FUNCTIONALITY ASSESSMENT OF ALGORITHMS FOR THE COLORING OF IMAGES IN TERMS OF INCREASING RADIOMETRIC VALUES OF AERIAL PHOTOGRAPHS ARCHIVES

OCENA FUNKCJONALNOŚCI ALGORYTMÓW KOLOROWANIA OBRAZÓW W ASPEKCIE ZWIĘKSZENIA WALORÓW RADIOMETRYCZNYCH ARCHIWALNYCH ZDJĘĆ LOTNICZYCH

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SUMMARY: Available on the commercial market are a number of algorithms that enable assigning to pixels of a monochrome digital image suitable colors according to a strictly defined schedule. These algorithms have been recently used by professional film studios involved in the coloring of archival productions. This article provides an overview on the functionality of coloring algorithms in terms of their use to improve the interpretation quality of historical, black-and-white aerial photographs. The analysis covered intuitive (Recolored) programs, as well as more advanced (Adobe After Effect, DaVinci Resolve) programs. The use of their full functionality was limited by the too large information capacity of aerial photograph images. Black-and-white historical aerial photographs, which interpretation quality in many cases does not meet the criteria posed on photogrammetric developments, require an increase of their readability. The solution in this regard may be the process of coloring images. The authors of this article conducted studies aimed to determine to what extent the tested coloring algorithms enable an automatic detection of land cover elements on historical aerial photographs and provide color close to the natural. Used in the studies were archival black-and-white aerial photographs of the western part of Warsaw district made available by the Main Centre of Geodetic and Cartographic Documentation, the selection of which was associated with the presence in this area of various elements of land cover, such as water, forests, crops, exposed soils and also anthropogenic objects. In the analysis of different algorithms are included: format and size of the image, degree of automation of the process, degree of compliance of the result and processing time. The accuracy of the coloring process was different for each class of objects mapped on the photograph. The main limitation of the coloring process created shadows of anthropogenic objects, where grey degree values were corresponding to forests.

1. INTRODUCTION

Coloring is a computer supported process to provide color to archival monochrome photographs or films (Burns). In other words, it is a process of assigning the chromatic

values to the luminance values of each pixel of a panchromatic image (Liu, Zhang, 2012) (Levin *et al*., 2004). In literature there are two main methods of coloring distinguished. The first involves assigning a color to each individual pixel, using information about its intensity value and basing on the comparison of DN values of its corresponding pixel of the color image showing a similar object. The second method involves segmentation of the image to regions, to which the algorithm then assigns a uniform color (hue) (Sousa *et al*.). Liu *et al*. (2012) and Cheng *et al*. (2015) indicate a division of existing methods of coloring to scribble-based colorization (a technique using color „daubs") and example-based colorization (coloring based on example RGB images).

In this study archival, panchromatic aerial photograph were colored by tools implemented in commercial software (Magix Video Pro X, Recolored, AKVIS Coloriage 10.0, Adobe After Effects CC, EDIUS Pro 8, Sony Vegas Pro, Movie Studio 13.0, Photoshop CC, DaVinci Resolve 10.1.5) and in an open- source program – GIMP 2.8.16. The test results specified in this article provide an overview on functionality of software on the market in the context of coloring monochrome images.

2.   TEST DATA CHARACTERISTICS

In the studies archival monochromatic aerial photographs of the western part of Warsaw district with various land cover including: forests, crops, exposed soils, water reservoirs and anthropogenic objects, were used (Figure 1). Images of aerial photographs recorded at a resolution of 8 bits/pixel were provided by the Central Documentation Centre of Geodesy and Cartography in Warsaw.

Fig. 1. Monochromatic aerial photograph from 16/05/1982 used for the analysis (left) and color photograph from 16/05/2015 (right)

Used as a reference material in the analysis was a color aerial photograph image of vegetation from same area during a similar period (Figure 1). The potential of this image was limited due to a significant period of time passed from its registration in relation to the monochrome image.

3. REVIEW OF IMAGES COLORING METHODS

In recent years, a growth of interest in the subject of coloring monochromatic images with regard to the broadly understood digital image processing is observed. Many solutions for coloring of individual monochromatic images and their sequence were proposed. Their significant number belongs to semi-automatic methods, which require a specific degree of user interaction.

