among students and coworkers at the Division of Signal Processing and Electronic Systems, Poznań University of Technology. Historically, four types of experiments were performed. The first three were preliminary experiments while the newest one, i.e. the fourth one, has been the main experiment. Differences between particular experiment types are of secondary importance and consist merely in the manner and extent the red component could be shifted (consecutively by one pixel in the first experiment version, consecutively with a controlled shift step-length in the second and the third experiment versions, up to the controlled and resolution relative pixel shifts in the fourth experiment type). As older experiments were already described in our previous publications [4, 5], we focus here on the fourth experiment type only.

In our main (fourth) experiment 71 people (mostly students) were examined. Observers were sitting in front of a 24 inch diagonal LCD wide-screen *DELL P2411Hb* with about 0.8 m distance from the viewer to the screen. The examined people wore anaglyph glasses with the red filter on the left eye and the cyan filter on the right eye. Laboratory room was illuminated by artificial light with a little day lighting. The viewers have been instructed that they will observe test images using anaglyph glasses.

Three following images were displayed on the aforementioned screen: *auto* with resolution 767×576 pixels as an example of the frame according to the PAL standard motion-picture camera like in typical CCTV systems, *chopin* with resolution 960×720 from Canon 400D digital camera and *lena_color* with resolution 512×512 pixels as an example of the standard test image (Fig. 1.).


a) b) c)

Fig.1. Images for the main experiment: a) *auto*, b) *chopin*, c) *lena_color*

All images were tested with the red color component shifted by 0, 1.5, 3.0, 4.5, 6.0, 7.5, 9.0 and 10.5% of the original image horizontal resolution to the left and to the right hand side. This results in 15 shift versions for each image. The shift step-length was 1.5% of the image width because longer experiment was too tiring for the examined people and thus the relevant differences between images could be unnoticed. Each viewer saw 45 images. Images were shown starting from the original image (that without any shift) and proceeding with images with the increasing values of the shift parameter alternately to the left and to the right side. The leftmost and the rightmost side regions of the images, i.e. those with lack of one or two color components were cut in order not to disturb in the 3D effect perception.

For the image testing we used the same software application as for the third experiment type described in [5]. An application window during the test of the *chopin* image is presented in Fig. 2. Viewers rated the images by answering to the following 3 or 4 questions depending on whether they saw the 3D effect or not.

The first question was: “Can you see any 3D effect in the picture?” and there were two possible answers: “yes” or “no”. A perceived change (increase or decrease) of the distance between the image and the viewer was interpreted as a visible 3D effect.

The second question was: “Are there any visible artifacts?” with two possible answers: “yes” or “no”. Shadows, phantoms, false colors, or other phenomena, which adversely affects perception of the 3D effect were interpreted as artifacts.

The third question asked: “How does the distance between the viewer and the displayed image change?” and the possible answers were: “increases” or “decreases”. If the observer did not see any 3D effect, this question was deactivated.

The last question was: “What is the perceptible quality of the picture?” and there were three possible answers: “good”, “medium”, or “bad” according to the respective score points: “3”, “2”, and “1” [5]. The image quality assessment was entirely subjective evaluation of the viewers.

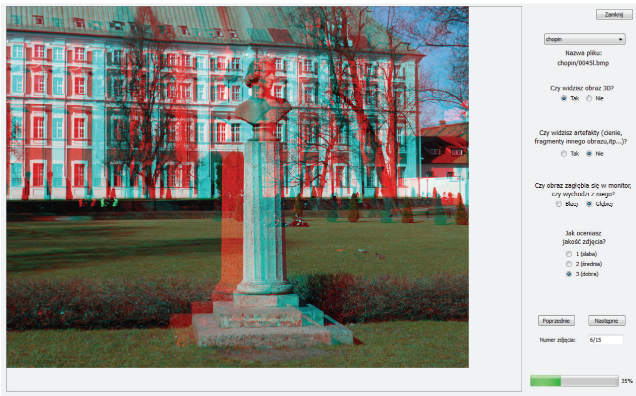


Fig.2. A window of the application used for the image testing (with *Chopin* image)

Fig. 3a) illustrates visibility of the 3D effect for particular images averaged among viewers as a function of the red color component shift. In Fig. 3b) an averaged function for all images is presented. A negative value of the shift parameter means that the red color component was shifted to the left and a positive value means that the red color component was shifted to the right. This rule is also referring to Figs. 4–7. For all three pictures the shapes of the obtained curves are similar. The smallest number of people saw the 3D effect for images without the red color component shift, as expected. The highest number of viewers saw the 3D effect for the red color component shift to the left. Based on these results, the optimal shift value has been found to be 4.5% of the image width. Almost 90% of the examined people saw the plausible 3D effect just for this shift value of the red color component.

