Research on Mosaic Tile Color Model Based on HIS Color Space Model and Particle Square Optimization Algorithm

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Abstract. Based on the conversion between RGB color space and HSI color space, combined with the relevant knowledge of optimization problems, this paper reasonably solved the color selection problem of mosaic tiles.

Firstly, this paper establishes a color selection model based on his color space. Based on the conversion relationship between RGB color space and HSI color space, the original RGB parameters in the topic are converted into HSI parameters which are more suitable for calculation. The color difference is used to quantify the similarity between different colors, and a more reasonable formula for calculating color difference is determined to improve the accuracy of color selection results. Finally, the color difference between the original color and each existing tile color is compared, and the tile color with the smallest color difference is determined as the color selection result.

Next, because this problem is about the optimal solution of the whole color difference value, it is nonlinear and has a large solution space. In this paper, a heuristic global search algorithm based on swarm intelligence, Particle Swarm Optimization, is adopted to gradually approach the global optimum by updating the individual optimal solution and global optimal solution of particles. When searching for the global optimal solution, it is easy to fall into the trap of local optimal solution, and the PSO algorithm used in this paper can take many measures to avoid it. By continuously debugging the size of population size, iteration times and learning factors, the optimal solution for developing new colors is finally obtained.

In this paper, when considering the similarity between different colors and the follow-up problems, the HIS color space model is used reasonably, which greatly improves the accuracy of color selection results.

1. Introduction
Mosaic ceramic tile is a square ceramic tile with a small size (the common specification is that the side length does not exceed 5cm), which is convenient for laying on uneven surfaces and easy to splice and combine various characters or patterns. However, due to the limitation of technology and cost, the colors of ceramic tiles can only be limited. When splicing patterns, users should first select tiles with similar colors according to the colors in the original picture before splicing.

2. Color selection model based on HIS color space
Both the original picture color and the given tile color are in 24-bit true color format, i.e RGB color space. RGB color space is a cubic three-dimensional coordinate space structure, which uses three primary colors red, green and blue to represent three coordinates. Because image acquisition and display equipment uses RGB color space, RGB color space is the most basic and commonly used color space in color image processing. However, RGB color space is not intuitive, uneven, and dependent on
hardware devices, so RGB color space is a device-related space with incomplete intuitive color description. [1]

In order to overcome the disadvantages of uneven and non-intuitive RGB color space, color space which is more in line with color visual characteristics can be used in color image processing. HSI color space describes color with Hue, Saturation and Brightness are from the perspective of human visual system. HSI color space can be described by a cone space model, which is quite complex, but it can clearly show the changes of hue, brightness and saturation. HIS color space is shown in Figure 1.

![Figure 1: HIS color space model based on circular color plane](image)

Because people's vision is much more sensitive to brightness than color shade, in order to facilitate color processing and recognition, people's vision system often adopts HSI color space, which is more in line with people's visual characteristics than RGB color space. In image processing and computer vision, a large number of algorithms can be conveniently used in HSI color space, and they can be processed separately and independently. Therefore, the workload of image analysis and processing can be greatly simplified in HIS color space.

HSI color space and RGB color space can be converted to each other by a certain algorithm. Given an image in RGB color format, the chroma component $h$ of each RGB pixel is

$$H = \left\{ \begin{array}{ll} \frac{\theta}{360} & B \leq G \\ 360 - \frac{\theta}{360} & B > G \end{array} \right.$$  

Type is defined as $\theta$

$$\theta = \arccos \left( \frac{1}{2} \left[ (R - G) + (R - B) \right] \right) \left/ \left( (R - G)^2 + (R - G)(G - B)^2 \right) \right.$$  

Saturation component $s$ is

$$S = 1 - \frac{3}{(R + G + B)} \left[ \min(R, G, B) \right]$$  

The intensity component $I$ is

$$I = \frac{1}{3} (R + G + B)$$  

As can be seen from the above formula, the chromaticity component is within the range of $[0^\circ, 360^\circ]$, and it is divided into $360^\circ$ to the range $[0, 1]$. If the given RGB value is in the $[0, 1]$ interval, the saturation component and the intensity component are also within the $[0, 1]$.