The term „coloring" was introduced by Wilson Markle in 1970, in order to identify the process of coloring "black-and-white" feature films and television programs. The method of coloring was patented in 1986, which relied on determining the scope of grey level of the individual objects present in each frame of the film and then assigning suitable colors based on common knowledge, survived film props or advertising color photographs (US Patent No: 4606625). In 1987 Gonzalez and Woods used in the coloring process the LUT table, which allowed for assigning to each level of grey in a "black-and-white" image three values that define the color: hue, saturation and brightness. This method does not work when we want to distinguish objects of the same value of intensity. Welsh *et al*. (2002) used the information about the value of intensity and statistics of pixel vicinity in order to find similar elements in the color image and then transfer chromatic values from the matching pixel to the pixel of the monochrome image. This article was inspired by the work of Reinhard *et al*. (2001), which refers to the modification of colors between two color images. Levin *et al*. (2004) presented an interactive method of coloring based on the assumption that the adjacent pixels that have similar levels of grey should have similar colors. It is a method that does not require precisely made manual segmentation. The user indicates by means of color scribbles the inside of the element he wants to color, unlike many programs of graphic processing where exact boundaries of the object are to be outlined. However, as a result of inaccurate determination of boundaries, the color of the object is often incorrectly transmitted to other elements. Irony *et al.* (2005) applied in the coloring process a division of the reference color image to regions obtained as a result of segmentation. Abadpour i Kasaei (2007) developed a method for coloring monochrome images as well as changing the color palette of a color image using the advantages of Principal Component Analysis (PCA). Liu *et al*. (2008) proposed a method of a type example-based relying on differences in the luminance between a monochrome image and a reference color image, wherein RGB images of similar objects were searched for on the Web. Liu and Zhang (2012) used a locally weighted regression LWR of the monochrome image histograms and the reference color image. Zhang *et al*. (2016) applied Convolutional Neural Networks (CNN). Lipowezky (2006) proposed a method for the coloring of satellite images and aerial photographs in the scale of grey. He based his research on the finding that objects of similar textures should have similar colors.

4. REVIEW OF IMAGERY COLORING PROGRAMS

The development of image processing technologies and the application of image data in many areas of the economy have contributed to the rapid increase in the number of commercially available graphic programs. The algorithms implemented in them vary in the degree of technical sophistication. Some of these programs are very intuitive for the user

and are applied to the processing of single photographs, while others are complex applications that allow performing advanced transformations of image sequences. This section is a brief compendium of the commercially available software for graphic processing of images in the context of coloring.

4.1. Magix Video Pro X

Image formats handled by Magix Video Pro X include: BMP, GIF, JPEG, PNG, TIF, TGA. It is possible to export image data to the formats: BMP, JPEG (maximum image size equal to 9600 x 9600 pixels). The program enables the application of image masks of a specific shape with the possibility of their graduation. The lack of a tool that enables to define irregular shapes on photographs excludes the use of masks created within the software in the coloring process of monochrome aerial photographs. A useful function is Substitution that enables converting a monochrome image into a three-channel image (Figure 2).

Fig. 2. Monochrome image and the image obtained by using the Substitution tool in Magix Video Pro X (own development)

Therefore the obtained image in the RGB composition can assist the process of coloring archival aerial photographs in the range of distinguishing green objects from exposed soils. The resulting color image contains a number of errors related to construction works, shadows and water represented by the color green. For this reason, the Substitution tool cannot be used as a target method for coloring black-and-white photographs.

4.2. Recolored

Recolored allows coloring monochrome images by using Strokes. The process of transmitting colors is based on a coarse outlining of the object, after prior selection of the appropriate color (RGB or IHS space). The method based on color outlines has been described, among others, in the work (Lavin *et al.*, 2004). The program allows for working on images in BMP, JPEG and PNG formats. Limitations of Recolored in the context of coloring aerial photographs relate to the dimensions of the source image and the need for

outlining a number of relatively small elements present in the image. In order to color the test image, its dimensions were reduced to 1074 x 1300 pixels (Figure 3).

