Colorization of Medical Images

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***Abstract*—Colorization is a term used to describe a computerized process for adding color to black and white pictures, movies or TV programs. This process can also be used to convert the gray scale medical images to their colorized version, as color increases the visual appeal of an image and it also makes a medical visualization more attractive. Changes in color are more easily perceived than changes in shades of gray and therefore this procedure makes the interpretation and understanding of the image easier.**

During colorization process a scalar value representing pixel's intensity is being replaced by a vector in a given color space. Since the mapping between intensity and color has no inherently correct solution, human interaction and external information usually plays a large role.

In this paper we present a novel colorization method based on the morphological distance transformation which considers the image structures to automatically propagate the color inserted into the image by a user. The effectiveness of the algorithm allows to work interactively and to obtain desired results promptly after providing the color information. In the paper we show that the proposed technique allows for high quality colorization of medical images.

I. Introduction

With the rapid development of computer technology, adding color to gray scale images and movies in a way that looks natural to human observers became a problem that challenged the motion picture industry and has recently attracted renewed interest within the computer vision community. In the last few years, several advanced and effective techniques for images and video have been proposed. These techniques are based on: *luminance keying* and *color transfer* [1], *image analogies* [2], *motion estimation* [3], *segmentation* [4], *color prediction* [5], *probabilistic relaxation* [6] and *chrominance blending* [7], among many other techniques.

In this paper we show that using our novel colorization method based on the modified distance transformation, it is possible to obtain satisfactory colorization results in very short time and with small amount of work.

This paper is organized as follows. The next Section presents the proposed colorization algorithm. Subsection II-A reviews a standard fast algorithm for computing an approximation of the Euclidean distance between pixels. In Subsection II-B we extend the distance transform to take into account image structures, and in Subsection II-C we describe the color blending process. Finally, in Section III we present medical image colorization results and in Section IV we formulate the final conclusions.

II. The Proposed Algorithm

In this section we present our novel algorithm for image colorization, that exploits the modified distance transform, which considers information contained in the source gray scale image, such as: changes in intensity values, location of edges, gradient magnitudes and their direction. Our goal is to create a fast and effective colorization algorithm, which does not require precise segmentation or reference images.

Figure 1 illustrates the idea of the proposed colorization process, in which the color information is provided by a user by scribbling the gray scale image, and then the color is automatically propagated using the algorithm described in the following sections.

(a) source image (b) scribbled image (c) colorization result

Fig. 1: Illustration of the proposed colorization process.

A. Standard distance transform

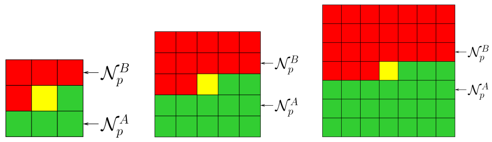
Since, the color is provided simply by scribbling the image, the first step of our algorithm, after the user inserts the scribbles, is to isolate them and compute their distance to each pixel of the source gray scale image. We use the approximation of the Euclidean distance in order to significantly decrease the computational load of the *Distance Transform* (DT) algorithm [8]. Thus, let $\mathcal{P}$ be a binary image defined on the image domain $\mathcal{G}$ in which:

$$\begin{aligned} \langle \mathcal{P} \rangle &= \{p : p \in \mathcal{G} \wedge \mathcal{P}(p) = 1\}, \\ \langle \bar{\mathcal{P}} \rangle &= \{p : p \in \mathcal{G} \wedge \mathcal{P}(p) = 0\}, \end{aligned} \tag{1}$$

are proper subsets of $\mathcal{G}$. For a given metric, the distance transform of $\mathcal{P}$ associates with every pixel p of $\langle \mathcal{P} \rangle$ the distance from p to $\langle \bar{\mathcal{P}} \rangle$.

