Morphological Color Change in Morning Glory

Hiroaki Kotera; Kotera Imaging Laboratory, Chiba, Japan

Abstract

The color of nature changes with passing time. Natural images are composed of clustered color objects that have the similar colors to be shared among them. "PC color matching" model by Kotera was firstly applied for automatic color correction of color prints and scene to scene color transform. Reinhard advanced the concept of color sharing between two images as "scene color transfer" model. "Color stealing" by Barnsley is an another concept of Fractal-based color sharing and used for synthesizing a new image by picking up a region color in one image and moving it to another image. This paper proposes a morphological color change model to create the sequential intermediate images between the source and destination. The PC color matching model is extended to a sequential color stealing and combined with a morphological median sequence for image warping. The proposed model needs not any control points or animator's skill for image warping in conventional methods. It creates the morphological median images with warping by a simple binary logical operations and colorization. The paper introduces an application for creating a movie clip in the seasonal color changes such as Souvenir D'ANNE FRANK or Morning Glory.

Introduction

The color of nature changes with passing time. Natural images are composed of clustered color objects with similarity to be shared each other. A concept of color transfer between two images is introduced to PC (Principal Component) color matching model[1] and scene color transfer model[2]. Color stealing by Barnsley[3] is a concept of Fractal-based color sharing and used for synthesizing a new image by picking up a region color in one image and moving it into another image. Mochizuki[4] applied this idea to CG as "stealing autumn color". On the other hand, image morphing technology has been a powerful tool for creating interesting visual effects in film, TV, or CG industries. This paper extends the PC color matching model to a sequential color stealing and combines a morphological binary median sequence for image warping. The model is applied to imitate a seasonal color change in flowers.

Sequential Color Stealing

Cross Dissolving

A most simple way for morphing is cross dissolving[5] which creates the intermediate image by blending the pixel colors with the time-varying ratio of (1-α_n) and α_n for the source $\boldsymbol{S}$ and target $\boldsymbol{T}$ as follows.

$$\boldsymbol{R}(n) = (1-\alpha_n)\boldsymbol{S} + \alpha_n \boldsymbol{T} \;\; for \;\; \alpha_n = n/N \; ; \; n = 0,1,\cdots,N \quad (1)$$

Morphological Median

The cross dissolving causes the double exposure or ghost effect due to the shape change from $\boldsymbol{S}$ to $\boldsymbol{T}$. The morphological median reduces this effect by the morphological interpolation[6] for binary, gray, and color images to produce the halfway image between them.

The intermediate image $\boldsymbol{R}$ between $\boldsymbol{S}$ and $\boldsymbol{T}$ is created by the "*morphological median*" process as

$$\boldsymbol{R} = \sup_{\forall\lambda}\left[inf\left\{ \delta^{(\lambda)}\left(inf(\boldsymbol{S},\boldsymbol{T}), \varepsilon^{(\lambda)} sup(\boldsymbol{S},\boldsymbol{T}) \right) \right\} \right] \quad (2)$$

Where, '*sup*' and '*inf*' denote *supremum* and *infinimum* operations. $\delta^{(\lambda)}$ and $\varepsilon^{(\lambda)}$ represent λ=1, 2, ... times dilations and erosions to be continued until converging.

The time-sequential medians are successively generated starting from the initial pair of ($\boldsymbol{S}$, $\boldsymbol{T}$) and calculating Eq. (2) by repeating the iterations for i until converging as

$$\begin{aligned} &\boldsymbol{Z}_0 = inf(\boldsymbol{S},\boldsymbol{T}),\; \boldsymbol{W}_0 = sup(\boldsymbol{S},\boldsymbol{T}),\; \boldsymbol{R}_0 = inf(\boldsymbol{S},\boldsymbol{T}) \\ &\boldsymbol{Z}_i = \delta(\boldsymbol{Z}_{i-1}),\; \boldsymbol{W}_i = \varepsilon(\boldsymbol{W}_{i-1}),\; \boldsymbol{R}_i = sup[inf(\boldsymbol{Z}_i,\boldsymbol{W}_i), \boldsymbol{R}_{i-1}] \end{aligned} \quad (3)$$

PC Color Matching

Though both cross dissolving and morphological median reflect the shape transition from $\boldsymbol{S}$ to $\boldsymbol{T}$, the blended color appearance is unnatural, because it comes from the mixture of unrelated different pixels. Since the seasonal color change in flowers mostly appears in the petal, the PC color matching model transfers the colors smoothly from $\boldsymbol{S}$ to $\boldsymbol{T}$ based on the clustered color distribution..

Fig.1 illustrates the sequential PC color matching model between $\boldsymbol{S}$ and $\boldsymbol{T}$ for Anne Frank. The intermediate image at time n is successively created by the following two steps.

[*Step1*] Make a color set $\boldsymbol{R}$ blended with $\boldsymbol{T}$ and $\boldsymbol{S}$.