Fig. 4a) illustrates visibility of artifacts for particular images averaged among viewers as a function of the red color component shift. Fig. 4b) illustrates the averaged function for all images. Artifacts visibility strongly depends on the image content. Generally, for higher values of the shift parameter, more artifacts are perceived. Artifacts are less visible for the red color component shifts to the left.

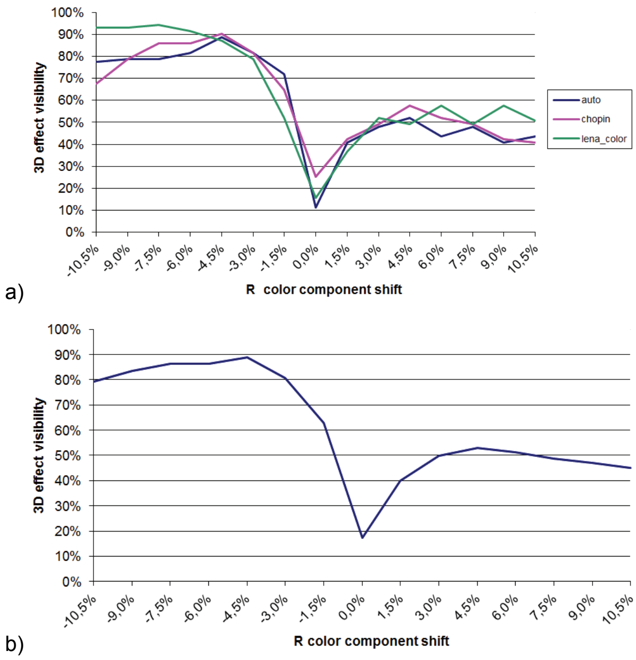
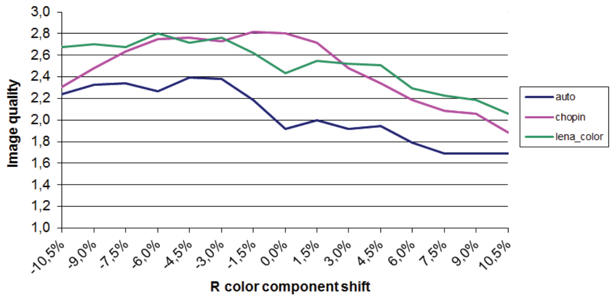


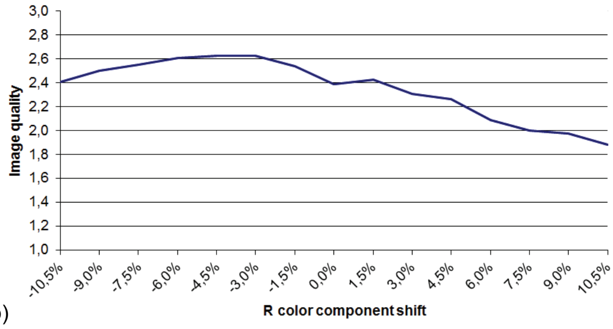
Fig.3. A 3D effect visibility among viewers as a function of the red color component shift: a) for each test image separately, b) averaged for three test images

Fig.4. Artifacts visibility among viewers as a function of the red color component shift: a) for each test image separately, b) averaged for three test images

Fig. 5a) illustrates dependency of the image quality on the red color component shift. An averaged function for all images is presented in Fig. 5b). Images with the red color component shifted to the left hand side seem to have better quality than those with the red color component shifted to the right hand side. Additionally the perceived image quality (similarly to the visibility of the artifacts) strongly depends on the image content.