For any $p \in \mathcal{G}$ let $\mathcal{N}_p^B$ (pixels in the neighborhood relation *before scan*) be the set of pixels adjacent to p that precedes q when $\mathcal{G}$ is scanned, and let $\mathcal{N}_p^A$ (*after scan*) be the remaining neighbors of p, (see Fig. 2). Then, during the first scan (in top-left to bottom-right direction) we compute:

$$f_1(p) = \begin{cases} 0 & \text{if} \quad p \in \langle \mathcal{P} \rangle \\ \min\{f_1(q) + 1 : q \in \mathcal{N}_p^B\} & \text{if} \quad p \in \langle \bar{\mathcal{P}} \rangle \end{cases} . \tag{2}$$



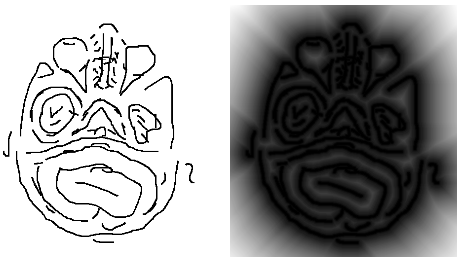
(a) 3×3 (b) 5×5 (c) 7×7

Fig. 2: Structuring elements with $\mathcal{N}^B$ (red) and $\mathcal{N}^A$ (green) neighbors of the central pixel (yellow).

After the first scan, we approach to the second scan in reverse direction (bottom-right to top-left), and compute the following:

$$f_2(p) = \min\{f_1(p), f_2(q) + 1 : q \in \mathcal{N}_p^A\}. \quad (3)$$

Thus, after the second scan we obtain the distance values, that can be expressed as intensities of points within the gray scale image, (Fig. 3).



(a) isolated scribbles (b) result of standard DT

Fig. 3: Scribbles isolated from Fig. 1b and the standard distance transform (DT) performed on those scribbles.

B. Hybrid distance transform

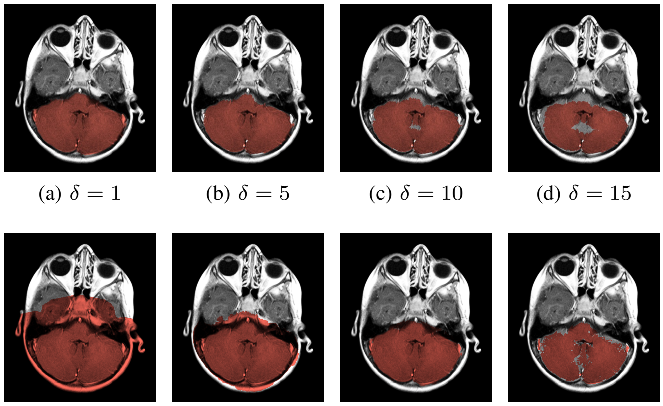
In order to avoid the disability of the standard distance transformation to capture the structural information contained within the source gray scale image, we propose to modify it by constructing a cost function which will be used in the definition of the *hybrid distance transform* (HDT).

Assuming, that two pixels located within the same object in the image should have similar intensity values, we decided to utilize the changes of intensity in order to detect boundaries between objects. They are calculated by taking the absolute value of the difference between intensity values of two neighboring image points p and q, and the total cost is defined as: $\mathcal{D}_e(p, q) = |\mathcal{Y}(p) - \mathcal{Y}(q)|^\gamma + \delta$, where $\mathcal{Y}(p)$ denotes intensity value at a point p, γ is a coefficient and δ is a parameter which takes into account the topological distance between pixels. The experiments revealed that $\gamma = 2$ and $\delta = 1$ give satisfying results, (see Fig 4).

The gradient magnitude used for the cost function F_g was approximated using the Sobel operator and it is depicted as intensities of points within a gray scale image in Fig. 5a. Another cost function F_d penalizes the changes in gradient direction. This cost is defined as [10]:

$$F_d(p, q) = \arccos\{d_p(p, q)\} + \arccos\{d_q(p, q)\}, \quad (4)$$

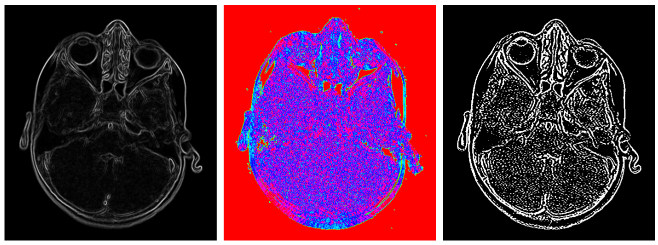
$$d_p(p, q) = \boldsymbol{G}^\perp(p) \cdot \boldsymbol{L}(p, q), \;\; d_q(p, q) = \boldsymbol{G}^\perp(q) \cdot \boldsymbol{L}(p, q), \quad (5)$$



(a) $\delta = 1$ (b) $\delta = 5$ (c) $\delta = 10$ (d) $\delta = 15$

(e) $\gamma = 0$ (f) $\gamma = 1$ (g) $\gamma = 2$ (h) $\gamma = 3$

Fig. 4: Dependence of the colorization results on the parameters δ and γ in the cost $\mathcal{D}_e$.