Letting a set of P_n pixels be $\boldsymbol{P}$ taken from the source $\boldsymbol{S}$ and a set of Q_n pixels be $\boldsymbol{Q}$ stolen from the target $\boldsymbol{T}$, the mixed color set $\boldsymbol{R}$ is given by the blended pixels as

$$\begin{aligned} &\boldsymbol{R} = \boldsymbol{P} \cup \boldsymbol{Q} \\ &{}_{\boldsymbol{R}}\boldsymbol{X}_k = \{L_k^*, a_k^*, b_k^*\} = {}_{\boldsymbol{P}}\boldsymbol{X}_i \cup {}_{\boldsymbol{Q}}\boldsymbol{X}_j \in \boldsymbol{R} \;\; for \; k = 1 \sim R_n \\ &{}_{\boldsymbol{P}}\boldsymbol{X}_i = \{L_i^*, a_i^*, b_i^*\} \in \boldsymbol{P} \subset \boldsymbol{S} \;\; for \; i = 1 \sim P_n \\ &{}_{\boldsymbol{Q}}\boldsymbol{X}_j = \{L_j^*, a_j^*, b_j^*\} \in \boldsymbol{Q} \subset \boldsymbol{T} \;\; for \; j = 1 \sim Q_n \end{aligned} \quad (4)$$

Where, ${}_{\boldsymbol{P}}\boldsymbol{X}_i$, ${}_{\boldsymbol{Q}}\boldsymbol{X}_j$, and ${}_{\boldsymbol{R}}\boldsymbol{X}_k$ denote the CIELAB color vectors for pixel i, j, and k in each set.

The mixed color set $\boldsymbol{R}$ is composed of $R(n)=P_n+Q_n$ pixels uniformly sampled from the source image $\boldsymbol{S}$ with P pixels and the target image $\boldsymbol{T}$ with Q pixels. That is, $\boldsymbol{R}$ is a blended set of two images $\boldsymbol{S}$ and $\boldsymbol{T}$ by the ratios of (1-α_n) and α_n=n/N changing as a function of time n.

$$R(n) = P_n + Q_n, P_n = (1-\alpha_n)P, \; Q_n = \alpha_n Q; \; n = 0,1,\cdots,N \quad (5)$$

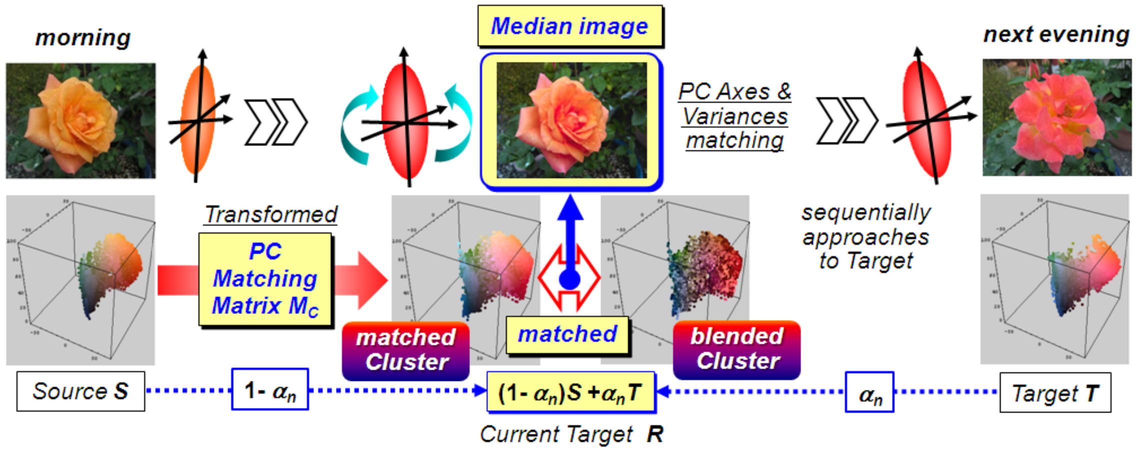

Fig.1 *Sequential color stealing for Souvenir D' Anne Frank by PC color matching model*

[*Step2*] Transform the color in source image $\boldsymbol{S}$ to match with that in mixed color set $\boldsymbol{R}$.

Here, the PC matching algorithm[1] is applied to the color transformation. Both the source color vector ${}_S\boldsymbol{X}$ in $\boldsymbol{S}$ and the mixed color vector ${}_R\boldsymbol{X}$ in $\boldsymbol{R}$ are projected into the vectors ${}_S\boldsymbol{Y}$ and ${}_R\boldsymbol{Y}$ in the common PC space by Hotelling Transform as

$$
\begin{aligned}
&{}_S\boldsymbol{Y}={}_S\boldsymbol{A}({}_S\boldsymbol{X}-{}_S\boldsymbol{\mu}),\ \ {}_R\boldsymbol{Y}={}_R\boldsymbol{A}({}_R\boldsymbol{X}-{}_R\boldsymbol{\mu})\\
&{}_S\boldsymbol{\mu}=E\{{}_S\boldsymbol{X}\},\ \ {}_R\boldsymbol{\mu}=E\{{}_R\boldsymbol{X}\}\ \text{: mean vectors}
\end{aligned}
\tag{6}
$$

${}_S\boldsymbol{A}$ and ${}_R\boldsymbol{A}$ are the eigen vectors of covariance matrices ${}_S\boldsymbol{C}_X$ and ${}_R\boldsymbol{C}_X$ for ${}_S\boldsymbol{X}$ and ${}_R\boldsymbol{X}$.

