Research Article
Isolated Pixel Filtering-Based Image Inpainting Methods for Drawing Robots

Chun-Chieh Wang

Department of Automation Engineering and Institute of Mechatronoptic Systems, Chienkuo Technology University, Taiwan

ABSTRACT

The purpose of this thesis is to show that isolated pixel filtering-based image inpainting methods for drawing robots. For watercolor painting, HSI color space is used to improve the effect of color simplification such that the recognition of image processing results is enhanced, firstly. Second, that less-affected isolated point color is replaced with the surrounding color via isolated pixel filtering methods. Third, we use image inpainting technology to reduce the distortion caused by the isolated pixel filtering. Besides, we adjusted the path planning as well as reduced isolated points to dramatically reduce drawing time. For sketch painting, through the image resolution adjustment as well as the shortening of the spacing of the drawing lines, the robot can draw more detailed pictures in the same size of drawing space. To allow LabVIEW to directly issue commands to control the drawing robot, the communication function has been added. The measured results confirm that the application of the technology in this paper can shorten the drawing time by about 57% to 59% on the drawing robot system.

1. Introduction

In view of that many street painters usually takes a long time to draw a picture such that it is impossible to produce a large amount in a short time. Therefore, we hope to develop a drawing robot that can assist painters. With the help of robots, the artist can improve their work efficiency and complete more paintings in the same time.

In the literature of robot drawing in the past, the image detection applied in a watercolor painting robot proposed by Hung YY [1] in 2017. It is characterized by using HSV color simplification method with a self-made drawing mechanism, and then using a limited variety of colors to complete the drawing. Although the recognition of the image is acceptable, the long drawing time is a major disadvantage. In 2016, Hong M.J. [2] proposed robotics artistic colorful picture drawing and painting using visual feedback control system. Two different painting styles were used. 2017 Columbia University Creative Machines Lab / PIX18 [3] uses Gantry multi-axis robotic arm to draw pictures with artificial

intelligence. In the same year, Massachusetts Institute of Technology Dane Kouttron et al. [4] used online PNG to SVG software to simplify the colors used Linux CNC with a multi-axis robotic arm for drawing.

For the sketch drawing part, Lin L.C. [5] used edge detection to generate contour images and used mobile robots to draw on a flat surface in 2017. In 2009, Mac T.T. [6] and Chuang L.W. [7] used PI and PID controllers to adjust motors to control multi-axis robotic arms to draw portraits, respectively. The above three documents are all drawn with the edge of the image.

To ameliorate the above shortcomings, we apply isolated pixel filtering-based image inpainting methods to drawing robots. Please refer to [8] for the initial improvement results. In addition, the measurement results in this article prove that the drawing time can be shortened by about 57% to 59%, which is about 2% to 4% higher than the improvement results of [8].

Corresponding author's E-mail: jasonccw@ctu.edu.tw

2 Research Method

2.1 HSI color model and color simplification

We know that the parameters of the RGB color space are all connected, which makes image processing difficult. In contrast, the parameters of the HSI color space are independent of each other. Although the HSI color model is very similar to the HSV color model, there is a difference in the representation of the Intensity of HSI and the Value of HSV, as shown in Fig.1. From these two color spectrums, it can be found that the overall color change of the HSI color model is relatively smooth. In contrast, the HSV color model has more compact changes between light colors and primary colors, and it is more difficult to set the color reduction range. Therefore, this article uses the HSI color model with smoother color changes for color simplification. For other details, please refer to [8].

