The voxel V_i discussed in the embodiments below is associated with the position P_i, the value d_i of the state quantity at the position P_i, the transparency T_i, and the display color C_i. The voxel V_i can be represented as expression 1 below:

$$\text{Voxel } V_i = V_i(P_i, d_i, T_i, C_i) \qquad (1)$$

[0011] ***Description of configuration***

Referring to Fig. 1, the functional configuration of the image processing apparatus 1 is described. The image processing apparatus 1 includes a numerical value receiving unit 10, a transparency determination unit 20, a display color determination unit 30, the voxel display unit 40, a voxel data saving unit 50, and a color scale saving unit 60.

(1) The numerical value receiving unit 10 receives a specification of a numerical value D of interest. Using an input device such as a mouse, the user specifies the numerical value D. The user may specify either one or multiple numerical values D of interest.

(2) The transparency determination unit 20 determines the transparency T_i of each voxel V_i based on the specified numerical value D and the value d_i retrieved from the voxel data saving unit 50. The value d_i to be retrieved may be latest data or data at a certain point of time. Specifically, for a voxel V_i with a small absolute value of a difference between the numerical value D and the value d_i, the transparency T_i is made low, while for the voxel V_i with a large absolute value, the transparency T_i is made high. Detailed operations of the transparency determination unit 20 will be described later.

(3) The display color determination unit 30 determines the display color C_i for each voxel V_i based on the value d_i retrieved from the voxel data saving unit 50 and the display color information retrieved from the color scale saving unit 60. Detailed operations of the display color determination unit 30 will be described later.

(4) The voxel display unit 40 displays the voxel V_i on the screen of the display device 220 based on the transparency T_i determined by the transparency determination unit 20 and the display color C_i determined by the display color determination unit 30.

(5) The voxel data saving unit 50 stores the position P_i of the voxel V_i and the value d_i of the state quantity. The position P_i and the value d_i may be measured data or simulation data.

(6) The color scale saving unit 60 stores a color scale necessary for the display color determination unit 30 to determine the display color.

[0012] ***Description of operation***

Fig. 3 is a flowchart illustrating the operations of the image processing apparatus 1. Referring to Fig. 3, the operations of the image processing apparatus 1 are described. The parentheses in each step of Fig. 3 indicate the entity that performs the operation.

[0013] <Step S10>

At step S10, the numerical value receiving unit 10 receives the numerical value D. Specifically, the user moves a slider 401S of the numerical value specifying part 401 in Fig. 2 with a mouse and determines the numerical value D. With the numerical value specifying part 401 of Fig. 2, the numerical value D is a value equal to or greater than 0 to 50 or less. Once the numerical value D is determined with the slider 401S, the numerical value receiving unit 10 receives the numerical value D.

[0014] <Step S20>

At step S20, the transparency determination unit 20 determines the transparency T_i of the voxel V_i based on the received numerical value D and the value d_i of the state quantity. The transparency T_i of the voxel V_i is determined by whether the received numerical value D and the value d_i of the voxel V_i are close to each other.

Specifically, it is determined as follows. The numerical value receiving unit 10 calculates the transparency T_i of the voxel V_i according to expression 2 below using an absolute value of the difference between the value d_i of the voxel V_i and the received numerical value D. In expression 2, Z is an arbitrary coefficient. The transparency T_i is indicated in %.

$$T_i = |D - d_i| \times Z \quad (\%) \quad (2)$$

When the transparency T_i is 0 (%), the voxel V_i is opaque. That is, when $D = d_i$, the voxel V_i is opaque. As the difference between D and d_i is greater, the voxel V_i is closer to transparent. When the transparency T_i is 100 (%) or higher, the voxel V_i is transparent.