Thus the covariance matrices ${}_S\boldsymbol{C}_Y$ and ${}_R\boldsymbol{C}_Y$ for ${}_S\boldsymbol{Y}$ and ${}_R\boldsymbol{Y}$ are diagonalized in $\boldsymbol{PC}$ space as given by

$$
\begin{aligned}
&{}_S\boldsymbol{C}_Y={}_S\boldsymbol{A}({}_S\boldsymbol{C}_X)_S\boldsymbol{A}^t=diag\{{}_S\lambda_1,\ {}_S\lambda_2,\ {}_S\lambda_3\}\\
&{}_R\boldsymbol{C}_Y={}_R\boldsymbol{A}({}_R\boldsymbol{C}_X)_R\boldsymbol{A}^t=diag\{{}_R\lambda_1,\ {}_R\lambda_2,\ {}_R\lambda_3\}
\end{aligned}
\tag{7}
$$

Where, $\{{}_S\lambda_i\}$ and $\{{}_R\lambda_i\}$ are the eigen values of ${}_S\boldsymbol{Y}$ and ${}_R\boldsymbol{Y}$.

Now since the source color vector ${}_S\boldsymbol{Y}$ and the mixed color vector ${}_R\boldsymbol{Y}$ are mapped onto the same PC axes, ${}_S\boldsymbol{Y}$ is transformed to match ${}_R\boldsymbol{Y}$ by the scaling matrix ${}_S\boldsymbol{S}_R$ as follows.

$$
\begin{aligned}
&{}_R\boldsymbol{Y}=({}_S\boldsymbol{S}_R)\cdot({}_S\boldsymbol{Y}),\\
&{}_S\boldsymbol{S}_R=diag\left\{\sqrt{{}_R\lambda_1/{}_S\lambda_1},\sqrt{{}_R\lambda_2/{}_S\lambda_2},\sqrt{{}_R\lambda_3/{}_S\lambda_3}\right\}
\end{aligned}
\tag{8}
$$

Connecting Eq. (6) to Eq. (8), the source colors $\{{}_S\boldsymbol{X}\}$ in $\boldsymbol{S}$ is transformed to the set of destination colors $\{{}_D\boldsymbol{X}\}$ that is approximately matched to the colors $\{{}_R\boldsymbol{X}\}$ in the mixed color set $\boldsymbol{R}$ by the matrix $\boldsymbol{M}_C$[7]. $\boldsymbol{M}_C$ matches the hue by cluster rotation and the variance by scaling as

$$
{}_D\boldsymbol{X}=\boldsymbol{M}_C({}_S\boldsymbol{X}-{}_S\boldsymbol{\mu})+{}_R\boldsymbol{\mu}\cong{}_R\boldsymbol{X},\ \ \boldsymbol{M}_C=({}_R\boldsymbol{A}^{-1})({}_S\boldsymbol{S}_R)({}_S\boldsymbol{A})
\tag{9}
$$

Since the matching matrix $\boldsymbol{M}_C$ changes with time as a function of color stealing ratio $\alpha_n=n/N$, the color vectors $\{{}_D\boldsymbol{X}\}$ reflect the time-sequential color changes from $\boldsymbol{S}$ to $\boldsymbol{T}$.

Fig.2 shows a comparison of time-sequential color changes in D'ANNE FRANK by the above three models.

The petal color has changed to deep pink from light pink in a day and a half. A double exposure effect is striking for the halfway image in the cross dissolving, while the morphological median surely reduces the ghost, but looks rather obscure in the petal. Clearly, the PC color matching model resulted in the smoothed color transition better than the other two.

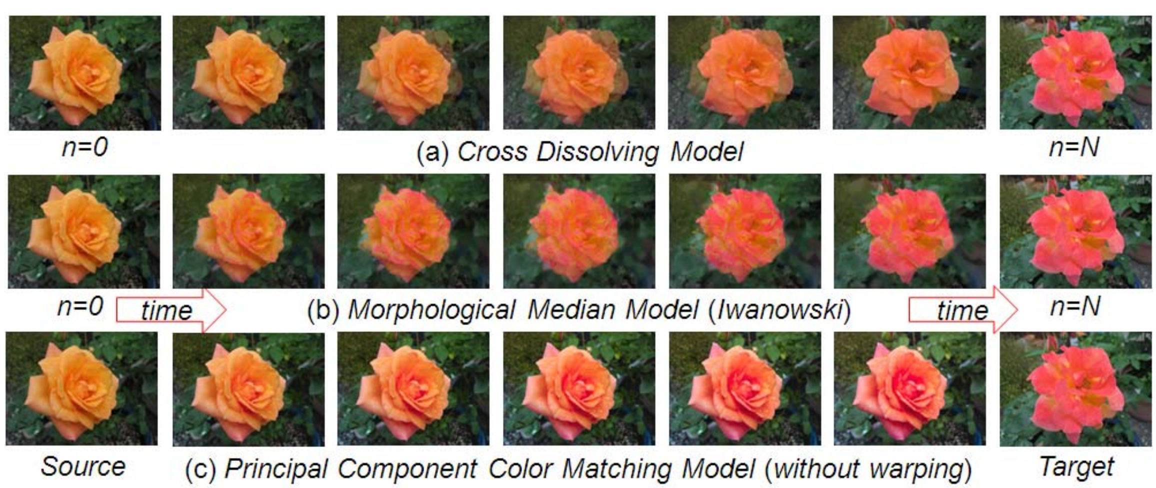

Fig.2 *Comparison of models for sequential color change in Souvenir D'ANNE FRANK*

Fig.3 shows the more detailed result in a "*Souvenir D' Anne Frank*" by PC color matching model. Time- sequential color changes are successively generated only from just two images, source ***S*** captured in the morning and target ***T*** captured in the next evening. It shows how well the color of source ***S*** approaches to that of target ***T*** by the successive *color stealing* and ***PC** color matching*. It's notable that the synthesized image color for the mixed set of ***R***(4) around *n*=4,well matches the image ***R*** observed in the evening and also target ***T*** for ***R***(10) in one day after.