In this paper, the scanning method from left to right and top to bottom is used to perform HSI color simplification on the color of each pixel. First, it is necessary to convert the RGB value to the HSI value before further processing, as shown in Fig.2. Since the hue representation in HSV and HSI color models is the same, the hue part continues the setting of reference [1] Since everyone's perception of color is different, this article is based on the author's perception of color to simplify the range of adjustments. For other details, please refer to [8].
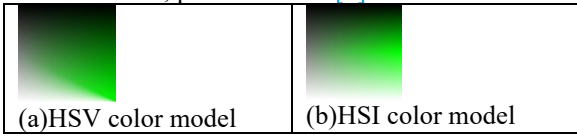

(a)HSV color model   (b)HSI color model

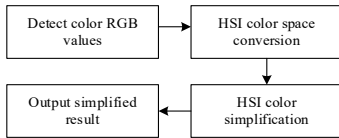**Fig.1.** Comparison of HSV and HSI Green Chromatogram
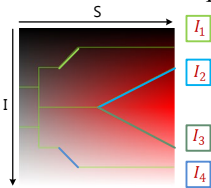

Fig. 2. The process of color simplification

Fig. 3. Distribution of Color simplification range

$$I_1 = 128 - S \tag{1}$$

$$I_2 = \left| \frac{24448 - (64 \times S)}{127} \right| \tag{2}$$

$$I_3 = \left| \frac{8064 - (64 \times S)}{127} \right| \tag{3}$$

$$I_4 = 128 + S \tag{4}$$

In Fig. 3, in the diagonal part, we use Eq.1~Eq4 to import the S value to get the relative range of I value. The scope

of HSI color simplification is summarized in a rule table. Through the H, S, and I parameters in the captured target pixel, we can determine from the rule table which shade of color the pixel belongs to. In order to avoid errors in recognizing pictures with the naked eye due to too close shades, the 39 simplified colors are fine-tuned. The color codes used are shown in reference [9].

2.2 Isolated pixel filtering for watercolor system

In the process of image thumbnailing, the intersection of different colors is prone to color mixing. This change in color mixing is usually not too large. We want to remove the mixed color as much as possible and replace it with the surrounding colors. In addition, filtering out isolated pixels with low influence in the image can reduce the time it takes to repeatedly raise and lower the pen. Therefore, this paper proposes to filter out the isolated pixels and replace them with surrounding colors to eliminate the isolated pixels, so as to reduce the time consumed for lifting and lowering a single pixel. The method of filtering out isolated pixels starts from the upper left corner of the picture. As shown in Fig. 4(a), the central color is an isolated pixel, which will be replaced with the color of the largest area around it. When the surrounding eight pixels have the same color, they are not isolated points, as shown in Fig. 4 (b). For other details, please refer to [8].
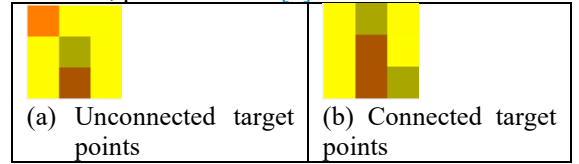

(a) Unconnected target points	(b) Connected target points

Fig.4. Judgment of target point connectivity for watercolor

When there are two or more colors with the largest pixel area around the target, the system will scan from left to right and then from top to bottom according to the scanning order, starting from the top left pixel, as shown in Fig. 5. After that, the first and second ranking colors are taken out. The HSI color space is used to convert these two colors to the target color. At the same time, H is used to determine which color is closer to the target color. After that, the color with a closer hue replaces the target color. Taking Fig. 6 as an example, since the number of orange and yellow pixels is 3, it is impossible to determine which color replaces the target color. Therefore, it is necessary to judge by hue. For other details, please refer to [8].
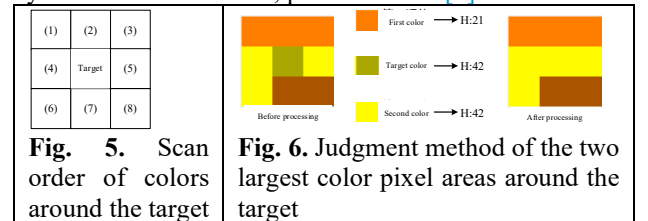

Fig. 5. Scan order of colors around the target	**Fig. 6.** Judgment method of the two largest color pixel areas around the target

