

Subjective Palette in Numerical Data Visualization

Vladislav M. Galkin

Tomsk Polytechnic University, 30 Lenin Avenue, Tomsk, 634050, Russia

Summary

For visualization of numerical fields, a color palette with a simple construction algorithm and colors of near-continuous distribution is proposed. On color images based on this palette, minimum and maximum values are identified without any scale.

Key words:

Color Palette, RGB Colors, Continuous Palette.

1. Introduction

The data obtained in numerical calculations, as a rule, require further representation. For this purpose, numerical fields are visualized by contour lines, or by data filling up to a continuous image and its subsequent painting based on certain palettes. The presence of objects with narrow spatial localization in the field under study complicates the use of contour lines. Therefore, image painting is in more common use. Palettes with shades of gray are now used very rarely, and the most common choice falls on chromatic palettes. With 4, 16, or 32 color palettes, a human with normal chromatic sensitivity can well perceive borders of each color on a large image. With 256 colors, it is possible to create a continuous palette with no visible color transition. For this number of colors, the coding is normally six or more bits per primary color, and additive mixtures in use are those of the *RGB* primary colors (*R* – red, *G* – green, *B* – blue).

Software packages for numerical data visualization use either built-in color palettes or custom color palettes. Built-in color palettes, as a rule, have a smooth color transition; however with no scale, visualization with them is ambiguous because the image color distribution may come into conflict with subjective experience of a human. Similar contradictions are readily found in modern journals and Internet resources where calculation results are represented as color fields with both green halftones and additive mixtures of primary colors. Moreover, the scale there is either absent or ill-defined.

Unfortunately, algorithms of custom palette formation are often hidden for user, and if not, they are rather complicated. In the work, a color palette with a simple construction algorithm and colors of near-continuous distribution is proposed to solve this problem.

2. Problem Statement

The problem to be solved is that of creation of a subjective palette (other names for a subjective palette are a custom palette, a subjective color scale, and pseudocolors [1]). The palette should meet the following conditions:

1. Encoding of *RGB* values with 6 bits per primary color
2. Minimum number of colors in the palette
3. Simple construction algorithm
4. Continuity, i.e., human eyes must perceive color transitions as being close to continuous ones
5. Identification of maximum and minimum temperature field reflections by a human without a color scale.

3. Experimental procedure

Color images of plane temperature fields based on different palettes were shown to 15 people with normal chromatic sensitivity. A color monitor with a cathode ray tube of 320/200 pixel resolution was used. There was no temperature-related color scale. The task for the people was to identify minima and maxima with naked eyes and to evaluate the color continuity on the images.

4. Experimental result

The experiments give the following results:

1. There exist palettes that meet the required conditions.
2. The palettes that meet the required conditions are close to temper colors on a steel sheet one of the edges of which is heated to bright glow and the other is cold. Hence, the lowest temperature is visually dark blue, and the highest temperature is light yellow. Evidently, the human brain ability to use available visual experience is realized in this case.
3. Palettes that fail to meet the requirements, as rule, contain only green halftones. In particular, this type of palettes is used for coloring geological and geophysical map with blue-to-brown colors and green hues;

Using the experimental results, a variant of subjective palettes with 190 colors was created and was calculated by the following algorithm:

$$P(i) = color(G(i), R(i), B(i)), \quad i = 0, 1, \dots, 190$$

$$G(i) = \begin{cases} 63 : i \in [0, 46] \\ 110 - i : i \in [47, 110], \\ 0 : i \in [111, 190] \end{cases}$$

$$B(i) = \begin{cases} 47 - i : i \in [0, 46] \\ 0 : i \in [47, 78] \\ i - 79 : i \in [79, 110], \\ 32 : i \in [111, 174] \\ 207 - i : i \in [175, 190] \end{cases} \quad (1)$$

$$R(i) = \begin{cases} 63 : i \in [0, 110] \\ 174 - i : i \in [111, 174] \\ 0 : i \in [175, 190] \end{cases}$$

where G, R, B are the intensity of green, red, and blue colors; i is the color index; $color$ stands for a function of additive color mixing. Figure 1 shows the palette components. Figure 2 shows the palette resulting from additive mixing of the RGB primary colors.