[0015] <Step S30>

At step S30, the display color determination unit 30 determines the display color of each voxel V_i according to display color information which defines the display color C_i of the voxel V_i in accordance with the value d_i of the state quantity. The display color C_i is determined by the value d_i of the voxel V_i. I_k closest to the value d_i is determined and once I_k is determined, color S_k is determined. Specifically, it is determined as follows. The color scale saving unit 60 stores a color scale [I, S] shown below. The color scale [I, S] is display color information. The color scale [I, S] can be represented by expression 3.

$$\text{Color scale [I, S]} = [\{I_1, I_2, \ldots I_N\}, \{S_1, S_2 \ldots S_N\}] \quad (3)$$

1, 2, .. N is the number of divisions of color. Here, k = 1, 2, 3... holds. The display color determination unit 30 determines the display color C_i of the voxel V_i in the following manner. The display color determination unit 30 calculates the display color C_i according to expression 6 below using the value d_i and the color scale [I, S].

Here,

$$f: I_k \rightarrow S_k \qquad (4)$$

is defined.

Also,

$$I_1 < I_2 < ... < I_N \qquad (5)$$

$$C_i = f(\arg\min|d_i - x|): x \in I_k \qquad (6)$$

The display color C_i of the voxel V_i is determined according to expression 6 as follows.

[0016] (1) The display color determination unit 30 selects I_k closest to the value d_i from I_1 to I_N. I_k is set as in expression 5. Thus, I_k is determined from the value d_i.

(2) Since I_k and S_k are associated as in expressions 3 and 4, S_k is determined from I_k.

(3) Thus, I_k is determined from the value d_i and S_k is determined from I_k. For the color scale, in the case of temperature, for example, S_1 is a color close to blue and S_N is set to a color close to red. While representation schemes such as RGB and CMYK can be used for color, any representation scheme may be used.

[0017] <Step S40>

At step S40, the voxel display unit 40 displays an image of the voxel V_i on the screen of the display device 220 based on the transparency T_i determined by the transparency determination unit 20 and the display color C_i determined by the display color determination unit 30.

Fig. 2 is an image of the voxel V_i displayed by the voxel display unit 40. The %-indication at V_1 (0%) in Fig. 2 indicates the transparency. In Fig. 2, voxels with a transparency of less than 100% are being displayed. In Fig. 2, voxel V_{18} is not displayed because its transparency is 100%.

Fig. 4 conceptually shows an image 400 displayed by the voxel display unit 40.

In Fig. 4, each individual cube indicates a voxel. The voxels appearing in the image 400 of Fig. 4 have a transparency of less than 100%. The image processing apparatus 1 receives a numerical value D of the user's interest, rather than receiving a specification of a voxel of interest. Thus, as shown in Fig. 4, "V_1, V_2" and "V_m, V_n" are opaque because they all have a transparency of 0% although they are at a distance from each other. In this way, the image processing apparatus 1 determines the transparency of a voxel by focusing attention to the value d_i possessed by the voxel rather than focusing attention to a voxel, so that a distribution of the numerical value D of interest can be known in a three-dimensional space.

[0018] ***Effect of Embodiment 1***

With the image processing apparatus 1 of Embodiment 1, a numerical value D of interest is specified instead of a voxel of interest being specified, and the transparency determination unit 20 of the image processing apparatus 1 determines the transparency T_i of the voxel V_i from the difference between the value di possessed by the voxel V_i and the specified numerical value D. This can improve the visibility of voxels having numerical data like sensor data in a three-dimensional space. For example, when voxels having temperature sensor data are to be displayed, one can easily understand where regions of high temperature or regions of low temperature are present. This is a benefit arising from setting not only the display color C_i but determining the transparency T_i of each voxel V_i based on the difference between the value d_i possessed by the voxel V_i and the numerical value D of interest.