2.3 Feature inpainting for watercolor system

After the isolated points are filtered out, some features in the image may be affected and cause distortion. The right-hand line features are distorted, as shown in Fig. 7(b). Therefore, a new feature inpainting method is proposed in this article. That is, a 3×3 array is used to determine whether it needs to be inpaintinged. First, the images before and after the isolated points are filtered out are subtracted from each other. In the subtraction result, the part where the pixel value is not equal to 0 is the position filtered by the isolated point. The color of the pixels before the filtering of the processed position points is captured from the image before the isolated points are filtered. At the same time, in the image after the isolated points are filtered, these location pixels are found and centered on it. Then the 9×9 matrix around it is extracted. If the color of the remaining 8 cells except the center point in the matrix is the same as the color of the pixel before filtering, it is judged to be inpaintinged. This inpaintinging action is to restore the "pixel in the image after filtering out the isolated point" to the "color of the pixel before filtering out". Fig. 8 shows the comparison before and after image inpainting.
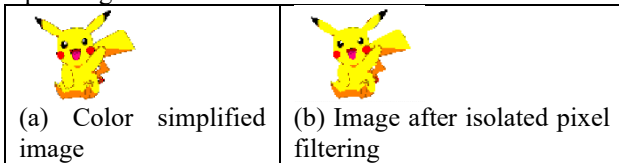

(a) Color simplified image | (b) Image after isolated pixel filtering

Fig. 7. Before and after filtering isolated pixels

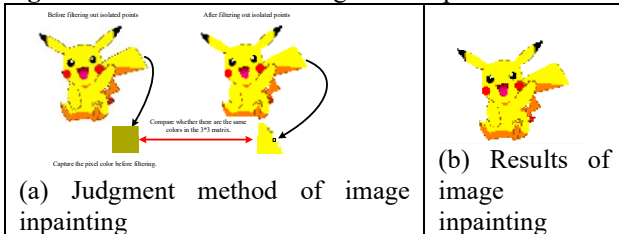(a) Judgment method of image inpainting | (b) Results of image inpainting

Fig. 8. Comparison before and after image inpainting

2.4 Optimized path movement for watercolor System

The area of the watercolor painting system consists of three parts: drawing, paint dipping, and brush cleaning. Fig. 9 is a schematic diagram of the movement of the brush. For other details, please refer to [8].
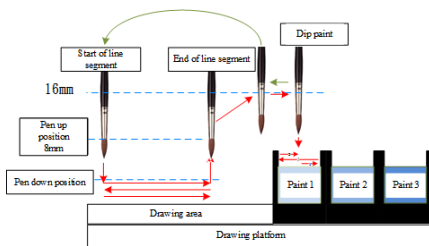

Fig. 9. Schematic diagram of the movement of the brush

2.5 Grayscale

The conversion formula is as follows:
$$Gray = 0.299R + 0.587G + 0.114B \tag{5}$$
For other details, please refer to [8].

2.6 Binarization

We use binarization to divide the grayscale image into black and white. Black represents the area not to be drawn, and white represents the area to be drawn. By setting 4 different thresholds, the specific part of the grayscale image is captured. For other details, please refer to [8].

2.7 Isolated pixel filtering and image inpainting for sketch system

The isolated point filtering and image inpainting in the sketch system will process the black and white pixels in the binary image, as shown in Fig. 10. If there is the same color around the target point, it is judged as connected. Conversely, if there is no same color around the target point, it is judged as an isolated point. The image inpainting method is the same as in section 2.2
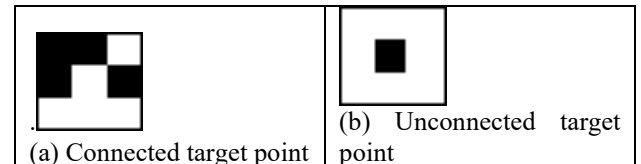

(a) Connected target point | (b) Unconnected target point

Fig. 10. Judgment of target point connectivity for sketch

2.8 Drawing method for sketch

We use lines in different directions for multi-level depiction. Draw the four shades of images mentioned earlier with lines in different directions, as shown in Fig. 11. The more the lines are stacked, the darker the color. In this way, the changes in depth are expressed.