Fig. 3. From the left: a fragment of monochrome image, distribution Strokes, resulting colored image (own development)

The presence of erroneously colored pixels is linked to the lack of making outlines of all elements of the image and the wrong color propagation to the adjacent pixels (e.g. from roofs to shadows). Technique Strokes was also used in AKVIS Coloriage 10.0. The advantage of this program compared to Recolored is that it relies on the ability to work on the source image without the necessity of degrading its dimensions.

4.3. Adobe After Effects CC

In Adobe After Effects there is the possibility to import raster files in many popular formats: BMP, JPG, IMG, PNG, PSD, GIF, TIF. The results of transformations can be saved, among others, in formats: JPG, PNG, PSD and TIF. The software allows working on the whole image of the aerial photograph, without the necessity to split it into fragments.

In the image coloring process the image should be manually defined into masks, separately for each photographed element (Figure 4).

Fig. 4. From the left: the original image, image with overlaid mask of a forest (own development)

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Adobe After Effects is equipped with a Roto Brush tool, which supports the process of tracking a specific object appearing in the images sequence. However, it does not change the fact that in order to apply a color, the process of object selection should be supervised and corrected. The program does not allow performing an automatic detection of objects characterized by similar distribution of grey levels in relation to the objects defined.

4.4. EDIUS Pro 8

This Grass Valley program enables handling the raster files in formats specific to 19 different graphic environments, of which the most popular are: GIF, JPEG, PNG, PSD, TIFF and Windows Bitmap. Using the 3-Way Color Correction tool the balance of white, black and grey can be changed (Figure 5), as well as YUV curves modified (Figure 6).

Fig. 5. From the left: the original image, image after changing balance parameters of white and black
(own development)

Fig. 6. Images after changing balance parameters of white and black and modification of YUV curves
(own development)

Fig. 7. Monochrome image (left), the resulting color image (right) (own development)

Edius tools allow for the automatic application of colors from green to beige on monochrome images. As a result, the colored image (Figure 7) is more realistic as compared to the results obtained from Magix, however, it contains also many erroneously colored pixels e.g. green buildings.

4.5. Sony Vegas Pro

Sony Creative Software enables working on images in popular formats such as: GIF, JPEG, PNG, PSD, TIFF, BMP. Using the available color adjustment functions or color curves makes it possible to obtain the color images provided below.

Fig. 8. Colored images obtained in Sony Vegas Pro (own development)

The tool used did not allow for the application of true colors to the archival black-and-white aerial photographs (Figure 8). Similar results are obtained in Movie Studio 13.0.

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4.6. Photoshop CC

This Adobe Systems program allows working on images in all popular recording formats (GIF, JPEG, PNG, PSD, TIFF, BMP, Targa) and exporting the results to a file of the same extension. Photoshop provides tools for automatic selection of elements present in the image. The Magnetic Lasso tool is dedicated to create a selection of objects clearly contrasting with the background, and the Magic Wand tool function is used to mark elements with specified ranges of grey level value. As a result of the modification of color balance and creating masks by the above mentioned tools (Figure 9), it was obtained respectively, the overall or partial coloring of images.

Fig. 9. The image obtained by modifying the balance of colors and masking by Quick Selection tool (left) and as a result of masking by Magic Wand tool (right) (own development)

In order to color the whole image, a manual or automatic selection of each object must be made, which would lead to an erroneous increase in the scope of grey levels values describing the object. In particular, it refers to pixels with high values of grey level located between pixels representing trees.

4.7. GIMP 2.8.16

GIMP enables working on raster files in many formats (BMP, GIF, JPG, PNG, TIFF, PSD) without having to reduce their sizes. The program has tools (Fuzzy Select and Select By Color) that provide automatic outlining of the image element with comparable values of the level of grey. Both tools are used for outlining the objects with sharp edges, contrasting with the background. The first one allows marking one object (all pixels, qualified as one object adjoin each other), while Select By Color outlines all clusters of pixels in the image which satisfy the condition of similarity in value of grey level to the initially indicated pixel (disjoint objects in the entire image). None of the above mentioned tools takes into account the texture of photographs of objects. Another method of coloring available in GIMP is manual masking without using the function of automatic outlining of individual objects.