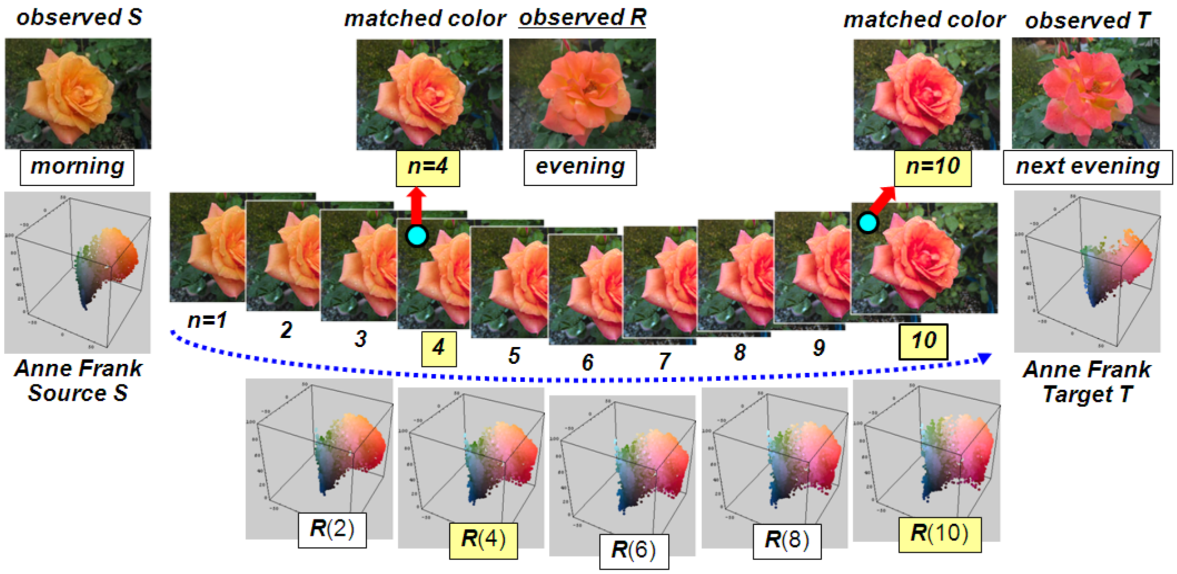

Fig.3 *Simulated color changes in one day and a half for Souvenir D' Anne Frank by PC color matching model*

Morphological Color Change Model

The PC color matching model seems to work safely for such cases as Fig.2, because the color and shape changes are small and gentle. However, the petal color such as Morning Glory dramatically changes "bluish" to "purple" in half a day, because the Heavenly Blue Anthocyanin pigment is responsible for the color change depending on the pH of the environment. In addition, the petal shape is also changing due to the different camera angles between morning and evening.

In order to adapt to this sort of change, the model should be extended to meet the requirements of

(1) Separation of petal area from the background
(2) Warping for responding to the shape change

Segmentation-based PC Color Matching

To reflect the major color change in the petal without blending any other color, the Morning Glory is simply segmented into two distinct parts. Before segmentation, the {*L*, a*, b**} images in source ***S*** and target ***T*** are pre-processed by a joint spatial-range *bilateral filter* to reduce the unwanted *"textures"* keeping the sharpness. Then ***S*** and ***T*** are segmented to two parts of *"petal"* and "background" by *k-means* clustering as shown in Fig.4.
Finally, the sequential color stealing by the PC color matching is operated only to the separated petal without changing the background. Thus the smoothed and natural pure color changes are obtained as illustrated in Fig.5.
However this extension doesn't correspond to the shape change in petal because of without warping.

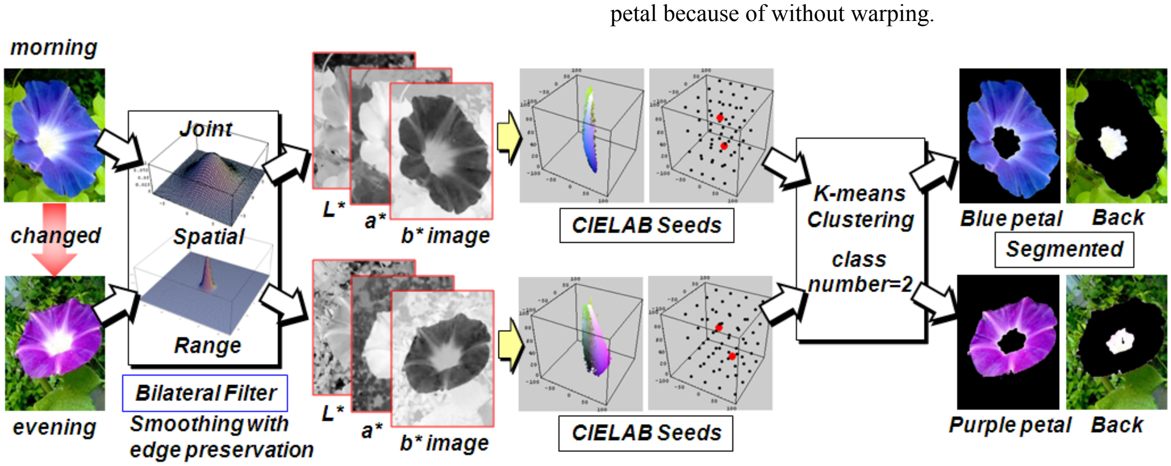

Fig.4 *Separation of petal by k-means clustering with bilateral filter to reflect the major color change*