Fig. 11. Drawing trajectory in four directions

3 System Architecture of drawing Robot

3.1 Configuration of drawing platform

Fig. 12 (a) is the plane configuration of the drawing area. Physical of the new drawing robot is shown in Fig. 12 (b).
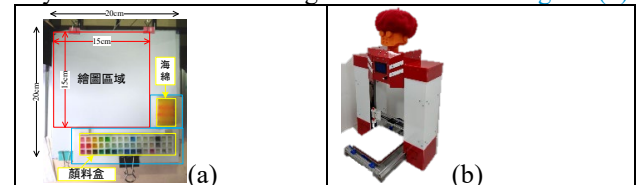

Fig. 12. (a) The plane configuration of the drawing area (b) Physical photo of the new drawing robot

3.2 Watercolor system

For the flow chart of watercolor painting system, please refer to [8]. The direct connection between the drawing platform and the computer replaces the previous steps of manually loading data into the drawing platform to complete the automation of the watercolor painting system.

3.3 Sketch system

For the flow chart of sketch system, please refer to [8]. By adjusting the image resolution and the line spacing of the drawing track, the drawing results are more detailed.

3.4 Communication system

To improve the convenience of use, we have added a communication part to the program. The user can decide whether to draw directly with LabVIEW through the buttons in the HMI. After the program converts the processing result and saves it as a G-Code file, if the button in the human-machine interface is not pressed, the program will be directly terminated, allowing the user to transfer data through the SD Card. If the user presses the button, LabVIEW will connect with the robot and send the drawing path data for drawing.

4 Experimental Results

4.1 Watercolor drawing results

Fig. 13 shows the drawing results of Picasso's abstraction picture (Background with Blue Cloudy Sky). The drawing time of literature [1] is 332 minutes. Our drawing time is shortened to 142 minutes. It saves 57.23%. The drawing results of Picasso's abstraction picture (Fernande with a Black Mantilla), as shown in Fig. 14. The drawing time of literature [1] is 507 minutes. Our drawing time is 207 minutes. It saves 59.17%.
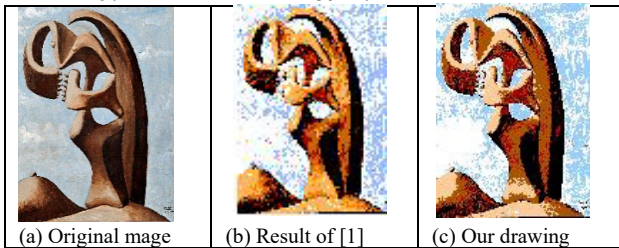
(a) Original image	(b) Result of [1]	(c) Our drawing

Fig. 13. The drawing results of Picasso's abstraction picture (Background with Blue Cloudy Sky)

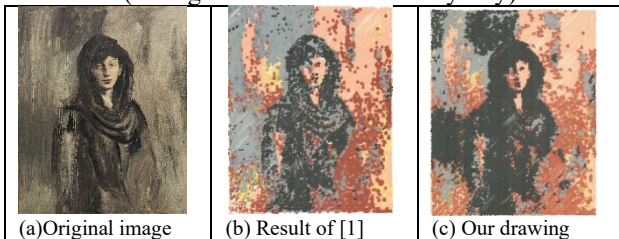| (a)Original image	(b) Result of [1]	(c) Our drawing

Fig. 14. The drawing results of Picasso's abstraction picture (Fernande with a Black Mantilla)