In addition, HIS color space has two important characteristics: firstly, the luminance component has nothing to do with the color information of the image, and because the chromaticity has nothing to do with flares and shadows, it is especially useful in some occasions where the luminance changes;
Secondly, chroma component is closely related to saturation component and the way people feel color, which is very useful for distinguishing objects with common colors. These characteristics make HSI color space very suitable for image processing and analysis based on human color perception. Therefore, before processing the original image, the original RGB parameters are processed into chroma, saturation and brightness through the conversion algorithm between RGB color space and HIS color space, so as to improve the efficiency and accuracy of color selection results.

We think the measurement of chromatic aberration is very important. In essence, chromatic aberration is a measure of the similarity of different colors. The greater the chromatic aberration, the smaller the color similarity. On the contrary, the smaller the chromatic aberration, the greater the similarity.

Because the chroma component is related to the saturation component, and the chroma component is circularly symmetric and has the characteristic of modulo $2\pi$, that is, the colors of chroma are the same at 0 rad and 2 $\pi$ rad, the similarity of chroma components between two color points is mainly considered when calculating chromatic aberration in HIS color space. In this paper, a color difference measurement method based on his color space is used to quantify the similarity between different colors. [2]

For any two points P1 and P2, H1, S1 and I1 in the HIS color space corresponding to the chrominance, saturation and brightness of the P1 point, the chrominance, saturation of the P1 point, respectively, H2, S2, and I2 of P1, respectively. And brightness. Then the chromaticity difference between the two points is

$$\Delta H(H_1, H_2) = \frac{1}{2} (S_1 + S_2) \sin \left( \frac{|H_1 - H_2|}{2} \right)$$

From essentially, this chromaticity difference definition method is based on the European geometric distance. As shown in Figure 2. If the saturation value of the two color points is the same (set to r), and is located in the same chromaticity plane, the angle $\theta = |H_1 - H_2|$. The string length corresponding to the angle is $2r \sin(\theta/2)$. At the same time, in order to define the chromaticity difference within the [0, 1], let $r = (S_1 + S_2)/4$, the chromaticity difference formula shown in the above formula can be obtained.

Figure 2: Euclidean geometric distance defined by chromaticity difference

Every color in the original picture and the existing 22 mosaic tile colors are converted from RGB color space to HIS color space, and the color difference between various colors is obtained by the color difference calculation formula defined in Formula, and the existing tile color with the smallest color difference is selected as the color selection result, so that the color selection process is more reasonable and accurate.
3. Color selection strategy based on particle swarm optimization

Particle Swarm Optimization (PSO) is a group-based evolutionary algorithm. The basic idea is to find the optimal solution through cooperation and information sharing among individuals in the group. [3]

When the PSO algorithm is used to solve the optimization problem, the solution of the problem corresponds to the "particles" in the search space. Each particle has its own position and speed (which determines the direction and distance of flight), and also has a Fitness Value determined by the corresponding function of the optimization problem. Then the particles follow the current optimal particles to search in the solution space.

PSO is initialized to a group of random particles (random solution), and then the optimal solution is found through iteration. In each iteration, the particle updates itself by tracking two extremums: one is the optimal solution found by the particle itself, which is called individual extremum; Another extreme value is the optimal solution found by the whole population at present, and this extreme value is the global extreme value.

In addition, only a part of the whole population can be used as neighbors of particles instead of the whole population, so the extremum in all neighbors is the local extremum.