In the case of two-dimensional display, only information on a specific aspect can be extracted. Thus, in order to understand the distribution of numerical data, it is necessary to repeatedly change the aspect of interest. By contrast, in the case of three-dimensional display, the distribution of numerical data can be understood via a

[0022] <Transparency determination unit 20>

The transparency determination unit 20 determines the transparency T_i of the voxel V_i based on the received state quantity change value and the plurality of values $d_{i,j}$ of the time series. In Embodiment 2, the transparency determination unit 20 uses the state quantity change value received by the numerical value receiving unit 10 as the numerical value D of expression 2. For the value d_i of expression 2, the transparency determination unit 20 determines the value corresponding to the state quantity change value received by the numerical value receiving unit 10 from the multiple values $d_{i,j}$ (j = 1, 2, ... N) for the voxel V_i. If the state quantity change value received by the numerical value receiving unit 10 is the difference Δ between the maximum and the minimum of the value d_i in the period indicated by the time series, the transparency determination unit 20 uses the difference Δ between the maximum and the minimum of the value d_i in the period from time 1 to time N as the value d_i of expression 2. If the state quantity change value received by the numerical value receiving unit 10 is the maximum of the value d_i in the period indicated by the time series, the transparency determination unit 20 uses the maximum of the value d_i in the period from time 1 to time N as the value d_i of expression 2. Cases where the state quantity change value received by the numerical value receiving unit 10 is the minimum or the mean are similar to the case of the difference Δ. Whether the state quantity change value specified by the user corresponds to the difference Δ, the maximum, the minimum, or the mean is predetermined.

[0023] <Display color determination unit 30>

The display color determination unit 30 determines the display color of each voxel V_i according to display color information which defines the display color C_i of the voxel V_i in accordance with the plurality of values $d_{i,j}$ of the time series, as display

color information. In Embodiment 2, the display color determination unit 30 uses, for the value d_i of expression 6, the value d_i which is determined by the transparency determination unit 20 from the multiple values $d_{i,j}$ (j = 1, 2, ... N) as the value d_i for use in expression 2.

[0024] <Voxel display unit 40>

The voxel display unit 40 displays an image of the voxel V_i on the screen of the display device 220 based on the transparency T_i determined by the transparency determination unit 20 and the display color C_i determined by the display color determination unit 30.

[0025] ***Effect of Embodiment 2***

In the image processing apparatus 1 of Embodiment 2, the transparency determination unit 20 determines the transparency T_i from the numerical value D, which is a state quantity change value, received by the numerical value receiving unit 10 and the value d_i determined from multiple values $d_{i,j}$ which change with time. Thus, it is possible to improve the visibility of voxels having a state quantity change value of interest among voxels having a state quantity changing with time.

[0026] Embodiment 3.

With Figs. 5 and 6, the image processing apparatus 1 of Embodiment 3 is described.

Fig. 5 is a functional block diagram of the image processing apparatus 1 of Embodiment 3.

Fig. 6 shows an image 400 displayed on the screen of the display device 220. In Fig. 6, a position specifying part 402 is displayed in addition to the numerical value specifying part 401. The position specifying part 402 has a slider 402S. The image processing apparatus 1 of Fig. 5 is of a configuration that additionally includes a

surfaces, and a floor 330 as objects. On the ceiling 310, three lights 311 and three air conditioners 312 are arranged as objects.

[0034] ***Effect of Embodiment 4***

The image processing apparatus 1 of Embodiment 4 displays objects and voxels in a superimposed manner as in the image 400 of Fig. 9. Thus, the image processing apparatus 1 can clearly indicate around what kinds of objects the numerical value D of interest is distributed.

[0035] Embodiment 5.

Referring to Figs. 10 and 11, the image processing apparatus 1 of Embodiment 5 is described.

Fig. 10 is a functional block diagram of the image processing apparatus 1 of Embodiment 5. The image processing apparatus 1 of Fig. 10 additionally includes an object receiving unit 75 relative to the image processing apparatus 1 of Fig. 7.