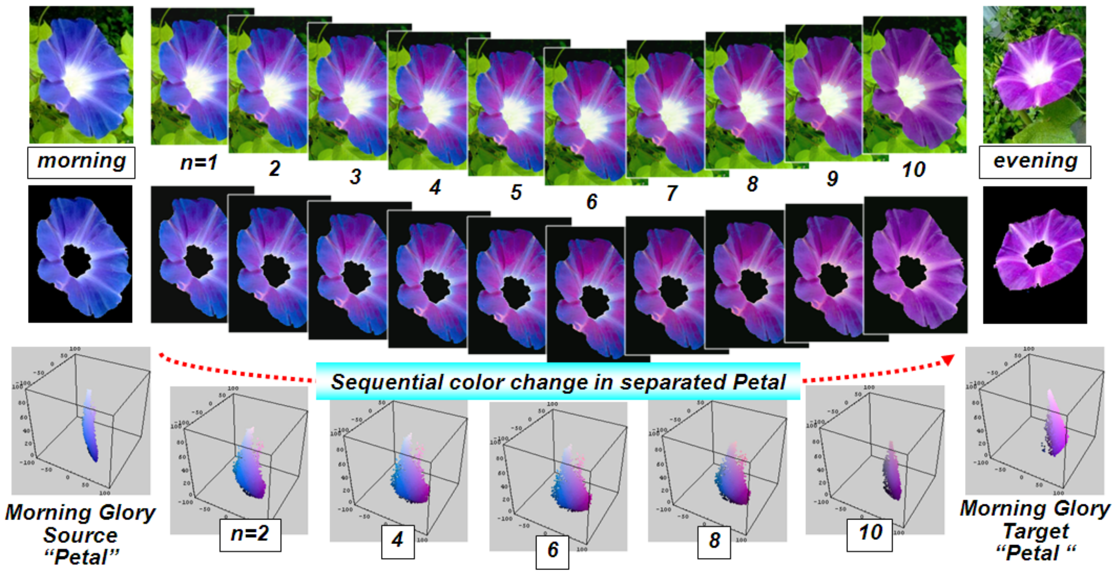

Fig.5 Sequential color change in Morning Glory by segmentation-based PC color matching without warping

Warping by Morphological Binary Median

Generally, the image morphing technology involves the warping process before cross dissolving. PC-based color matching method is used as a better substitute for cross dissolving to avoid the double-exposure effect, but lacks the warping function for shape matching. So far, many warping techniques, such as Mesh warping[8], feature-based warping[9], or TPS (Thin-Plate Spline)-based warping[10] have been developed. However it's a hard task to specify the control points, or to select the pair of feature lines automatically. Usually these control points should be selected interactively and the result depends on the animator's skill.

As a second extension of PC color matching, the morphological binary median process is applied to the segmented petal image which can be manipulated as a '*binary*' pattern[11].

Now Eq. (2) and (3) are rewritten for the binary bit images of source $\boldsymbol{S}_B$ and target $\boldsymbol{T}_B$ after segmentation as

$$\boldsymbol{R}_B = \bigcup_{\forall\lambda}\left[\left\{\delta_B^{(\lambda)}(\boldsymbol{S}_B \cap \boldsymbol{T}_B)\right\} \cap \left\{\varepsilon_B^{(\lambda)}(\boldsymbol{S}_B \cup \boldsymbol{T}_B)\right\}\right] \tag{10}$$

$$\begin{aligned} &\boldsymbol{Z}_{B0} = (\boldsymbol{S}_B \cap \boldsymbol{T}_B),\ \boldsymbol{W}_{B0} = (\boldsymbol{S}_B \cup \boldsymbol{T}_B),\ \boldsymbol{R}_{B0} = (\boldsymbol{S}_B \cap \boldsymbol{T}_B) \\ &\boldsymbol{Z}_{Bi} = \delta_B(\boldsymbol{Z}_{Bi-1}),\ \boldsymbol{W}_{Bi} = \varepsilon_B(\boldsymbol{W}_{Bi-1}) \\ &\boldsymbol{R}_{Bi} = \left[(\boldsymbol{Z}_{Bi} \cap \boldsymbol{W}_{Bi}) \cup \boldsymbol{R}_{Bi-1}\right]\ i = \text{iteration until converging} \end{aligned} \tag{11}$$

Since the suffix B means *binary*, δ_B and ε_B denote '*binary dilation*' and '*binary erosion*' respectively. Also '*sup*' and '*inf*' operators are replaced by '*binary or*' and '*binary and*'.

Fig.6 illustrates the order of binary median sequences for M=3. The first morphological binary median image $\boldsymbol{R}_B(4)$ is created just the halfway between $\boldsymbol{S}_B$ and $\boldsymbol{T}_B$ after the iteration by Eq. (10). The first result $\boldsymbol{R}_B(4)$ may be the second target for the source $\boldsymbol{S}_B$ to produce the second binary median $\boldsymbol{R}_B(2)$ or the third source for the target $\boldsymbol{T}_B$ to produce the third binary median $\boldsymbol{R}_B(6)$. Thus the sub-divided morphological binary median image $\boldsymbol{R}_B(n)$ is successively created between $\boldsymbol{S}_B$ and $\boldsymbol{T}_B$ for n=1~ 2^M-1.