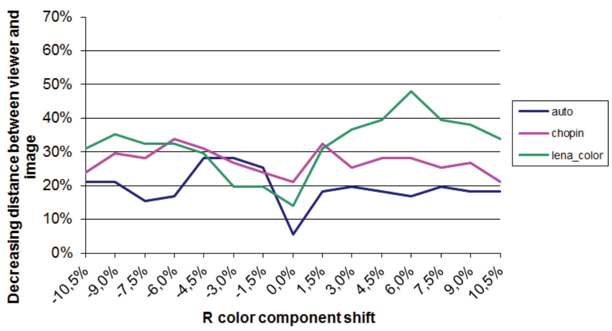
a)



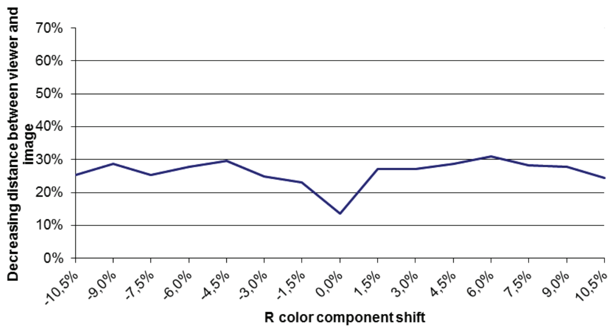
b)

Fig.5. Image quality among viewers as a function of the red color component shift: a) for each test image separately, b) averaged for three test images

Fig. 6a) illustrates impression of visibility of the decreasing distance between the viewer and the perceived image as a function of the red color component shift among those viewers, who perceived the 3D effect of this type. In Fig. 6b) the averaged function for all images is illustrated. The level of impression of the decreasing distance to the image is relatively low and is practically the same for the left- and for the right hand side shift of the red color component.



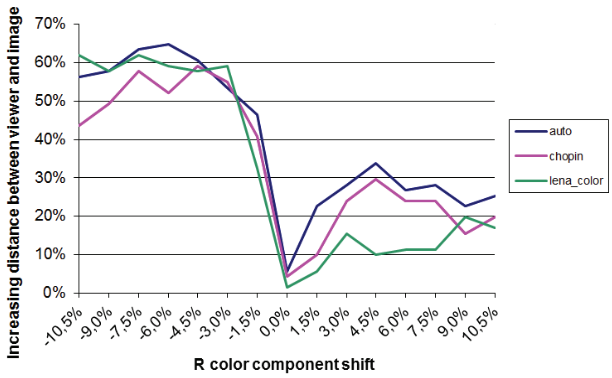
a)



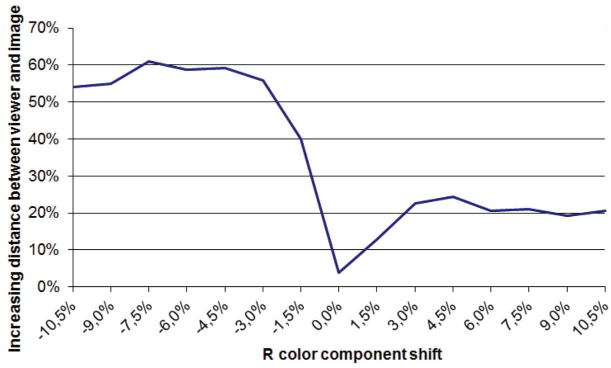
b)

Fig.6. Decreasing distance between viewer and image among viewers visibility as a function of the red color component shift: a) for each test image separately b) averaged value for three test images

In Fig. 7a) we illustrated visibility of the increasing distance between the viewer and the image as a function of the red color component shift among another part of viewers, i.e., those, who perceived the 3D effect of this type. The function values added from Fig. 6 and Fig. 7 are not equal to 100% because there were viewers who did not see any 3D effect could not evaluate any distance change. Fig. 7b) presents this averaged function for all images. A visibility of the increased distance is higher for the left than for the right hand side shift of the red color component.



a)



b)

Fig.7. Increasing distance between viewer and image visibility among viewers as a function of the red color component shift: a) for each test image separately b) averaged value for three test images

Based on the experiment results for a single image viewed by a single person, values of the image quality, the 3D effects, and the artifacts were investigated. These parameters are placed as dots of the dot charts in Figs. 8, 9, and 10, to describe dependences between two chosen parameters. This provides charts with dependencies between the perceived image quality and the 3D effect visibility (Fig. 8), the level of artifacts and the 3D effect visibility (Fig. 9), as well as the image quality and the level of artifacts (Fig. 10) for each image. Individual small blue dots on these charts indicate dependences between two properties averaged for a particular image observed by a particular person. The larger pink dots indicate the values averaged over all the viewers for a given image. Some blue dots overlap but the mean values marked as pink dots are calculated from all relevant (even overlapping) blue dots. These charts allow to determine whether the obtained dependences are repeatable for different kinds of images, or depend on the information content of a particular image.