Fig. 11 shows an image 400 displayed on the screen of the display device 220. Fig. 11 shows a case where a wall on the west side 501 is selected as an object. In Fig. 11, the wall on the west side 501, a wall on the south side 502, a floor 503, two desks 511, and eight chairs 512 are being displayed as objects. As the wall on the west side 501 has been selected as an object, voxel V_1 (0%), V_2 (0%), V_3 (0%), V_4 (40%), V_5 (40%), and V_6 (40%) are being displayed in Fig. 11.

Fig. 12 shows an image 400 of an object specifying part 403.

[0036] <Object receiving unit 75>

The object receiving unit 75 receives a specification of an object. As shown in Fig. 12, in the image 400, the object specifying part 403 is included in addition to the numerical value specifying part 401. An object to be specified is specified by the user using an input device such as a mouse. The image 400 of Fig. 12 is displayed within

apparatus 1 are implemented by hardware. An electronic circuit 90 of Fig. 15 is a dedicated electronic circuit for implementing the functions of the numerical value receiving unit 10, the transparency determination unit 20, the display color determination unit 30, and the voxel display unit 40 of the image processing apparatus 1. The electronic circuit 90 is connected to a signal line 91. The electronic circuit 90 is specifically a single circuit, a composite circuit, a programmed processor, a parallel programmed processor, a logic IC, a GA, an ASIC, or an FPGA. GA is an abbreviation for Gate Array. ASIC is an abbreviation for Application Specific Integrated Circuit. FPGA is an abbreviation for Field-Programmable Gate Array. The functions of the components of image processing apparatus 1 may be implemented in one electronic circuit or implemented as being distributed across multiple electronic circuits. Also, some of the functions of the components of the image processing apparatus 1 may be implemented by an electronic circuit and the remaining functions may be implemented by software.

[0058] Each of the processor 110 and the electronic circuit 90 is also called processing circuitry. In the image processing apparatus 1, the functions of the numerical value receiving unit 10, the transparency determination unit 20, the display color determination unit 30, and the voxel display unit 40 may be implemented by processing circuitry.

[0059] The foregoing supplementary description on the hardware configuration is also applicable to the image processing apparatuses 1 of Embodiment 2 to Embodiment 5.

[0060] The image processing apparatuses 1 of Embodiment 1 to Embodiment 6 have been described above. Two or more of these embodiments may be practiced in combination. Alternatively, one of these embodiments may be partially practiced. Alternatively, two or more embodiments out of these embodiments may be partially

CLAIMS

[Claim 1] An image processing apparatus comprising:

a numerical value receiving unit to receive a numerical value;

a transparency determination unit to determine a transparency of each of a plurality of voxels each associated with positional information indicating a position in a three-dimensional space and associated with a value of a state quantity of the three-dimensional space at the position indicated by the positional information, as any value within a transparency range which is a range including a first value indicative of the voxel being opaque and a second value indicative of the voxel being transparent and is a range between the first value and the second value, based on a difference between the received numerical value and the value of the state quantity;

a display color determination unit to determine a display color of each voxel according to display color information which defines the display color of voxel in accordance with the value of the state quantity; and

a voxel display unit to display the voxel for which the transparency and the display color have been determined on a display device.

[Claim 2] The image processing apparatus according to claim 1, wherein

each of the plurality of voxels is associated with a plurality of values of a time series as the value of the state quantity;

the numerical value receiving unit receives, as the numerical value, a state quantity change value indicating a change state of the state quantity of the three-dimensional space in a period indicated by the time series;

the transparency determination unit determines the transparency of the voxel based on the received state quantity change value and the plurality of values of the time series, and

the display color determination unit determines the display color of each voxel according to display color information which defines the display color of the voxel in accordance with the plurality of values of the time series, as the display color

information.

[Claim 3] The image processing apparatus according to claim 1 or 2, further comprising:

a position receiving unit to receive a position in the three-dimensional space, wherein

the voxel display unit displays the voxel at the received position on the display device.