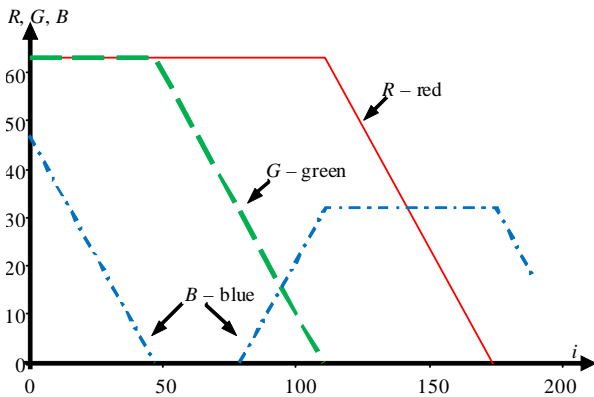


Fig. 1. Color components of the palette. i – color index



Fig. 2. Color distribution in the palette. i – color index

If we are to use N colors and $N > 190$, all numerical constants in palette (1) is multiplied by a factor $N/190$. In this case, the obtained palette is visually continuous. If we are to reduce the number of colors, e.g., two times, we use $P(i)$, where $i = 0, 2, \dots, 188, 190$, from palette (1). However, the palette thus loses its visual continuity.

5. Use of the palette

Proposed palette (1) was used to represent simulation results of heat exchange in spacecrafts in [2]. Moreover, in order to demonstrate the capabilities of palette (1), two model problems with visualization of results were solved: flow in a Laval nozzle and pressure distribution in an oil reservoir. The proposed palette was used to form images of calculated physical fields. The problems were solved by finite-difference methods on orthogonal grid, and the data were thus filled up in a cell by the following simple interpolation:

$$f(x, y) = (a + bx)(c + dy), \quad (2)$$

where a, b, c, d are coefficients calculated for each unit cell from values at the grid nodes.

Function (2) is the solution of the Laplace equation. This eliminates artifacts whose values differ from those at the grid nodes because, according to the theorem of maximum, a function being harmonic inside a limited area can not have a maximum or a minimum inside this area. So, the presence of objects with narrow spatial localization (point heat sources or heat sinks, heat pipes) can not garble the filling-up process.

5.1. Visualization of the flow in a Laval nozzle

The problem to be considered was the gas flow in an axisymmetric Laval nozzle. At the nozzle inlet the velocity is subsonic; at the nozzle exit it is supersonic. It is assumed that the gas is ideal and the flow is steady and is described by the equations:

$$\frac{\partial y \rho u}{\partial x} + \frac{\partial y \rho v}{\partial y} = 0, \quad \frac{\partial y (p + \rho u^2)}{\partial x} + \frac{\partial y \rho v}{\partial y} = 0, \quad (3)$$

$$\frac{\partial y \rho u v}{\partial x} + \frac{\partial y (p + \rho v^2)}{\partial y} = p, \quad \frac{\partial y \rho u H}{\partial x} + \frac{\partial y \rho v H}{\partial y} = 0,$$

where x and y are the longitudinal and transverse coordinates; u and v are the projections of the velocity onto the x and y axes; ρ is the density and P is the pressure; H is the total enthalpy; γ is the adiabatic index of the gas.

System (3) changes its form from elliptic to hyperbolic in the subsonic-to-supersonic flow transition. Therefore in the subsonic region and near the sonic line the approximate factorization method was applied [3], and in the supersonic region the explicit MacCormack scheme was used [4]. Figure 3 shows the distribution of the Mach number at the grid nodes and the filled-up image based on palette (1).

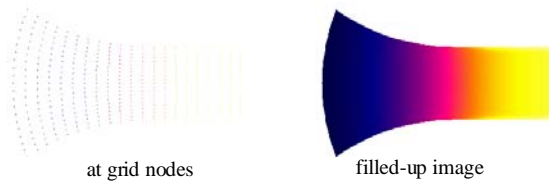


Fig. 3. Mach number distribution in the nozzle

5.2. Visualization of the temperature distribution in a spacecraft

Visualized calculation results for a transient temperature field on one of the panels of a spacecraft instrument module are shown in the figures below. Consideration was given to the spacecraft position with respect to the sun, cyclogram of the operation of the instruments, and heat pipe effect. The problem statement is described in [2]; the numerical data on temperature fields were provided by A.S. Tkachenko. Figures 4, 5 and 6 show the temperature distribution at the points in time corresponding to the winter solstice, intermediate value, and summer solstice.