Since n is renumbered from left to right in time sequence, the binary median images are created in order of $\boldsymbol{R}_B(4)$, $\boldsymbol{R}_B(2)$, $\boldsymbol{R}_B(6)$, $\boldsymbol{R}_B(1)$,…, $\boldsymbol{R}_B(7)$ according to each iteration depth of m=1~M.

In the sequence of Fig.6, the shapes of morphological binary median images between the segmented binary petals of source $\boldsymbol{S}_B$ and target $\boldsymbol{T}_B$ are gradually warping and approaching the target.

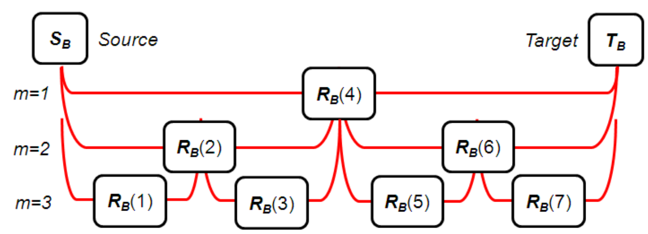

Fig.6 Generation order of binary morphological medians

Colorization of Morphological Binary Median

Since the pixel colors in each binary median image are unknown, the corresponding grayscale median image $\boldsymbol{R}(n)$ should be restored by any colorization algorithm. We can make use of a set of {$\boldsymbol{S}$, $\boldsymbol{T}$, $\boldsymbol{S}_B$, $\boldsymbol{T}_B$, $\boldsymbol{R}_B(n)$} for getting the colored morphological median images.

The petal and background areas are colorized by choosing the paint colors according to the logical mask operations with binary logical masks as shown in Fig 7.

The logical operations for colorization are given by

$$\boldsymbol{R}(n)\begin{cases} = \boldsymbol{S}\begin{cases} \text{if}\ \ \boldsymbol{R}_B(n) \cap \overline{\boldsymbol{T}}_B = 1\ \text{for petal} \\ \text{if}\ \ \overline{\boldsymbol{R}}_B(n) \cap \boldsymbol{T}_B = 1\ \text{for back} \end{cases} \\ = (1-\alpha_n)\boldsymbol{S} + \alpha_n\boldsymbol{T}\begin{cases} \text{if}\ \ \boldsymbol{S}_B \cap \boldsymbol{R}_B(n) \cap \boldsymbol{T}_B = 1\ \text{for petal} \\ \text{if}\ \ \overline{\boldsymbol{S}}_B \cap \overline{\boldsymbol{R}}_B(n) \cap \overline{\boldsymbol{T}}_B = 1\ \text{for back} \end{cases} \\ = \boldsymbol{T}\begin{cases} \text{if}\ \ \boldsymbol{R}_B(n) \cap \overline{\boldsymbol{S}}_B = 1\ \text{for petal} \\ \text{if}\ \ \overline{\boldsymbol{R}}_B(n) \cap \boldsymbol{S}_B = 1\ \text{for back} \end{cases} \end{cases} \tag{12}$$

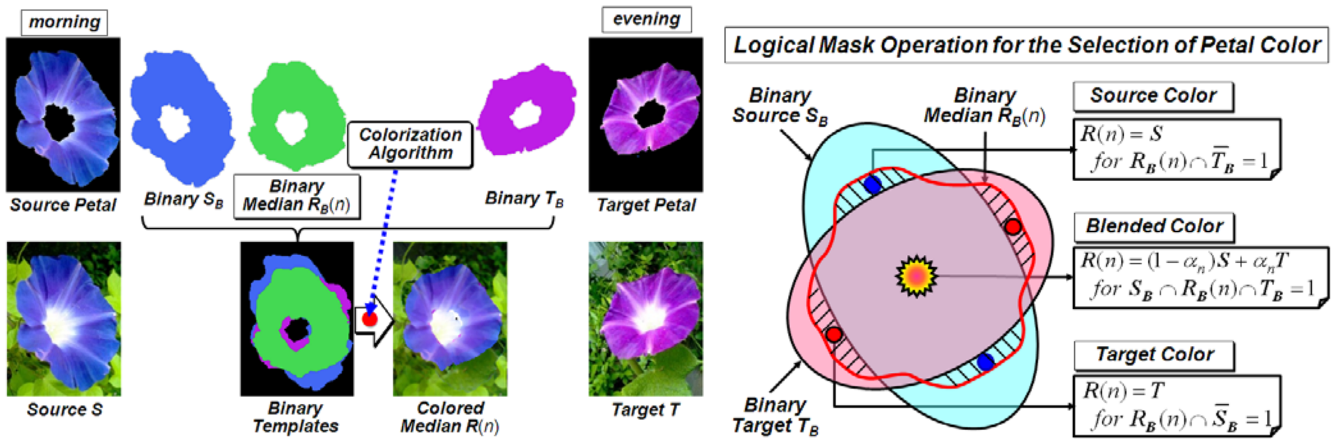

Fig.7 *Colorization process for binary medians by the selection of paint colors with logical mask operation*

Where, the symbols $\overline{S}_B$ and $\overline{T}_B$ denote the '*binary not*'.

The colorization for the background areas are performed by just the complementary logical operations with the inverted binary masks of {S_B, T_B, $R_B(n)$} against the petal.

Here, the time-varying blending ratios of (1-α_n) and α_n are simply used for cross dissolving after warping.