[Claim 4] The image processing apparatus according to any one of claims 1 to 3, further comprising:

an object display unit to, using object data indicating data for object that is arranged in the three-dimensional space, display the object over the voxel on the display device.

[Claim 5] The image processing apparatus according to claim 4, further comprising:

an object receiving unit to receive a specification of a object, wherein

the voxel display unit displays voxel around the received object.

[Claim 6] The image processing apparatus according to claim 4 or 5, further comprising:

an object extraction unit to extract object data from drawing data including the object data.

[Claim 7] An image processing program that causes a computer to execute:

a numerical value receiving process of receiving a numerical value;

a transparency determination process of determining a transparency of each of a plurality of voxels each associated with positional information indicating a position in a three-dimensional space and associated with a value of a state quantity of the

three-dimensional space at the position indicated by the positional information, as any value within a transparency range which is a range including a first value indicative of the voxel being opaque and a second value indicative of the voxel being transparent and is a range between the first value and the second value, based on a difference between the received numerical value and the value of the state quantity;

a display color determination process of determining a display color of each voxel according to display color information which defines the display color of voxel in accordance with the value of the state quantity; and

a voxel display process of displaying the voxel for which the transparency and the display color have been determined on a display device.

[Claim 8] An image processing method comprising:

receiving, by a computer, a numerical value;

determining, by the computer, a transparency of each of a plurality of voxels each associated with positional information indicating a position in a three-dimensional space and associated with a value of a state quantity of the three-dimensional space at the position indicated by the positional information, as any value within a transparency range which is a range including a first value indicative of the voxel being opaque and a second value indicative of the voxel being transparent and is a range between the first value and the second value, based on a difference between the received numerical value and the value of the state quantity;

determining, by the computer, a display color of each voxel according to display color information which defines the display color of voxel in accordance with the value of the state quantity; and

displaying, by the computer, the voxel for which the transparency and the display color have been determined on a display device.

[Claim 9] An image processing apparatus comprising:

a numerical value receiving unit to receive a numerical value;

a transparency determination unit to determine a transparency of each of a plurality of voxels each associated with positional information indicating a position in a three-dimensional space and associated with a value of a state quantity of the three-dimensional space at the position indicated by the positional information, in which as a difference between the received numerical value and the value of the state quantity is greater, the transparency of the voxel is determined as a value closer to a value that is defined as a value making the voxel transparent;

a display color determination unit to determine a display color of each voxel according to display color information which defines the display color of voxel in accordance with the value of the state quantity; and

a voxel display unit to display the voxel for which the transparency and the display color have been determined on a display device.

[Claim 10] An image processing program that causes a computer to execute:

a numerical value receiving process of receiving a numerical value;

a transparency determination process of determining a transparency of each of a plurality of voxels each associated with positional information indicating a position in a three-dimensional space and associated with a value of a state quantity of the three-dimensional space at the position indicated by the positional information, in which as a difference between the received numerical value and the value of the state quantity is greater, the transparency of the voxel is determined as a value closer to a value that is defined as a value making the voxel transparent;

a display color determination process of determining a display color of each voxel according to display color information which defines the display color of voxel in accordance with the value of the state quantity; and

a voxel display process of displaying the voxel for which the transparency and the display color have been determined on a display device.

[Claim 11] An image processing method comprising:

receiving, by a computer, a numerical value;

determining, by the computer, a transparency of each of a plurality of voxels each associated with positional information indicating a position in a three-dimensional space and associated with a value of a state quantity of the three-dimensional space at the position indicated by the positional information, in which as a difference between the received numerical value and the value of the state quantity is greater, the transparency of the voxel is determined as a value closer to a value that is defined as a value making the voxel transparent;

determining, by the computer, a display color of each voxel according to display color information which defines the display color of voxel in accordance with the value of the state quantity; and

displaying, by the computer, the voxel for which the transparency and the display color have been determined on a display device.