(a) (b) (c)

Fig. 5: Gradient magnitude (a), its direction (b) and the zero-crossings of the LoG (c).

where $\boldsymbol{G}^\perp(p)$ and $\boldsymbol{G}^\perp(q)$ are the the unit vectors perpendicular (rotated 90 degrees clockwise, $\boldsymbol{G}^\perp = [G_y, -G_x]$) to the gradient vectors $\boldsymbol{G}(p)$, $\boldsymbol{G}(q)$ at pixels p and q and $\boldsymbol{L}(p, q)$ is a unit vector linking pixels p and q defined as:

$$\boldsymbol{L}(p, q) = \frac{1}{\|\boldsymbol{p} - \boldsymbol{q}\|} \begin{cases} \boldsymbol{r}, & \text{if} \quad \boldsymbol{G}^\perp(p) \cdot \boldsymbol{r} \geq 0 \\ -\boldsymbol{r}, & \text{if} \quad \boldsymbol{G}^\perp(p) \cdot \boldsymbol{r} < 0 \end{cases}, \quad (6)$$

where $\boldsymbol{r} = \boldsymbol{q} - \boldsymbol{p}$ ia a vector joining pixels p and q as depicted in Fig. 6.

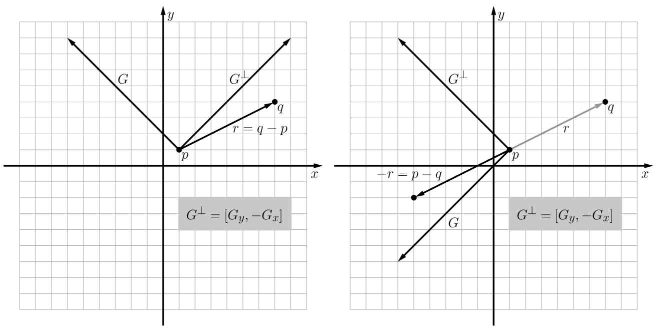


Fig. 6: Construction of the gradient direction cost.

The proposed cost function returns low directional cost values for homogenous regions and produce high cost values at the edges. The result of gradient direction cost function is depicted in Fig. 5b.

The Laplacian of Gaussian (LoG) was approximated using a 5×5 mask. The result of the zero-crossings of LoG is depicted in Fig. 5c. When an edge is detected using the zerro-crossing of the Laplacian then the cost F_l connected with the edge at a given pixel position is 1 otherwise it is equal to zero.

The information derived from the gray scale image modify the distance transformation (Eqs. 2, 3) resulting in the following equations defining the new hybrid distance transform:

$$f_1(p) = \begin{cases} 0 & : p \in \langle \mathcal{P} \rangle \\ \min \left\{ f_1(q) + \mathcal{K} : q \in \mathcal{N}_p^B \right\} & : p \in \langle \bar{\mathcal{P}} \rangle \end{cases} , \qquad (7)$$

$$f_2(p) = \min \left\{ f_1(p), f_2(q) + \mathcal{K} : q \in \mathcal{N}_p^A \right\} , \qquad (8)$$

where $\mathcal{K} = \alpha_e \mathcal{D}_e + \alpha_g F_g + \alpha_d F_d + \alpha_l F_l$ is the total cost derived from intensity changes $\mathcal{D}_e$, gradient magnitude F_g and its direction F_d as well as from Laplacian on Gaussian zero-crossing F_l with corresponding α coefficients regulating the influence of the corresponding costs on the overall value of $\mathcal{K}_t$. The result of extended distance transform performed on the scribbles from the Fig. 1b is depicted in Fig. 7.

