BIOMEDICAL IMAGE COLORIZATION USING PIXEL MEMBERSHIP PROPAGATION

Summary. In the paper we present a new algorithm of biomedical image colorization based on distance transformation and modified bilateral filtering approach. The method utilizes the scribbles inserted by the user to properly cover the image regions with desirable colors. We present the idea of our algorithm, explain the role of tunable parameters and provide some examples of biomedical image colorization using our approach.

Keywords: biomedical image processing, colorization, segmentation

KOLORYZACJA OBRAZÓW BIOMEDYCZNYCH OPRATA NA MECHANIZMIE PROPAGACJI PIKSELI

Streszczenie. W artykule przedstawiono nową technikę koloryzacji, wykorzystującą transformatę dystansową oraz modyfikację filtru bilateralnego. Proponowana metoda opiera się na wskaźnikach koloru wprowadzanych przez użytkownika w celu zgrubnego początkowego zaznaczenia oczekiwanych kolorów dla poszczególnych elementów obrazów. W artykule wyjaśniono zasadę działania algorytmu, role jego parametrów oraz przedstawiono przykłady barwnych obrazów biomedycznych uzyskanych dzięki proponowanej nowej technice.

Słowa kluczowe: przetwarzanie obrazów biomedycznych, koloryzacja, segmentacja
1. Introduction

The grayscale medical images are obtained in several diagnostic techniques, like in computer tomography (CT), ultrasonography (USG), magnetic resonance (MRI), transmission electron microscopy (TEM) or in infrared imaging (IR) [1, 2, 3]. Such images are usually difficult to analyze, since the diagnosed human internal organs have to be assessed only by the analysis of pixel intensity variations. Therefore, the colorization, which adds color information to monochromatic images, plays an important educational and diagnostic role in medical imaging as it enables more detailed view of the region of interest and allows for highlighting the pathological tissues.

In general, there are two types of colorization: automatic and semiautomatic. Due to the fact, that in medical applications there is a strong requirement of physician supervision, the semiautomatic algorithms are usually more preferable. Such algorithms utilize the idea of scribbling the image, i.e. introducing color hints, to indicate coarsely which image part should be colorized with a given color.

One of the most cited semiautomatic colorization algorithms was described in [4, 5]. The authors present the utilization of the minimization of color differences between adjacent pixels and make an assumption, that the neighboring pixels with similar gray scale intensities should also have similar colors. Some of the image pixels are given the colors of inserted scribbles, while for the remaining ones the color is estimated by the minimization employing the Least Squares approach.

The use of digital paths between adjacent image pixels were investigated in [6, 7, 8] The authors compute the membership arrays for each scribbled color, which capture the distance (topographic and/or intensity-based) between a scribble and any other image pixels. Those arrays are calculated with either the distance transformations or using the Dijkstra’s algorithm and are utilized in the final color blending.

In this article, we present a novel colorization method, which is a modification of already elaborated algorithms introduced in [6, 8]. We combine the distance transformation [9] and bilateral filtering [10] to create a novel technique, which allows for high image colorization quality. In the remainder of this paper we show the construction of our algorithm and explain the role of the tunable parameters. We also exhibit some exemplary results of applications of the proposed colorization method in various biomedical imaging modalities and describe the plans for future improvements of this algorithm.
2. Algorithm

Our algorithm utilizes the idea of color blending, where every image pixel is given the membership to each color indicated by a user. To calculate the membership array for a single color, we utilize the schema inspired by the bilateral filtering in the processing order given by the pixel distance from a scribble. The final color estimation in a given pixel is obtained from the weighted average of all inserted colors, where the weights are taken from the membership maps.