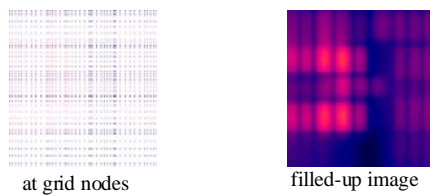


Fig. 4. Temperature distribution on the panel at the winter solstice

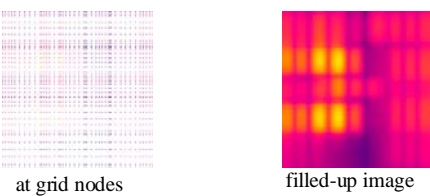


Fig. 5. Temperature distribution on the panel at an intermediate value

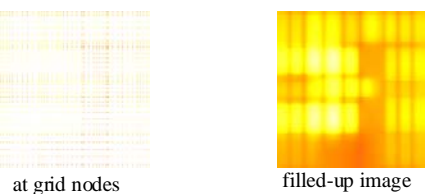


Fig. 6. Temperature distribution on the panel at the summer solstice

5.3. Visualization of the pressure distribution in an oil reservoir

The element under consideration was a five-point development element of a flat oil reservoir. The development element consists of one production well and

four injection wells. The flow is steady and described by the elliptic equation:

$$\frac{\partial}{\partial x} \left(\sigma \frac{\partial P}{\partial x} \right) + \frac{\partial}{\partial y} \left(\sigma \frac{\partial P}{\partial y} \right) = q(x, y), \quad (4)$$

where P is the pressure; σ is the water permeability factor; x and y are Cartesian coordinates; q is a source term. The well flow rate and conditions at the boundaries of the rectangular area are specified. Equation (4) was solved by the pseudo-transient method with the use of the program taken from [5]. Figure 7 shows the pressure distribution in the reservoir obtained in calculation and plotted with palette (1).

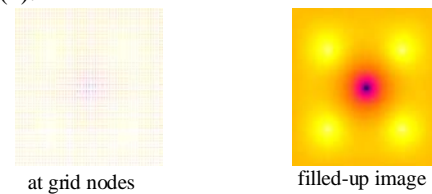


Fig. 7. Reservoir pressure distribution

6. Comparison

For comparison, Figure 8 shows the result of visualization based on the terrain palette used in Surfer 8 Golden Software [6] and Style 2 in Microsoft Office Excel 2007 [7]. The numerical values were taken from Section 5.3.



Fig. 8. Reservoir pressure distribution. Filled-up image

Comparison of Figure 7 and Figure 8 shows that proposed palette (1) compares well with Surfer and Excel in self-descriptiveness.

7. Conclusion

The palette of 190 colors with 6-bit encoding of each RGB primary color was constructed. With the proposed palette, the plane physical fields obtained in numerical calculation were visualized. The color distribution is near-continuous. Visual identification of a maximum and minimum does not require a scale.

Acknowledgments

The author is grateful to A.S. Tkachenko for provision with the numerical data used in the work.

References

- [1] T. Pavlidis, "Algorithms for graphics and image processing", Computer Science Press, 1982.
- [2] V. P. Kozhukhov, A.S. Tkachenko, I. V. Sherbakova, "Heat exchange computer modeling of the U unit leaky device section in geostationary spacecrafts", Proceedings of 5th All-Russia Scientific Conference on Fundamental and Applied Problems in Modern Mechanics, Tomsk. Gos. Univ., pp. 386–387, 2006.
- [3] V. G. Butov, S. B. Khalimov, "Calculation of nonpotential ideal gas flows in axisymmetric nozzles by the approximate factorization method", U.S.S.R. Comput. Math. Math. Phys., vol. 27, pp. 170–174, 1987.
- [4] R.W. MacCormack, "The effect of viscosity in hyperbolicity impact cratering", AIAA Paper, No.354, 1969.
- [5] <http://www.lib.tpu.ru/fulltext/m/2008/oil01.xls>
- [6] <http://www.goldensoftware.com>.
- [7] <http://www.microsoft.com>



Vladislav M. Galkin received the C. Sc. degree in Physics and Mathematics from Tomsk State University. He is now an associate professor at Petroleum Geology and Oil & Gas Field Development Department of Tomsk Polytechnic University, Russia.