Suppose that in a D-dimensional target search space, there are N particles forming a community, in which the i-th particle is represented as a D-dimensional vector

\[ X_i = (x_{i1}, x_{i2}, \ldots, x_{id}), i = 1, 2, \ldots, N \]

The "flying" speed of the i-th particle is also a D-dimensional vector, which is written as

\[ V_i = (v_{i1}, v_{i2}, \ldots, v_{id}), i = 1, 2, \ldots, N \]

The optimal position searched by the i-th particle so far is called individual extremum, which is written as

\[ p_{best, i} = (p_{i1}, p_{i2}, \ldots, p_{id}), i = 1, 2, \ldots, N \]

The optimal position searched by the whole particle swarm so far is the global extreme value, which is written as

\[ g_{best} = (p_{g1}, p_{g2}, \ldots, p_{gd}) \]

When these two optimum values are found, the particle updates its speed and position according to the following formula:

\[ v_{id} = w \times v_{id} + c_1 r_1 (p_{id} - x_{id}) + c_2 r_2 (p_{gd} - x_{id}) \]

\[ x_{id} = x_{id} + v_{id} \]

Because particle swarm optimization algorithm has efficient searching ability, it is beneficial to get the optimal solution in the sense of multi-objective; By representing the whole solution set population, multiple non-inferior solutions are searched simultaneously in parallel, that is, multiple Pareto optimal solutions are searched.

At the same time, Particle Swarm Optimization has good universality, is suitable for dealing with various types of objective functions and constraints, and is easy to combine with traditional optimization methods, thus improving its own limitations and solving problems more efficiently. Therefore, applying particle swarm optimization to this problem can get a high-precision solution.
In this paper, the basic steps of particle swarm optimization are as follows:

Step 1: For new M-color problems, take m random colors with 22 existing tile colors.

Step 2: Initialization particle group, including group size N, position X and speed V of each particle.

Step 3: Calculate the adaptivity value \( F_{it} \) of each particle.

Step 4: For each particle, compared with its adaptivity value \( F_{it} \) and individual extreme value \( p_{best}[i] \), if \( F_{it}[i] > p_{best}[i] \), use \( F_{it}[i] \) to replace \( p_{best}[i] \).

Step 5: For each particle, compared with its adaptivity value \( F_{it}[i] \) and global extreme value \( g_{best} \), if \( F_{it}[i] > g_{best} \), use \( F_{it}[i] \) to replace \( g_{best} \).

Step 6: Update the speed V and position X.

Step 7: If the end condition is met (the error is good enough or reaches the maximum number of cycles), exit, otherwise, return Step 2.

The fitness of the objective function to be optimized is:

\[
F = \sum_{i=23}^{n} \Delta H = \sum_{i=23}^{n} \frac{1}{2} (S_1 + S_2) \cdot \sin \left( \frac{|H_1 - H_2|}{2} \right)
\]

The result is RGB(2.9208, 169.4010, 238.6782) by programming with C++ language.

The fitness values of the global optimal solution under different iteration times are drawn by MATLAB, as shown in Figure 4. It can be observed that the fitness and fitness values of the global optimal solution do not change after about 40 iterations. The variation of particle position in the iterative process is shown in Figure 5, and the fitness value of the global optimal solution finally fluctuates in a small range of about 2.7752.

![Figure 4: Global optimal trend chart of fitness value](image-url)
Figure 5: Location diagram of brief visualization example

4. Conclusion
The HSI color space model used in this paper starts from human visual system, and describes color with hue, color saturation and brightness, which is more in line with human visual characteristics than RGB color space. In addition, the parameters of HSI color space can be processed separately and are independent of each other, which is more suitable for computer algorithm processing. HSI color space and RGB color space are just different representation methods of the same physical quantity, and there is a definite conversion relationship between them. Therefore, converting to HIS color space will not affect the attributes of the original data.

The solution of color selection strategy is based on the solution of the problem. For the optimization model of this problem, the particle swarm optimization algorithm we adopted has strong applicability and flexibility. It is a kind of uncertain algorithm, which embodies the biological mechanism of nature. In solving some specific problems, it is a deterministic algorithm. And the problem-solving process is gradual and easy to understand.

References
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