A dependence between the 3D effect visibility and the perceived image quality for particular test images is illustrated in Fig. 8. Generally, a better 3D effect visibility is obtained for images with the higher values of the rated quality.

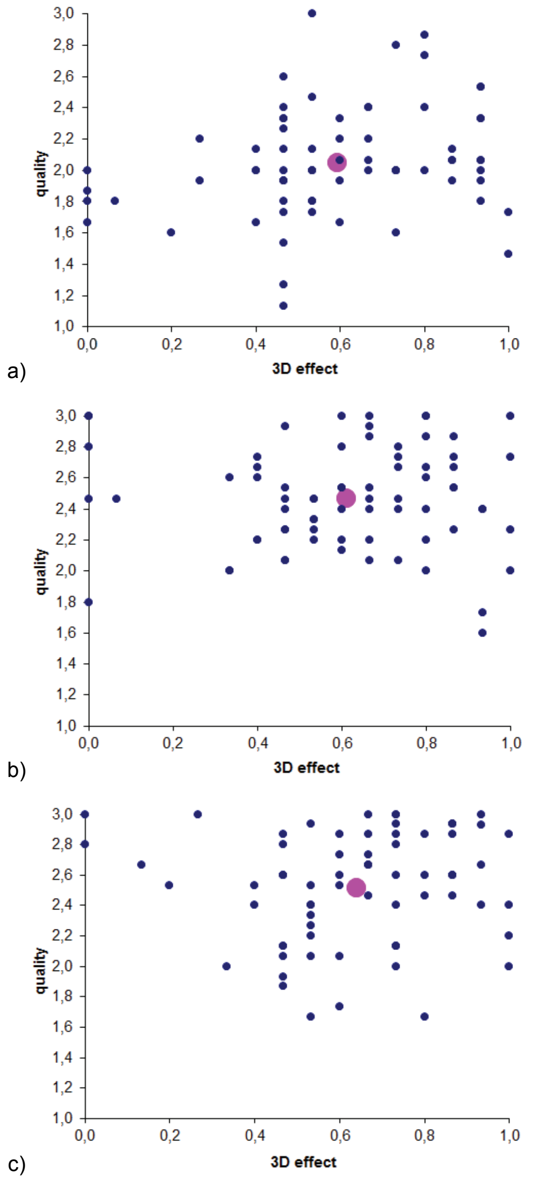


Fig.8. Dependence between 3D effect visibility and image quality among viewers for particular test images: a) *auto*, b) *chopin*, c) *lena_color*