Fig. 10. Original image (left), the resulting image obtained by using tools for automatic outlining of objects (right) (own development)

Coloring of a black-and-white aerial photograph in GIMP (Figure 10) does not show the expected results and is reduced to the coarse grouping of pixels according to their grey level values.

4.8. DaVinci Resolve 10.1.5 Lite

Blackmagic software, known on the market of video services, enables working on images in formats: TIF, JPG, PNG, DPX, EXR, DNG, PSD.

Fig. 11. Images obtained by modifying the balance of colors (own development)

The software has tools for adjusting the balance of colors (Figure 11) and for selection of panchromatic image elements of interest to the user basing on grey level values. There is a possibility to make a regular mask or a shape set by the user. Additionally, there is also a function of tracking the object in the image sequence.

5. ANALYSIS OF COLORING RESULTS

Visual analysis of the obtained color images allowed for making a preliminary assessment of the effectiveness of the coloring process. The analysis was performed for algorithms that allow to apply colors to each pixel of the image i.e. Magix, Recolored, EDIUS, Sony Vegas and DaVinci on a representative portion of the image basing on the four distinguished classes of land cover (forest, low vegetation, exposed soils, anthropogenic objects) (Figure 12). Selected for each class were 20 points occurring mainly in areas where the expected accuracy of the coloring was the lowest. The correctness of classification of all points was checked by visual comparison of the panchromatic and color image portion.

Fig. 12. From the left: the distribution of analysed points, the resulting images: Magix, Recolored, EDIUS, Sony Vegas, DaVinci (own development)

A matrix of errors was created for each resulting image and calculated was the value of the classification accuracy index *oa*.

$$oa = \frac{\sum_{i=1}^{m} p_{ii}}{\sum_{i=1}^{m} \sum_{j=1}^{m} p_{ij}} \tag{1}$$

The index is a quotient of the sum of correctly classified pixels p_{ii} and the sum of all pixels subjected to the analysis p_{ij} (Walczykowski, Jenerowicz, 2016).

Specified below are the values of the total coloring accuracy (Table 1) and values of accuracy for individual classes of the covering (Figure 13).

Table 1 Values of the total coloring accuracy expressed in percentage for individual algorithms of the coloring

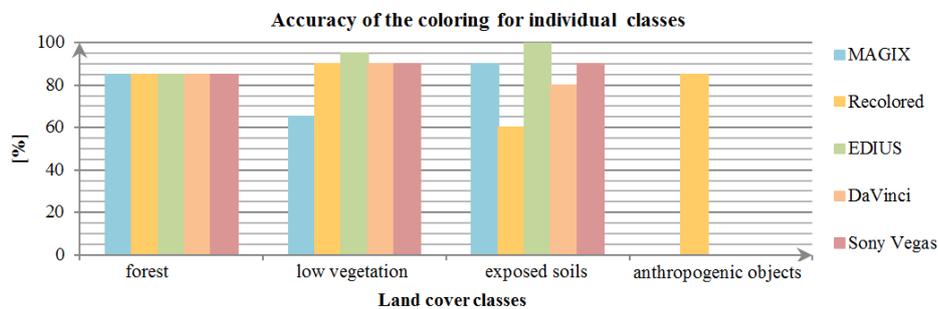| Software	Magix Video Pro X	Recolored	EDIUS Pro 8	Sony Vegas Pro	DaVinci Resolve 10.1.5
Toral accuracy of the coloring process [%]	60	80	68	66	64

Fig. 13. Diagram showing values of the coloring accuracy for individual classes of land cover expressed in percentage (own development)

The best results of the analysis of the coloring accuracy value were obtained by using Recolored tools. None of the other tested semi-automatic tools allowed for the detection of anthropogenic objects. While excluding from the analysis anthropogenic objects, among the tested semi-automatic tools distinguished was EDIUS, characterized by the highest values of coloring accuracy in each class, and hence the highest total accuracy of coloring which equals to 68%.

6. SUMMARY AND CONCLUSIONS

Programs used in the research vary in the degree of conversions advancement and interface intuitiveness. The simplest to use appeared to be the applications based on „color outlines" (Recolored, AKVIS), and the least intuitive was DaVinci Resolve.

