Image Fusion for Difference Visualization in Art Analysis

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***Abstract*—A new method for difference visualization is presented, oriented on the art analysis application. Compared images are combined into one fused image without losing important image context. Dissimilar regions are highlighted by color, which encodes localized differences. The method was developed for comparison of artwork copies, but it can be applied for general image comparison, too. The method is based on diverging color maps. The color representation of the difference is comprehensible, naturally ordered, and has maximal displayable resolution. The applicability of the method is demonstrated on hierarchy ordering of the copies of the "A boy with a bird" painting by Mons Bernardo (1624-1687).**

I. Introduction

A new method for base level image difference visualization is presented. The method was developed for a comparative analysis used in artwork investigation, when it is important to be able to display changes in composition (in case of underdrawings and underpaintings) and proportion deviations (multiple copies of the same artwork). Recent development creates high demand for such effective visualization algorithms, where all the important details are preserved and/or accentuated while the data dimensionality is reduced so we are able better understand captured scenes. Our method is meant for comparison of artwork copies, but it can be applied for image comparison in general, without exact specification of the "difference". The method is based on diverging color maps.

The comparison is based on the low level information, gained from pixel intensity values in HSV (Hue, Saturation, Value) color space and on any suitable local difference measure. The measure has to fulfill two conditions - it can have both positive and negative values and its zero value should represent a situation with no difference. These three dimensions - pixel intensities in both the original and the compared images, respectively, and the difference values - are combined into the HSV color representation.

New Value (V) is computed as an average intensity of both images. Spatially coherent fusion of the input images is necessary for good localization of the image difference. Hue (H) and Saturation (S) are reserved for the difference representation. New Hue reflects a sign of the estimated difference. New Saturation represents the absolute value of the estimated difference. Proposed color representation of the difference is comprehensible, aesthetic (according to the user selection), naturally ordered, and has maximal displayable resolution.

The difference measure, which has to be chosen in advance, has to reflect the data type of the compared structures. For multimodal images or images with different coloring any information-based measure can be applied, such as mutual information [4], Rényi distance, etc. We were comparing different copies of the same artwork and we decided to use the intensity difference of normalized and perspectively registered images. This approach gives us exact knowledge about the proportion deviation of the copyist.

The main goal of the proposed method was to highlight regions of expert interest (ROIs) and to visualize *difference values* specified by any appropriate difference measure for the further decision of an expert. Requirements for good visualization are:

(i) Visualization should be comprehensible.
(ii) Visualization should be aesthetic.
(iii) ROIs should be visualized in the context of compared images.
(iv) The whole scale of the similarity measure values should be recognizable.
(v) More than two images are compared without context loss.

Comprehensible visualization (i) is highly dependent on the selection of a *similarity measure*. Therefore we suggest similarity measure, which is comprehensible by an expert, who will use the visualization. We propose to use measures based on the low level information and which are defined for each pixel separately. Finally, the measure values should be real numbers in the interval containing the zero value, which represents "no difference". Positive values represent the difference in the first image and negative values the difference in the second image, respectively.

For the visualization, global measures must be adjusted for the local meaning and semi-local (region based) measures must be interpolated. We successfully tested localized measures of the information [3] and the normalized intensity difference of both images.

The method will be presented in the Section 2. Section 3 is demonstrating achieved results together with the illustrative visualizations. Finally, Section 3 concludes the paper and presents plans for the future work.

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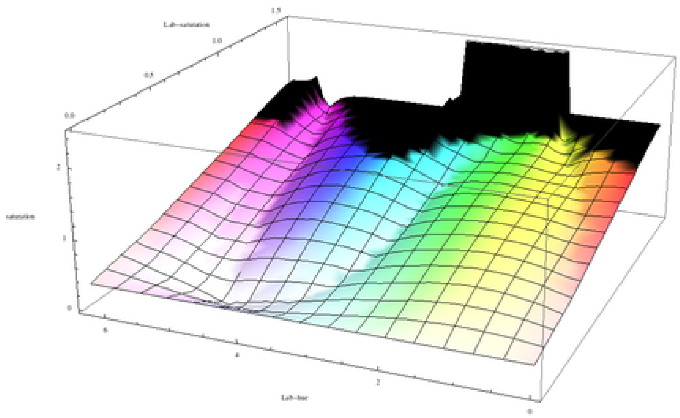

Fig. 1. The restriction of the saturation in CIELAB to the saturation in HSV color space. According to the hue and the saturation in CIELAB, the HSV saturation is perceived as continuous and linear. Black area contains colors out of the displayable range of the HSV color space. The lowest value of the *saturation* is in the white point - in this case D65 was used

Fig. 2. The comparison of two portraits of general Windischgrätz. The difference of the normalized intensity values of each corresponding pixel pair was employed as the difference measure.

II. Visualization method

The method is based on the fusion of the image intensities of both the original and the compared images, respectively and of their *difference value*. These values are evaluated for each pixel separately.

We work in CIELAB color space [2] where we define Hue and Saturation. However, the final result is visualized in HSV color space. The reason for the computation in CIELAB color space is the linearity of this space for human visual system and therefore better discriminability of ROIs in the resulting image. The HSV color space is used for visualization because we have to take into account limitations of an output device (typically a LED monitor).

The method workflow is as follows:

(1) Hues for each of the compared images are selected, based on the user preferences.

Hue selection is realized by the user input, electronically, and therefore due to the hardware limitations this selection is made in the HSV color space. In the output visualized image the negative and the positive difference values will be manifested by the first and by the second of the selected *hues*, respectively.

(2) Mapping of HSV *saturation* to the *difference values* is realized.