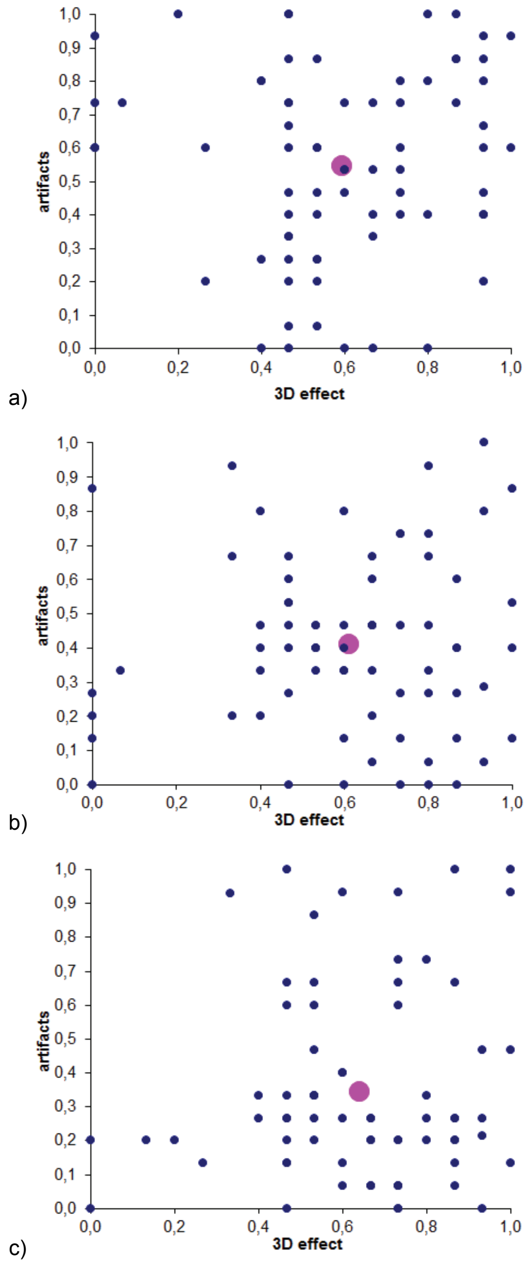


Fig.9. Dependence between the 3D effect visibility and perceived artifacts among viewers for particular test images: a) *auto*, b) *chopin*, c) *lena_color*

Fig. 9 presents dependences of the 3D effect visibility on the perceived artifacts for particular test images among all viewers. It can be noted that there is no distinct dependence between the 3D effect and the visibility of artifacts.

Fig. 10 presents dependences between the artifacts visibility and the perceived image quality among the viewers for particular test images. Similarly, as in the case discussed above, we can observe that there are no distinct dependences between the artifacts visibility and the perceived image quality.

Fig. 11a) illustrates repeatability of the 3D effect visibility for the same shift value for three test images. A 42% large part of the examined people gave at least 80% of unanimous answers for the visibility/imperceptibility of the 3D effect. For 69% of the examined viewers 60–100% of the 3D effect visibility answers for all three test images were entirely repeatable. It means that the 3D effect perception strongly depends on the red color component shift.

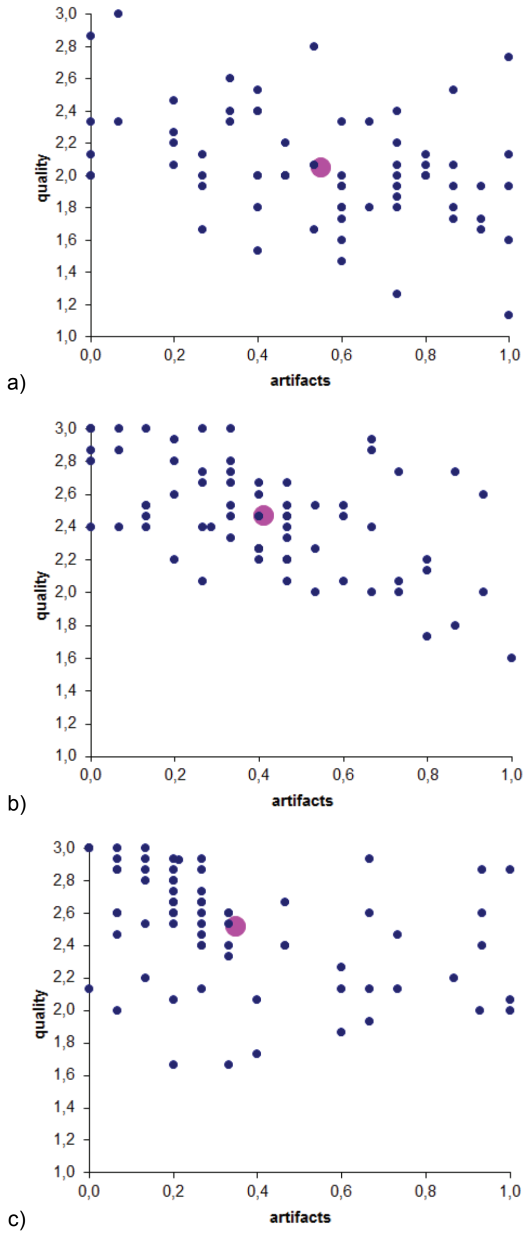


Fig.10. Dependence between artifacts visibility and perceived image quality among viewers for particular test images: a) *auto*, b) *chopin*, c) *lena_color*