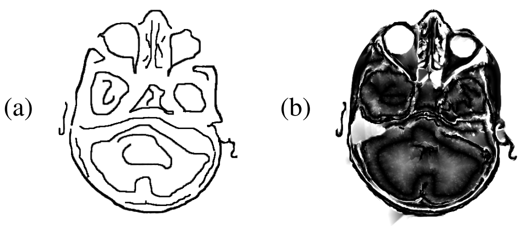


Fig. 7: Scribbles extracted from Fig. 1b (a) and HDT performed on these scribbles (b).

The proposed generalization of the distance transform can be regarded as the extension of [12] and can be also used in conjunction with the idea of probabilistic distance transform proposed in [13].

C. Color blending

In order to utilize the values obtained with the extended distance transform as weights in the blending of colors originating from successive scribbles, we have used the Gaussian function: $\mathcal{G}(d) = \exp\left(-(d/h)^2\right)$, where h is a parameter adjusted by the user and d denotes the value of the hybrid DT we obtain from Eqs. 7, 8, for each point of the gray scale image.

These weighting functions are then used as weights to determine the color *C* of a given point *p* during the additive color mixing process defined by:

$$C(p) = \frac{C_1 \cdot \mathcal{G}_1(d,p) + C_2 \cdot \mathcal{G}_2(d,p)}{\mathcal{G}_1(d,p) + \mathcal{G}_2(d,p)} \cdot r(p), \qquad (9)$$

where C_1 and C_2 are colors scribbled by the user and $\mathcal{G}_1(d,p)$ and $\mathcal{G}_2(d,p)$ are weights obtained for a given point p using the Gaussian weighting function. The $r(p)$ is a correction factor, which allows to preserve the original intensity $\mathcal{Y}(p)$ of the source gray scale image in newly propagated color:

$$r(p) = \frac{\mathcal{Y}(p)}{\max\{C_1 \cdot \mathcal{G}_1(d,p), C_2 \cdot \mathcal{G}_2(d,p)\}}. \qquad (10)$$

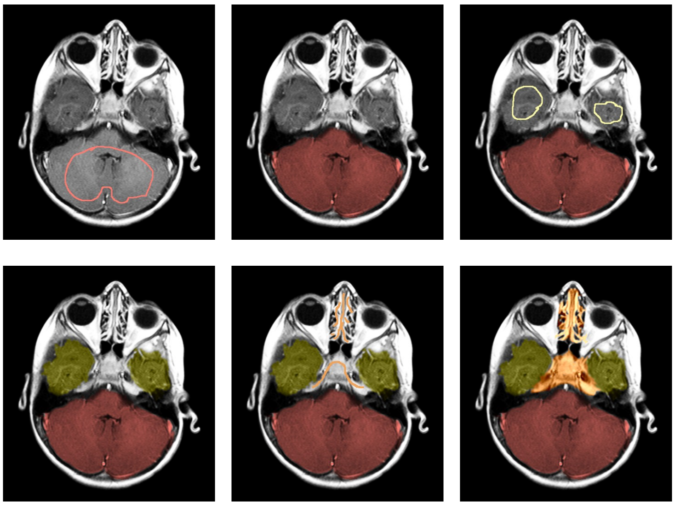


Fig. 8: Illustration of successive colorization steps.

Since the proposed algorithm is iterative and colors are added one by one, indices 1 and 2 in Eqs. 9, 10 correspond respectively to the current and previous colorization step. Figure 8 shows the successive steps leading to a colorized MRI image.

III. Results

The results shown below were obtained using the presented method that works on the basis of the hybrid distance transformation. Current implementation of our algorithm works fast enough to allow the user for interactive work without noticeable delays and achieving real-time preview.

The proposed method gives good colorization results for gray scale medical images of different types. In Fig. 9 we can observe the colorization results of computer tomography (*CT*) images. In columns from the left to right the original gray scale images, the ones scribbled with color and results of our colorization are shown.

The described technique can also be successfully applied to *PET* images (Fig. 10), *MRI* images (Figs. 8, 11), as well as *X-ray* images (Fig. 12), producing satisfactory results.

The important feature of the proposed technique is that the intensity of the original gray scale image is always preserved and the color information provided by a user can be hidden, so that no changes in the original image are introduced. In this way the color information can be used as a tool enabling the physician to point at important structures by coloring the region of interest. The future work will focus on further decrease of the computational load of the algorithm and the adaptive, automatic adjustment of the α parameters in the definition of the HDT.