In the first step of the algorithm we determine the topographic distance from the scribbled region to each of the image pixels. It is accomplished with the use of distance transformation [11] and the double-scan algorithm [9]. Initially, the distances are assigned to every pixel, so that the scribbled ones are assigned 0 and all other pixels are given $\infty$. Then, the sliding operational window (as presented in Fig. 1) is moved over the image twice, in a manner specified in Fig. 2, which is called the double-scan. There are several possible window shapes employed in distance transformation [12] however the simplest one was chosen, due to its lowest computational burden. The distance values are replaced in each step of sliding window, using the following formula:

$$d_0 = \min_i \{d_0, d_i + 1\},$$  

(1)

where $d_i (i = 1, 2, 3, 4)$ denotes the distance transformation value for pixel $P_i$. Eventually, after both scans, the estimations of Euclidean distances are obtained (see the consecutive distance estimation steps in Fig. 3). The procedure is repeated for each of inserted scribbles. The presented step of our colorization schema allows for specifying the order of memberships assignment in the next stage of the algorithm.

![Fig. 1. The masks utilized in double-scan algorithm.](image)

(a) Mask in first scan.  
(b) Mask in second scan.

Rys. 1. Maski wykorzystane w algorytmie double-scan.
In the next part, we establish a membership arrays for all scribbled colors. Initially, all the pixels are given 0 membership value, while the scribbled ones receive 1. Then, the pixels membership values are processed in the order defined by previously calculated distances (i.e. we start from pixels neighboring with the scribble and move toward the image boundary).

As the membership assignment is inspired by the bilateral filtering, we would like to first introduce its basis. This filtering approach was initially presented in [10] and was utilized for Gaussian noise suppression. In the original concept, the local neighborhood window slides through the image and replaces the intensity of window central pixel by the weighted average of intensities of its neighbors:

$$J_0 = \frac{1}{Z} \sum_{k=1}^{N^2} I_k e^{\left(\frac{(I_0-I_k)^2}{2\sigma_I^2}\right)} e^{\left(\frac{d_k^2}{2\sigma_d^2}\right)}$$

where $N\times N$ operational window is utilized, $J_0$ is the new estimation of the central pixel intensity, $Z$ is normalizing factor, $d_k$ is the topographic distance between $k$-th and central window pixel, $\sigma_I$ and $\sigma_k$ tune the influence of respectively, the intensity difference and the pixel's distance, on final smoothing. An exemplary $5\times5$ local operational window, with assigned distances to each window pixel, is exposed in Fig. 4. The bilateral filtering, in contrast to linear filtering algorithms, is capable of preserving the sharp edges in filtered images.
Inspired by the bilateral filtering approach, we propose to modify this schema to calculate the membership values in colorization algorithm. Instead of the weighted average, the maximum function is employed and also the distance weighting is removed. Our experiments revealed that the application of weighted average (instead of maximum), as in the bilateral filtering, leads to a very quick membership decrease thus only the pixels neighboring with a scribble are colorized properly. Similarly, the distance weighting, significantly hinders the transfer of colors from scribbles to distant pixels, making the colorization outcomes unsatisfactory.

The membership calculation is proceeded in the order defined by the distance transformation, i.e. starting from the pixels close to the scribble. The following processing formula, employing the exponential function of squared pixel intensity differences, is used:

\[
M_0 = \max_{k=1,\ldots,N^2} \left\{ M_k \exp \left( \frac{(I_0-I_k)^2}{2\sigma^2} \right) \right\},
\]

where \(M_0\) is the new estimation of membership of central pixel in a window, \(M_k\) \((k \geq 0)\) is the membership of \(k\)-th pixel in a window, \(I_k\) stands for the intensity of \(k\)-th pixel and \(\sigma\) is the parameter responsible for the strength of membership decrease. In such filtering design, the membership values are propagated between the pixels using the maximum operator (3), thus we name such a technique: the pixel membership propagation. The values of \(M\) gradually decrease from 1 (within the scribble) to 0 (far from the scribble) and the decrease is proportional to the encountered intensity differences. Therefore, any sharp edge significantly lowers the memberships, indicating that the pixels should not be colorized with a given color (see Fig. 5).
In the last part of our algorithm we modify only the chrominance of the image pixels, so that the intensity pixel component remains unchanged. The final chrominance is obtained by the weighted average of chrominance levels of all indicated colors, where the weights are taken from the membership arrays:

$$C_p = \frac{\sum_{s \in S} C_s M_s}{\sum_{s \in S} M_s},$$

where $C_p$ is an assigned chrominance of pixel $P$, $C_s$ is the chrominance of scribbled color $s$ from the set $S$ of all scribbled colors, $M_s$ is the membership of pixel $P$ to scribbled color $s$. After such a color blending, each pixel is given the color in accordance to its membership value to the corresponding color scribble. The result of colorization of the CT image presented in Fig. 5, is exposed in Fig. 6.

Fig. 5. Exemplary membership arrays. The gray scale map was chosen so that white and black level correspond respectively to full and no membership ($M = 1$ and $M = 0$)

Rys. 5. Przykłady macierzy przynależności. Odcienia szarości zostały dobrane tak, aby biały i czarny odpowiadały pełnemu oraz zerowemu stopniowi przynależności ($M=1$ i $M=0$)

Fig. 6. Colorization outcome for CT image presented in Fig. 5 ($\sigma = 20$, $N = 5$)

Rys. 6. Wynik koloryzacji obrazu CT zaprezentowanego na rysunku 5 ($\sigma = 20$, $N = 5$)
3. Tunable parameters

In the proposed method we introduced two tunable parameters: the strength of membership decline $\sigma$ and the size of local neighborhood $N$. Both of them influence the final colorization and should be adjusted to achieve desired colorization effect.

The $\sigma$ parameter, by its impact on membership calculations, influences mainly the final color blending level. If the boundary between the colorized regions should be sharp, then the lower $\sigma$ has to be applied. However, if one prefers smooth transitions between the colors, the higher $\sigma$ is suggested (see exemplary colorization effects, for two extreme $\sigma$ values, in Fig. 7).

This effect appears due to the fact, that $\sigma$ adjusts the level of membership decrease when the intensity gradients are encountered in an image. For low $\sigma$ values, even small brightness differences between adjacent pixels result in significant membership reduction. This leads to creation of sharp borders between the regions of different colors. On the other hand, higher $\sigma$ results in strongly blended (soft) colorization outcomes, as the weights ($M_k$) utilized in final blending (4) are close to each other.

![Colorization results for two extreme $\sigma$ values](image)

(a) $\sigma = 1$  
(b) $\sigma = 200$

Fig. 7. Colorization results for two extreme $\sigma$ values
Rys. 7. Wyniki koloryzacji dla dwóch ekstremalnych wartości parametru $\sigma$

The window size parameter $N$ modifies the area of details, which can be neglected during the membership calculation. If the image is highly textured (or contains impulsive noise), then higher $N$ is suggested, so that the smallish details do not disturb the membership transfer from scribbled pixels. An example of application of higher $N$ for better region separation in textured TEM brain tissue image is presented in Fig. 8.
4. Comparison with other methods

For comparison of the colorization quality of our algorithm with the outcomes of widespread algorithms, a complex TEM image example was utilized. Several scribbles were inserted to colorize the objects included in the registered scene. We implemented or used the available code for the following popular colorization methods: Colorization Using Optimization [4, 5] (CUO), Chrominance Blending Colorization (CBC) [7], and Distance Transformation based Colorization (DTC) [6].

The comparison results, presented in Fig. 9, indicate that the quality of our colorization is at the same, high level as for the other state-of-the-art methods. It is to be noted that the precise estimation and rating of the colorization outcomes is complicated and time-consuming process, as it is because each algorithm is tuned by at least two adjustable parameters, which can significantly affect the final outcomes. Therefore, in this paper we limited the comparison to the visual assessment of results which proves that our algorithm can provide colorized images of similar, high quality.