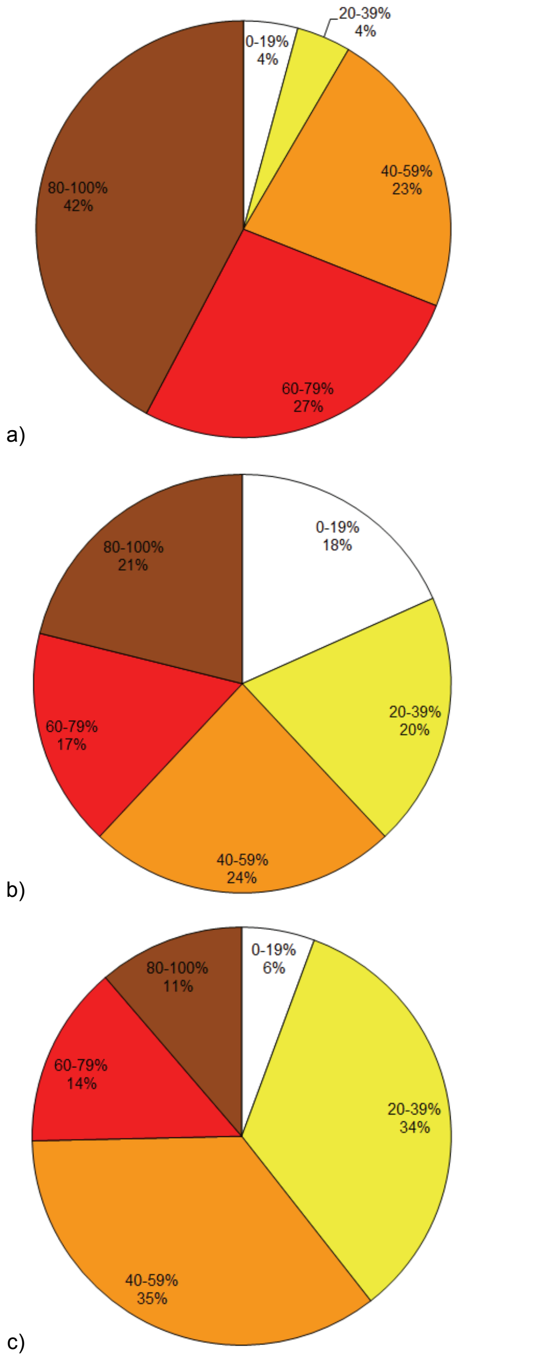


Fig.11. Repeatability of: a) 3D effect, b) change of distance, c) artifacts visibility for the same shift value for three test images; upper percentage value is the repeatability parameter range and the lower value is the percentage of viewers achieving this repeatability range

The repeatability of the change of the distance for the same shift value for three test images is illustrated in Fig. 11b). Only 21% of the viewers gave answers about the distance unanimously in 80–100% of cases. 18% of the viewers gave less than 20% of unanimous answers. Therefore we can assume that the distance perception is not repeatable and it depends on the human brain interpretation of the image content.

In Fig. 11c) a repeatability of the artifacts visibility is illustrated. Only 11% of the viewers unanimously perceived occurrence or absence of artifacts in 80–100% of the cases for three images for the same red component shift. Likewise in the case of the distance perception, artifacts perception is not repeatable and it depends on the human brain interpretation of the image content.

As a result the best observable 3D effect is for the left shift of the red color component with the value of about 4.5% of the image width. Artifacts do not have noticeable influence on the image quality marks.

Summarizing the results discussed above, we can state that the presented method based on the red color component shift allows to obtain a stable, strong, and well acceptable 3D effect. Obtained results encourage us to continue this research with further experiments on the human stereovision impression. Such parameters as the image content, viewer visual defects, age, or gender strongly influence the perception of the 3D effect and should be further examined.

The presented results of our 3D perception experiments constitute a good basis for development of methods for the real-time 2D to 3D image or video conversion.