4.2 Sketch drawing results

Fig. 15 shows the drawing results of different line spacing. Although the drawing time with denser lines will increase a bit, the recognition of the portrait will be significantly improved. Other drawing results with 0.5mm line spacing are shown in Fig. 16 (Aaron Kwok Fu Shing, Rainie Yang, and Jam Hsiao).
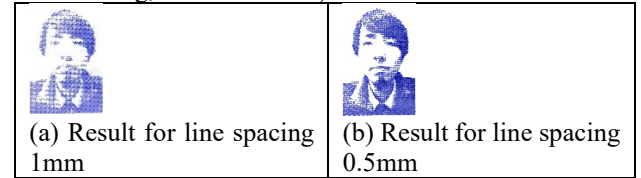
(a) Result for line spacing 1mm	(b) Result for line spacing 0.5mm

Fig. 15. The drawing results of different line spacing

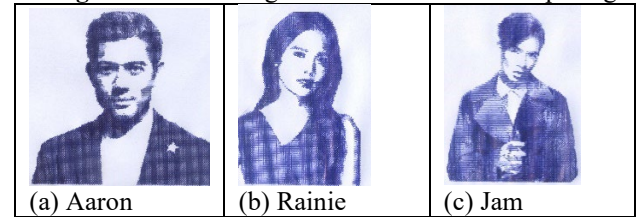| (a) Aaron	(b) Rainie	(c) Jam

Fig. 16. The drawing results of different line spacing

5 Conclusion

In this paper, HSI color space method strengthens the recognition of image processing results. Moreover, we use the isolated pixel filtering, image inpainting techniques and path planning optimization to effectively shorten the drawing time. In addition, through the image resolution adjustment as well as the shortening of the spacing of the drawing lines, the robot can draw more detailed pictures. Experimental results prove that isolated pixel filtering-based image inpainting methods have been successfully applied to drawing robots

References

[1] Hung Y.Y. (2017)，Image Detection Applied in a Watercolor Painting Robot, Master Thesis of Chienkuo Technology University.

[2] Hong M.J. (2016)，Robotics Artistic Colorful Picture Drawing and Painting Using Visual Feedback Control System，Master Thesis of National Taiwan University.

[3] Columbia University Creative Machines Lab PIX 18 or PIX 18 (Search date: Set. 20, 2021)

[4] Dane.Kouttron, Awakening an Old Robot, For Art (Search date: Set. 20, 2021)

[5] Lin L.C. (2017)，Trajectory Planning and Tracking Control of a FPGA-based Mobile Robot in a Picture Drawing Application, Master Thesis of National Taiwan University of Science and Technology.

[6] Mac T.T. (2009), Autonomous Drawing Manipulation of Humanoid Robot Arm, Master Thesis of National Taiwan University of Science and Technology.

[7] Chuang L.W. (2009), Human Portrait Generation System for Humanoid Robot Arm Drawing, Master Thesis of

National Taiwan University of Science and Technology.

[8] Wang C.C., Ye Z.X. (2021), Image Inpainting Techniques Combined with Isolated Pixel Filtering Applied to Multifunctional Drawing Robots, 2021 International Conference on Artificial Life and Robotics (AROB 26th 2021), on line Japan, Jan. 21-23, pp. 100-104, 2021. or https://cir.nii.ac.jp/ja/crid/1390851175703311488

[9] Ye Z.X. (2018), Isolated Pixel Filtering and Image Inpainting Techniques Applied in System Improvement of Multifunctional Drawing Robots, Master Thesis of Chienkuo Technology University.

Authors Introduction

Dr. Chun-Chieh Wan

He received the Ph.D. degree in Institute of Graduate School of Engineering Science and Technology from National Yunlin University of Science & Technology, Yunlin, Taiwan, in 2004. He currently is an Associate professor of Department of Automation Engineering and Institute of Mechatronoptic Systems of Chienkuo Technology University. His areas of research interest include robotics, image detection, electromechanical integration, innovative inventions, long-term care aids, and application of control theory. He is now a permanent member of Chinese Automatic Control Society (CACS). He is also a permanent member of Taiwan Society of Robotics (TSR)