Fig.8 and Fig.9 demonstrate the colorized results in grayscale median sequences with warping by the proposed model. Throughout the sequence, the color and shape are smoothly changing and approaching to the target. Although some artifacts appear in petal edges for Morning Glory because of the '*binary dilation*' and '*binary erosion*' process, the model needs not any control points or animator's skill for image warping. This is a distinctive advantage to the conventional methods.

In a morphological movie application, the edge artifacts may be or should be suppressed by any spatial filtering, which is left behind as a future work.

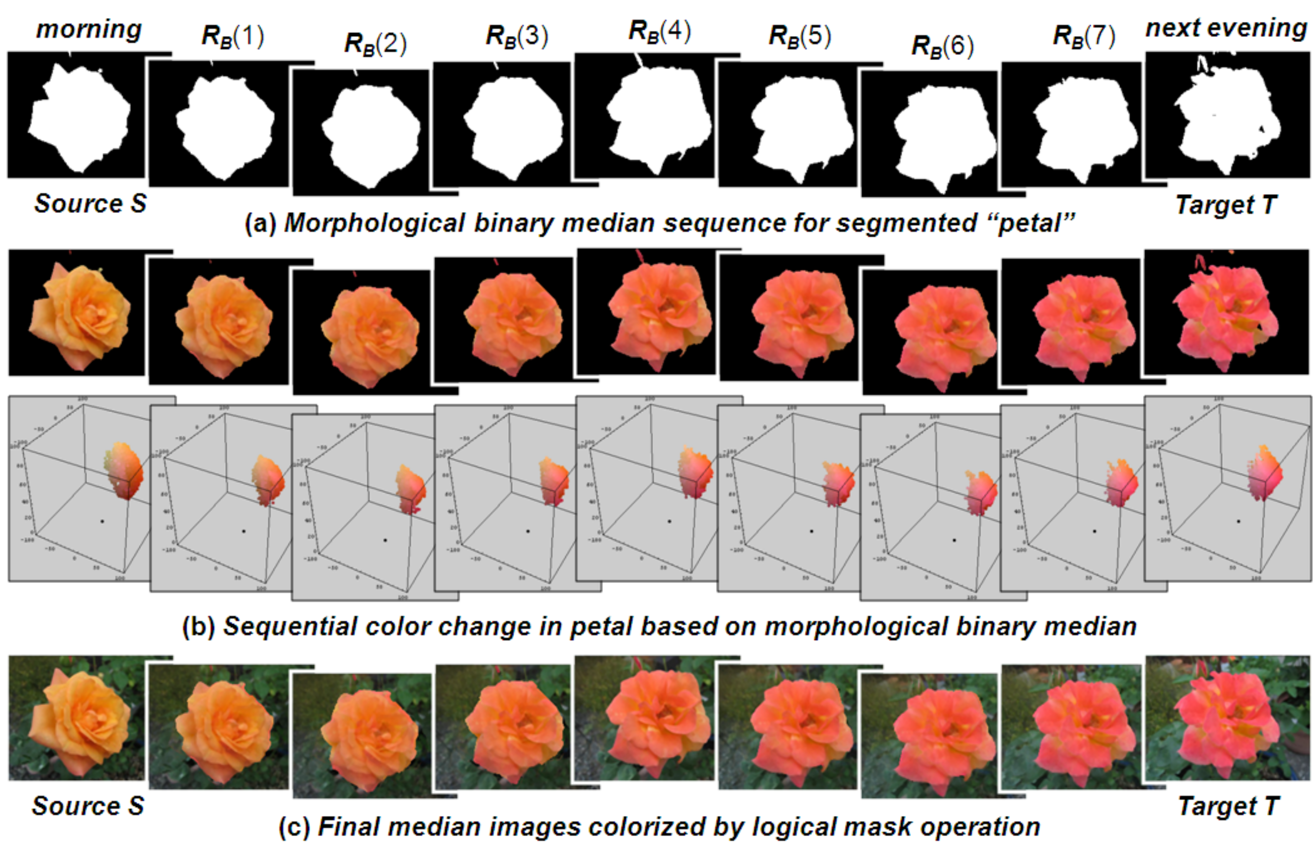

Fig.8 *Simulated results in color change of Souvenir D' Anne Frank by proposed morphing algorithm*