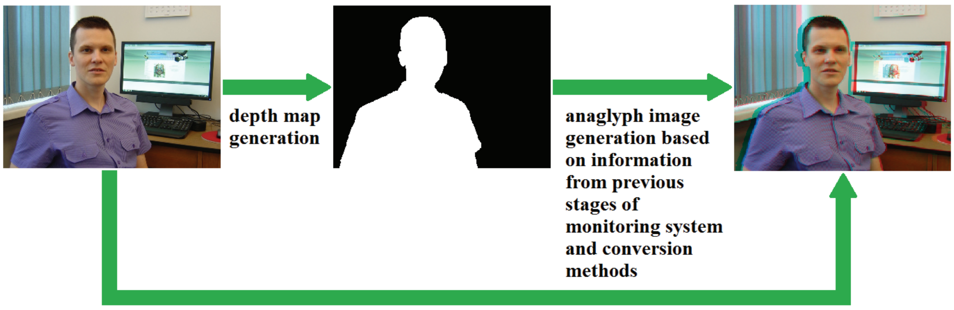


Fig.12. Schema for real-time 2D to 3D conversion system in monitoring system

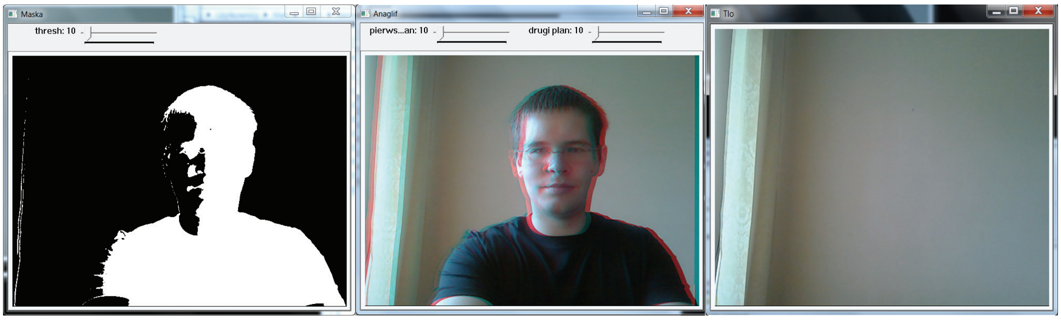


Fig.13. Screenshots from application for real-time 2D to 3D conversion (direct shift method)

Real-time 2D to 3D conversion

In practice the 3D effect should be realized with an efficient 2D to 3D conversion algorithm. It must be simple enough to operate in real-time on real video sequences. The proposed schema for the real-time 2D to 3D conversion system is illustrated in Fig. 12.

An example of the real-time 2D to 3D conversion application implemented using the OpenCV computer vision library is presented in Fig. 13. On the rightmost image the background is shown because the object is detected on the basis of a difference between the background image (obtained from the first frame) and the current image.

Simple methods for the 2D to 3D conversion were proposed in [4] and those based entirely on binary depth maps, according to our new approach, were described in our previous papers [4, 5]. Here we report the experimental results of the prepared real-time software application. Our method is based on intelligent red color component shifts and respective color filling separately for the foreground objects and for the background. The following variants were tested: direct shift, direct shift with interpolation, segment scaling, and segment shifting. They differ in the amount of the red color component distortions (c.f., Figs. 14 and 15). The algorithm details are available in [4] and [5].

As an illustrative example of an application of our 2D to 3D conversion method serves here the 3D option, which can be added to the standard 2D monitoring systems, as it can help to extract information and make the operator's work more attractive. Experiments were performed with a simple 3D impression approach based on anaglyphs.

We propose a mechanism for the real-time 2D to 3D conversion in order to increase the subjective informative content of the observed scene. Additionally, we offer a view diversity and improvement of the perceived quality of images to help the monitoring system operator to stay conscious and active during a quite monotonous and exhausting job consisting in observation the monitor screen(s) for many hours. It has to be stressed that the proposed 2D to 3D conversion (and the appropriate image transformations) are optional, thus they will never burden the monitoring operator. On the other hand, they will be especially helpful in special situations, e.g., if there is an interesting detail, which requires an increased attention.

One of the main facilities of the CCTV (closed-circuit television) systems is detection of motion [6]. Among advantages of using 3D instead of classic 2D views for this purpose are: reduction of false alarms especially in cases of difficult environmental conditions like shadows, reflections, rain, or snow, better operator concentration on the screen, and more precise information extraction (especially with the 3D perception based on two cameras). Additionally, in case of failure of one camera, the system can still operate with the remaining camera(s). Stereovision systems can be used for obstacle and vehicle detection directly in the traffic [7, 8].