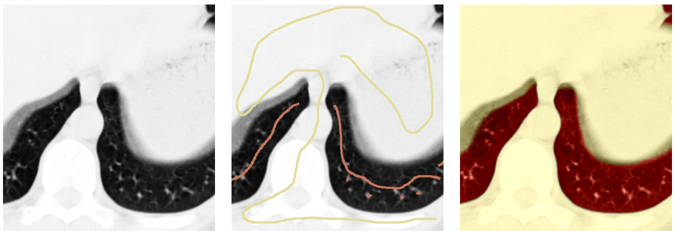


Fig. 9: Colorization example of a CT image. In columns from the left: gray scale image, scribbled image and the colorization result.

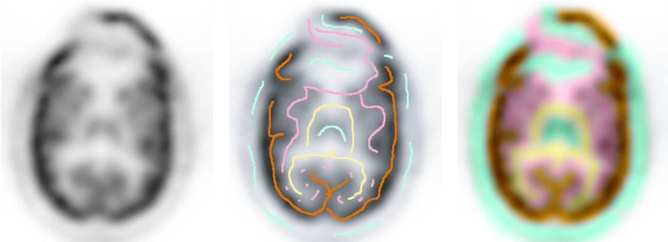


Fig. 10: Colorization example of PET image. From the left: gray scale image, scribbled image and our colorization result.

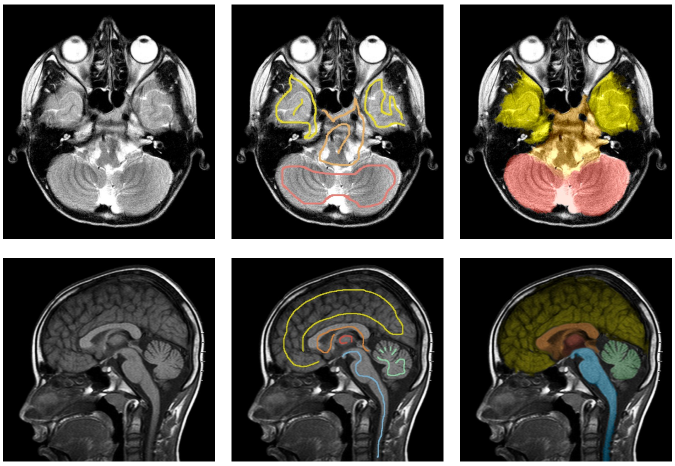
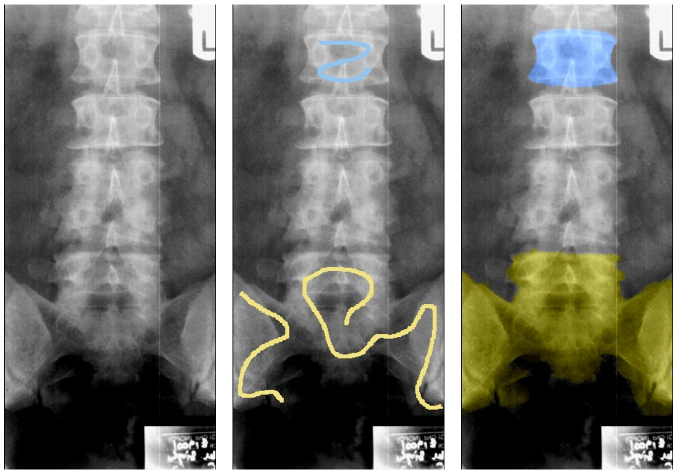


Fig. 11: Colorization example of MRI images. In columns from the left: gray scale images, scribbled images and the colorization result.

IV. Conclusions

In the paper a novel colorization method applied to medical images has been presented. The results of experiments performed on various gray scale medical images indicate, that the presented approach yields interesting results and can be successfully used for visualization purposes. As the new method does not introduce any changes in the intensity of the original image, the user can always use the original image without the chromaticity component. The proposed method can be used for various diagnostic purposes serving as a versatile visualization tool.



(a) (b) (c)

Fig. 12: Colorization example of image acquired with X-Rays: gray scale image (a), scribbled image (b) and our colorization result (c).

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