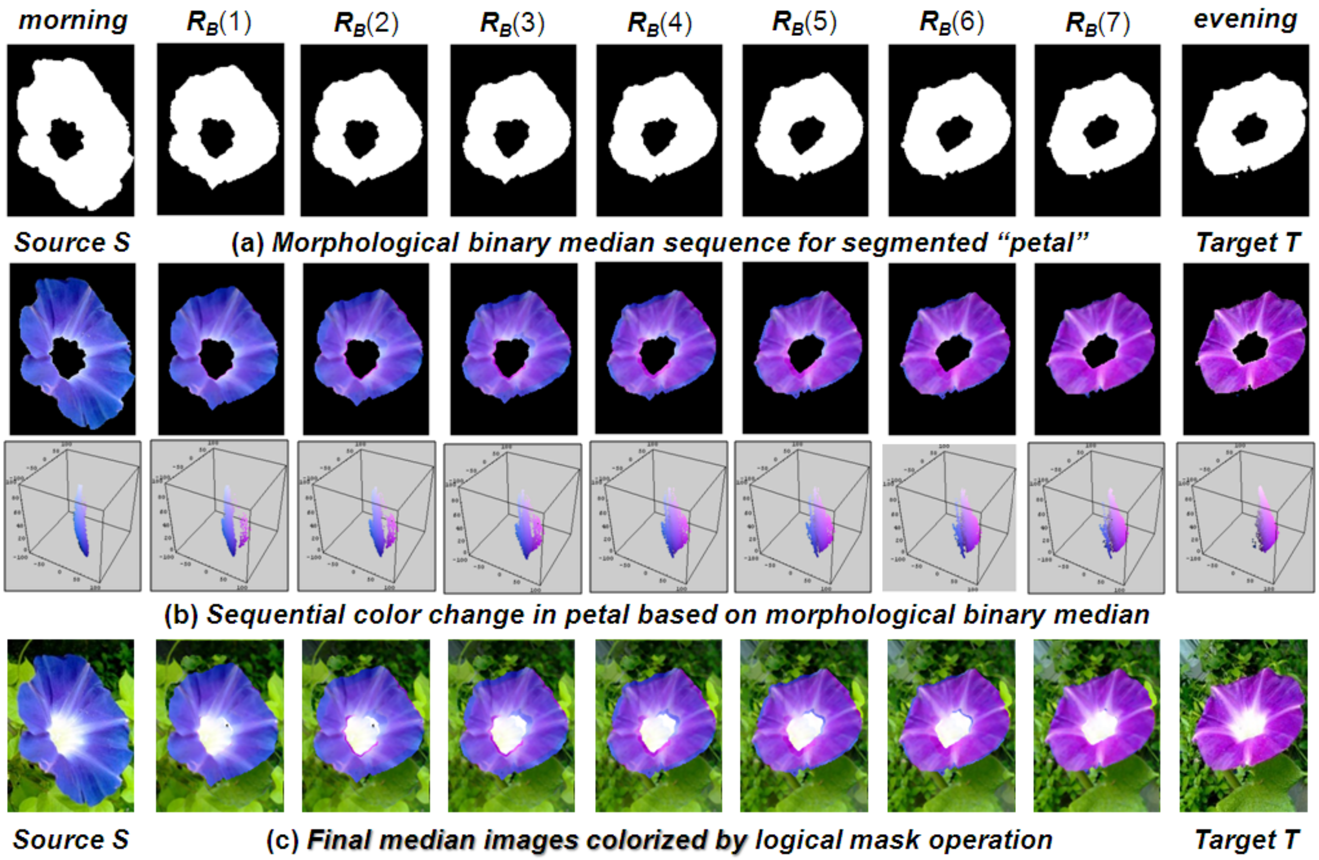

Fig.9 *Simulated results in color change of Morning Glory by proposed morphing algorithm*

Conclusions

PC *color matching* algorithm has been advanced to the time-sequential color stealing model and extended into a simple and novel morphological binary median sequence with image warping. The proposed model creates the sequential intermediate images between only two images of source ***S*** and target ***T***. Different from the conventional morphing methods, the new algorithm needs not any control points or animator's skill for image warping but creates the morphological binary median images coupled with image segmentation. The warped black/white binary images are finally colorized with a simple logical mask and a color blending method such as cross dissolving.

The model is applied to imitate a seasonal color change in flowers such as Hydrangea, Souvenir D' Anne Frank, or Morning Glory. Though the artifact near petal edge is not completely solved yet, the model mostly worked well to create the time-sequential video clips with smoothed color and shape transitions in petal. Towards the better image quality, the colorization algorithm may be improved in combination with not binary but grayscale morphological median sequence and the further research will be continued as a future work.

References

1. H. Kotera et al, Object-oriented Color Matching by Image Clustering, Proc. CIC6, 154-158, 1998
2. E. Reinhard et al, Color transfer between images, Proc.IEEE Comp. Graph. Appl., 34-40, Sep/Oct., 2001
3. M. Barnsley, Super Fractals, Cambridge Press, 2006
4. S. Mochizuki et al, Stealing Autumn Color, ACM SIGGRAPH, 2005
5. M. Grundland et al, Cross Dissolve without Cross Fade, Eurographics'06, 25, 3, 2006
6. M. Iwanowski and J. Serra, Morphological Interpolation and Color Images, Proc. ICIAP'99, 50-57, 1999
7. H. Kotera and T. Horiuchi, Automatic Interchange in Scene Colors by Image Segmentation, Proc. CIC12, 93-99, 2004
8. S. Y. Lee et al, Image morphing using deformable surface, Proc. Computer Animation, 200,31-39, 1994
9. T. Beier and S. Neely, Feature-based image metamor- phosis, SIGGRAPH'92, C.G., 35-42,1992
10. F. L. Bookstein, Thin-plate splines and decomposition of deformation, IEEE Trans., Pattern Anal. & Machine Intelligence, 11(6),567-585, 1989
11. M. Iwanowski, Morphological Binary Interpolation with Convex Mask, Proc. ICCVG'02, 360-367, 2002

Author Biography

Hiroaki Kotera *joined Matsushita Electric Industrial Co., in 1963. He received Doctorate from Univ. of Tokyo. After worked in image processing at Matsushita Res. Inst. Tokyo during 1973-1996, he was a professor at Dept. Information and Image Sciences, Chiba University until his retirement in 2006. He received 1993 journal award from IS&T, 1995 Johann Gutenberg prize from SID, 2005 Chester Sall award from IEEE, 2006 journal award from ISJ and 2008 journal award from SPSTJ. He is a Fellow of IS&T.*