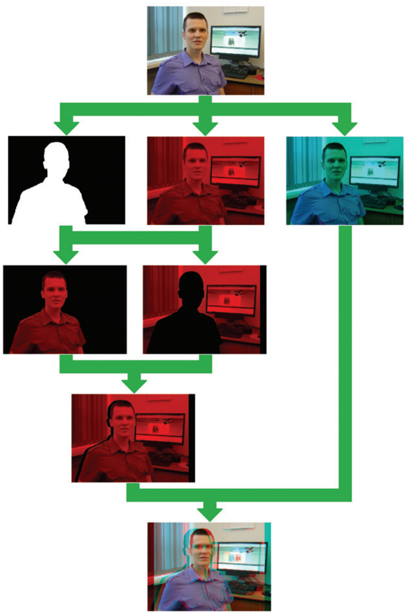


Fig.14. Direct shift method of anaglyph image generation

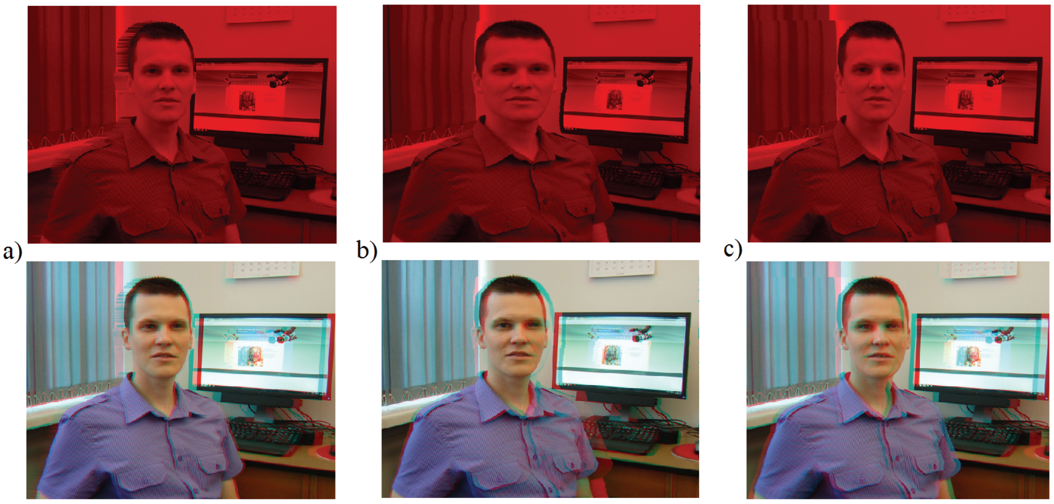


Fig.15. Red color component and resulting anaglyph created using: a) direct shift with interpolation, b) segment scaling, c) segment shifting

Conclusions

Stereovision impressions visualization in a typical 2D monitoring system is possible, e.g., with the use of anaglyph glasses or other equipment like special screens. The scenes are then perceived as if they contained objects at different distances to the viewer. This phenomenon may be used for visualization of important events that have to be noticed and correctly interpreted. Experiments on human 3D perception have been performed and the proper ways of image processing have been found. Due to 3D impressions, the monitoring operator job could be easier as his/her sight may easily be focused on the most important image regions and/or objects such as: people, cars, etc. This method can also help the monitoring operator to notice and remember important details.

One of the main conclusions following from our research is that even with the use of the proposed simple 2D to 3D conversion algorithms a sufficient subjective 3D impression quality can be achieved because of quite tolerant and self-adjusting abilities of the human 3D perception.

The red color component shift to the left gives better 3D effect visibility and lower level of artifacts than the red color component shift to the right, which is a characteristic feature of the human brain interpretation and we can try to find explanation of this problem in future. Experiments on the viewers fatigue during the tests can also be conducted.

The described approach for the image 2D to 3D transformations can be used in CCTV systems for processing both still and video images. The presented method is simple enough to be used in real time. Moreover it offers promising subjective results.

Current state of the experiments with the proposed conversion approach proved its reasonableness and encourages us for the further work on this subject. Thus, our future efforts will be focused on the improvement of the 2D to 3D conversion methods, the best choice of parameters, and comparison of particular method variants.

The paper was prepared within the INDECT and partly DS-2012 project.

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