In contrast to the currently available colorization methods, the proposed approach allows for avoiding obstacles while assigning membership values to pixels. It is due to the usage of maximum membership in a local window (3), which can be enlarged to reject minor defects or foreground objects. To the best of our knowledge, there is no method, which is similarly robust against such type of impulsive noise. As an example, in Fig. 10, we show a part of microscopic image crossed by several black lines, which may be considered as defective image regions, annotations, grids, etc. Only the proposed method was capable to properly colorize the regions associated with various objects, while all other methods failed. This advantage of our method can be utilized when colorizing images disturbed by any kind of unwanted artifacts.
Fig. 9. The outcomes of colorization of biomedical microscopy image provided by various algorithms

(a) Scribbled test image  (b) Scribbles
(c) CUO  (d) CBC  (e) DTC  (f) Proposed  
\((N = 3, \sigma = 20)\)

Fig. 10. The colorization of biomedical image corrupted by artifacts

(a) Scribbled test image  (b) Scribbles  
(c) CUO  (d) CBC  (e) DTC  (f) Proposed  
\((N = 5, \sigma = 20)\)
5. Applications

There are several benefits from using colorization in biomedical images. First, it may be applied for better visualization of different structures for the educational purposes. It can be also helpful during the image assessment and sharing the opinions and diagnosis between the physicians. We should also note the additional capability of colorization to segment images. It can be accomplished by simple classification of pixels according to the largest membership values, where the number of classes equals the number of indicated colors. In Fig. 11 we present some examples of applications of our method in various imaging techniques widespread in medical diagnostics.

6. Summary

A novel method of biomedical image colorization has been presented in the article. The novel approach is inspired by the bilateral filtering scheme, which enables the calculation of membership of pixels to given scribbled color. The method utilizes also the distance transformation to obtain the order of pixels processed in the filtering phase. Two tunable parameters are introduced, which allow the user to modify the final color blending and the algorithm robustness against local textures and artifacts. By the adjustment of those parameters, one may easily fulfill the colorization requirements in any, even annotated or corrupted, biomedical image. We presented also several high-quality colorization examples of images obtained by different techniques, widely used in medicine.

We plan to extend the capabilities and investigate further some of the parts of our algorithm. We will test the possibility of using median or trimmed mean instead of current maximum function. Various shapes of the filtering window will be also evaluated to assess their usefulness for colorization of a specific image type. We also consider an adaptive colorization design, wherein the mask size changes as the varying textures are encountered within the image.
Fig. 11. Examples of colorization of biomedical imaging by our algorithm. Corresponding images include (from top to bottom): USG image of human joint, the TEM image of a human lung trachea, a CT slice through human brain, the infrared finger vascular system.

Rys. 11. Przykłady koloryzacji obrazów biomedycznych. Od góry: obraz stawu palca, obraz TEM tchawicy, obraz CT ludzkiego mózgu, obraz układu krwionośnego palca w podczerwieni

BIBLIOGRAPHY


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Omówienie

Obrazy biomedyczne uzyskiwane z wykorzystaniem rozmaitych technik, takich jak tomografii, ultrasonografii czy rezonansu magnetycznego, są obrazami monochromatycznymi.
Ich analiza oraz ocena może być znacznie ułatwiona dzięki zastosowaniu koloryzacji, co wynika z lepszej perceiving obrazów barwnych przez człowieka. W artykule przedstawiono nową technikę koloryzacji, wykorzystującą transformatę dystansową oraz modyfikację filtra bilateralnego. Proponowana metoda opiera się na wskaźnikach koloru wprowadzanych przez użytkownika w celu zgrubnego początkowego zaznaczenia oczekiwanych kolorów dla poszczególnych elementów obrazów. W artykule wyjaśniono role występujących w nim parametrów oraz przedstawiono przykłady koloryzacji obrazów biomedycznych z wykorzystaniem proponowanej nowej techniki.

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