The saturation (S) in CIELAB we define as an angle between our color vector and L axis. The range of CIE–saturation values is then restricted according to the selected *hue* transformed to CIE–hue, which is an angle between a axis and projection of color vector into $a * b$ plane, and HSV limitations (see figure 1). For a 'positive' *hue* we obtain angles in the range $[0°, \alpha]$ and for a 'negative' *hue* another range $[0°, \beta]$. According to these ranges the difference values are mapped into the range $[-\beta, \alpha]$ and then transformed to HSV–*saturation*.

(3) The HSV coordinates computation for each pixel.

The new *Hue* (H) reflects the sign of the computed difference measure (1). The new *saturation* (S) represents the absolute value of the chosen difference measure (2). Finally, the new *value* (V) is the average value of intensities of compared images, pixelwise.

(4) The resulting fused image is displayed.

III. Results

The proposed method was successfully applied for several art investigation cases. The methodology proved to be useful for art experts and helped them to get better insight into the studied art pieces. Two of them are shown here. Firstly, the comparison of two portraits of general Windischgrätz was realized. Here, the difference of the normalized intensity values of each corresponding pixel pair was employed as the difference measure (see fig. 2). Slight scale differences and changes in the head position are apparent.

In the second case, the method was employed in the investigation of the painting analysis. The art experts have four images depicting almost the same scene - the 'Boy with the bird' (see fig. 3). One of them was the original painting by Monsú Bernardo (1624-1687). Then, they have one original engraving and two copies, one found in Poland and one in Czech Republic. The image registration was done by the perspective transformation according to the manually selected point pairs. The applied difference measure is the difference in the normalized pixel intensities. The visualization of the proportion deviation was successfully applied to estimate the

Fig. 3. The 'Boy with the bird' painting - different versions. From the left - the original image by Monsú Bernardo, the engraving according to the original, the copy found in Poland, the copy found in Czech Republic.

hierarchy ordering.

The comparison was realized pairwise, the original painting (green) with the Polish copy (blue), with the engraving (red) and with the Czech (yellow) version, respectively. The best proportion matching is visible on the comparison with the Czech version (see fig. 4). The comparison of the copies themselves (fig. 5) shown that the Polish version is probably the copy of the engraving or vice-versa, see the significant matching of these two pairs (fig. 5, left image).

IV. Conclusions and Future Work

The new method for base level image difference visualization was presented. The method was developed for a comparative analysis used in artwork investigation. The method can be applied for image comparison in general, too, without exact specification of the "difference". The method is based on diverging color maps.

The comparison is based on the pixel intensity values in HSV color space and on any suitable local difference measure, such as the difference in the normalized pixel intensities. Proposed color representation of the difference is comprehensible, based on the consultations with the art experts. As far as we know such comparison task in the field of cultural heritage has been commonly solved by the image registration followed by the comparison made manually in Photoshop by warping and alpha blending.

The proposed method fulfills our requirements:

(i) Our method has an improving effect on the comprehension of the difference visualization, based on the reactions of the restores and art conservators. The identification of ROIs is faster and more precise.

(ii) The image context is kept with the image fusion approach of both input images in the HSV *value* (V) and with the coloring of the fused resulting image. In general, the difference sign identifies the image where the difference is present. The absolute value of the *similarity* measure is mapped to the final *saturation* (S).

(iii) The difference mapping is linear for human visual system by using CIELAB color space for the computation, which is important for further difference importance understanding.

(iv) For the comparison of more than two images (see figure 3) we propose to use the same hue (H) per image for all the fused image pairs (see figures 4 and IV).

(v) Finally, the coloring of the fused image is made by two hues harmonized by the user. The aesthetic requirement mostly depends on the user preferences.

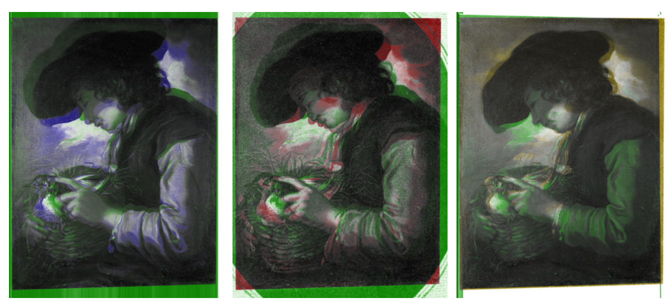

Fig. 4. The comparison of the original (green) with (from the left) the Polish (blue), with the engraving (red) and with the Czech (yellow) version, respectively. The best proportion matching is visible on the comparison with the Czech version. The registration was made by the perspective transformation according to the manually selected point pairs. The difference measure is the difference in the normalized pixel intensities.

For the future we plan to study the influence of the similarity measure choice. The selection of the difference measure is the most problematic part in our practice. Such measure has to match the type of the data to be compared. We often work with multitemporal or multimodal images. Very often we have to deal with different versions/copies of the same painting. For the difference measure we successfully used the difference in the normalized intensity values, the difference of the most significant principal component [1] and other information measures [3]. We would like to offer methodology for the universal difference measure.

Fig. 5. The comparison of the three non-original pairs. The same colors and the difference measure as in figure 4 were applied. We can see significant matching of the engraving with the Polish version. Probably one was used as the model for creation of the second.

The presented method was developed in the cooperation with the Academic Materials Research Laboratory of Painted Artworks where it has been successfully used in the art investigation process. Matlab implementation can be found at Matlab Central - File Exchange. Java implementation is included in our project software Fresco (http://m3art.utia.cas.cz/fresco.php). This software can be used for free.

Our experience proved usefulness of the method for the image comparison. Moreover, it could be applied for the visual valuation of the image registration or of the segmentation precision.

ACKNOWLEDGMENT

This work has been supported by Czech Science Fundation, (project no. P103/12/2211).

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