Tools of the analysed programs allow for manual or semi-automatic coloring of black-and-white digital images. In the case of semi-automatic methods, the obtained color images contain a number of incorrectly colored pixels caused by the propagation of color between adjacent elements of the cover, as well as by the lack of masking of all small objects present in the image. The presence of so called faulty pixels is caused by the limitation of implemented algorithms, depending on the selection of objects based only on the difference

of grey level value without regard to their texture. Functions of the tested programs allowed to carry out only the rough coloring of monochrome images by the manual or automatic defining of masks for individual objects (Magix, After Effects, Photoshop, GIMP, DaVinci Resolve), color outlines (Recolored, AKVIS) and to modify the balance of colors (Magix, After Effects, GIMP, EDIUS, Sony Vegas, Photoshop, DaVinci Resolve). None of the tools used ensured the required coloring effectiveness of aerial images. This is confirmed by the performed visual analysis, according to which the total coloring accuracy for the applied semi-automatic tools equals to 60 - 68 %. The coloring accuracy of black-and-white aerial photographs increases with the degree of human intervention (Recolored – 80 %). Applications offered on the market are intended to increase the visual appeal of digital images, but they do not work in the case of the coloring process for archival aerial photographs, due to their large information capacity.

By increasing the interpretation capacity of archival aerial images, the coloring process can enter to current trends in remote sensing development (Borkowski *et al.* 2012). The challenge for this type of action is to develop a fully automated algorithm for coloring black-and-white aerial photographs, which with high efficiency could greatly improve the interpretation quality of an aerial photograph image, especially if it applies to historical photographs (Ewiak, Brodowska, 2012). This article shows that the coloring process is complex and the algorithmic solutions existing on the market are not suitable to meet the demands of professionals involved in the analysis of contents of historical aerial images. The basis for high efficiency of the coloring process of monochrome aerial photographs relies on finding a mathematical dependence between the value of grey level of any monochrome image pixel and its equivalents in different color channels, which should also take into account the technical and external conditions that accompany the execution of the photograph.

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Streszczenie

Na rynku komercyjnym dostępnych jest szereg algorytmów umożliwiających przypisanie pikselom monochromatycznego obrazu cyfrowego odpowiednich barw według ściśle określonego schematu. Algorytmy te są wykorzystywane przez profesjonalne studia filmowe zajmujące się kolorowaniem archiwalnych produkcji. Niniejszy artykuł stanowi przegląd funkcjonalności algorytmów kolorowania w zakresie możliwości ich wykorzystania do poprawy jakości interpretacyjnej historycznych, monochromatycznych zdjęć lotniczych. Przedmiotem analiz były programy intuicyjne (Recolored), a także bardziej zaawansowane (Adobe After Effect, DaVinci Resolve). Ograniczeniem wykorzystania ich pełnej funkcjonalności była zbyt duża pojemność informacyjna obrazu zdjęcia lotniczego. W przypadku monochromatycznych historycznych zdjęć lotniczych, których jakość interpretacyjna w wielu przypadkach nie spełnia kryteriów stawianych opracowaniom fotogrametrycznym, istnieje potrzeba zwiększenia ich czytelności. Rozwiązaniem w tym zakresie może być proces kolorowania obrazów. Autorzy artykułu przeprowadzili badania zmierzające do ustalenia, w jakim zakresie testowane algorytmy kolorowania umożliwiają automatyczną detekcję elementów pokrycia terenu na historycznych zdjęciach lotniczych oraz nadanie im barwy zbliżonej do naturalnej. W badaniach zostały wykorzystane archiwalne monochromatyczne zdjęcia lotnicze powiatu warszawskiego zachodniego udostępnione przez Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej, których wybór wiązał się z występowaniem w ich obrębie różnorodnych elementów pokrycia terenu, takich jak: wody, lasy, uprawy rolne, odkryte gleby, a także obiekty antropogeniczne. W analizie poszczególnych algorytmów zostały uwzględnione: format i rozmiar obrazu, stopień automatyzacji procesu, stopień zgodności wyniku oraz czas przetworzenia. Dokładność procesu kolorowania była różna dla poszczególnych klas obiektów odwzorowanych na zdjęciu. Głównym ograniczeniem procesu kolorowania były cienie obiektów antropogenicznych, których wartości stopni szarości odpowiadały lasom.

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