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(54) **METHOD AND SYSTEM FOR CHROMA KEY MASKING**

6,618,444 B1 * 9/2003 Haskell et al. 375/240.24

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(58) **Field of Search** 382/162, 172, 382/283, 298; 358/517; 375/240.08, 240.24; 348/36, 140, 587, 592

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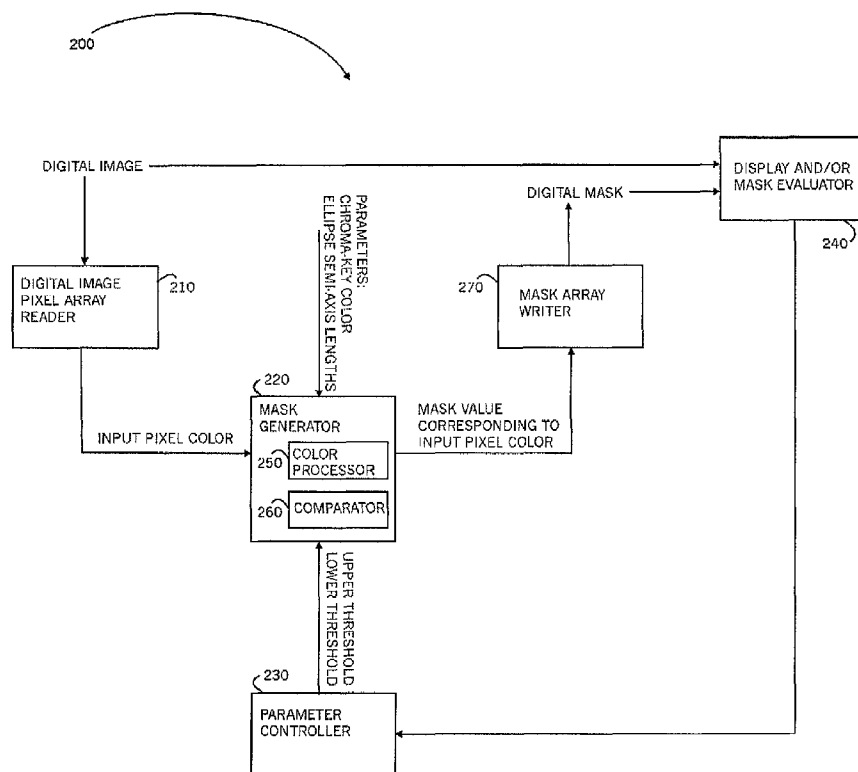
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(57) **ABSTRACT**

A method for chroma key masking including for a given pixel color, calculating a quadratic function of the pixel color coordinates based on a prescribed chroma key color, the quadratic function corresponding to an ellipsoid in a color space, generating a substantially transparent mask value for the given pixel color, if the quadratic function is less than a prescribed lower threshold, generating a substantially opaque mask value for the given pixel color, if the quadratic function is greater than a prescribed upper threshold, and generating a partially transparent mask value for the given pixel color, based on the value of the quadratic function, if the quadratic function is between the prescribed lower threshold and the prescribed upper threshold. A system is also described and claimed.

17 Claims, 2 Drawing Sheets



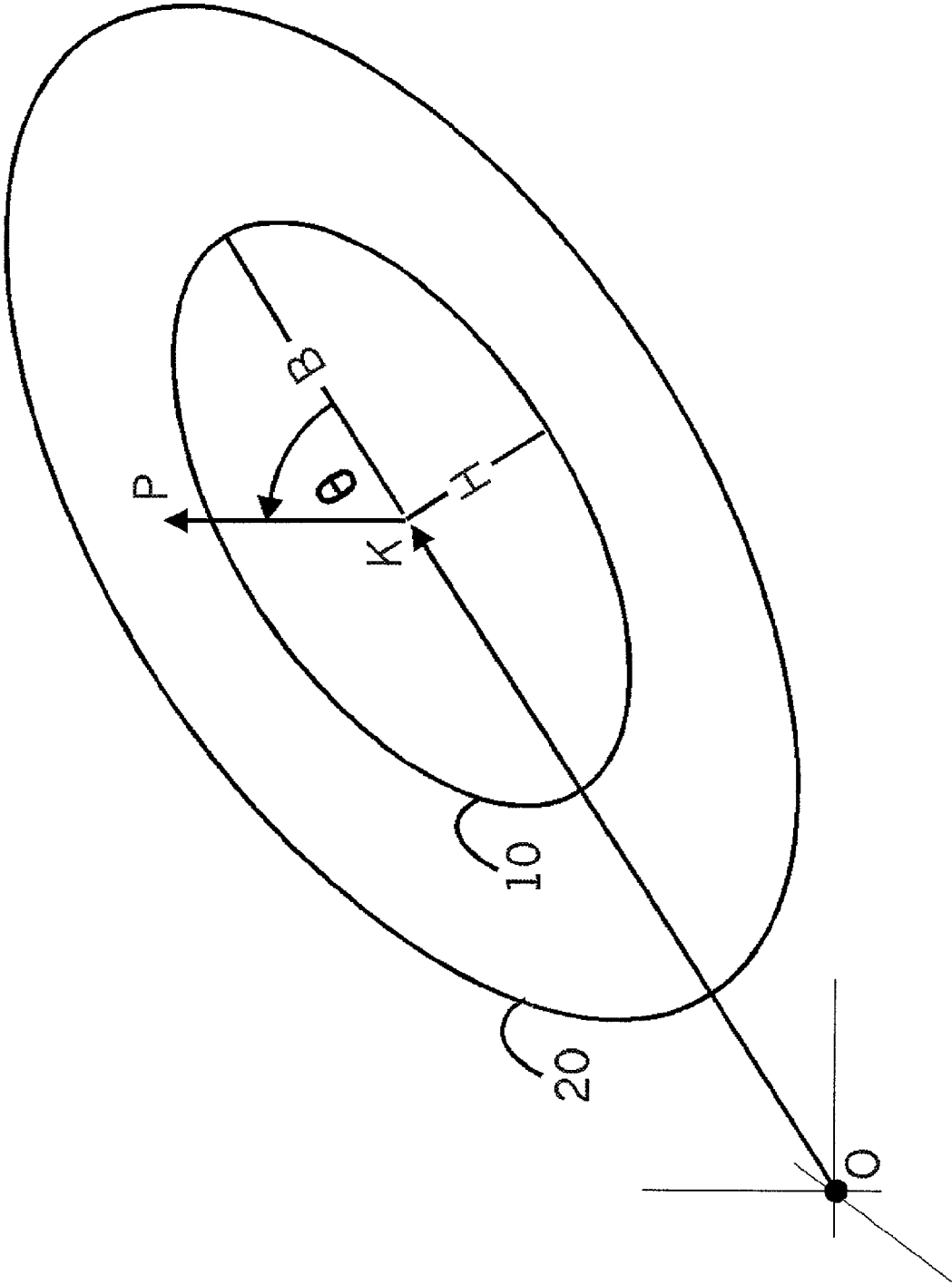


FIG. 1

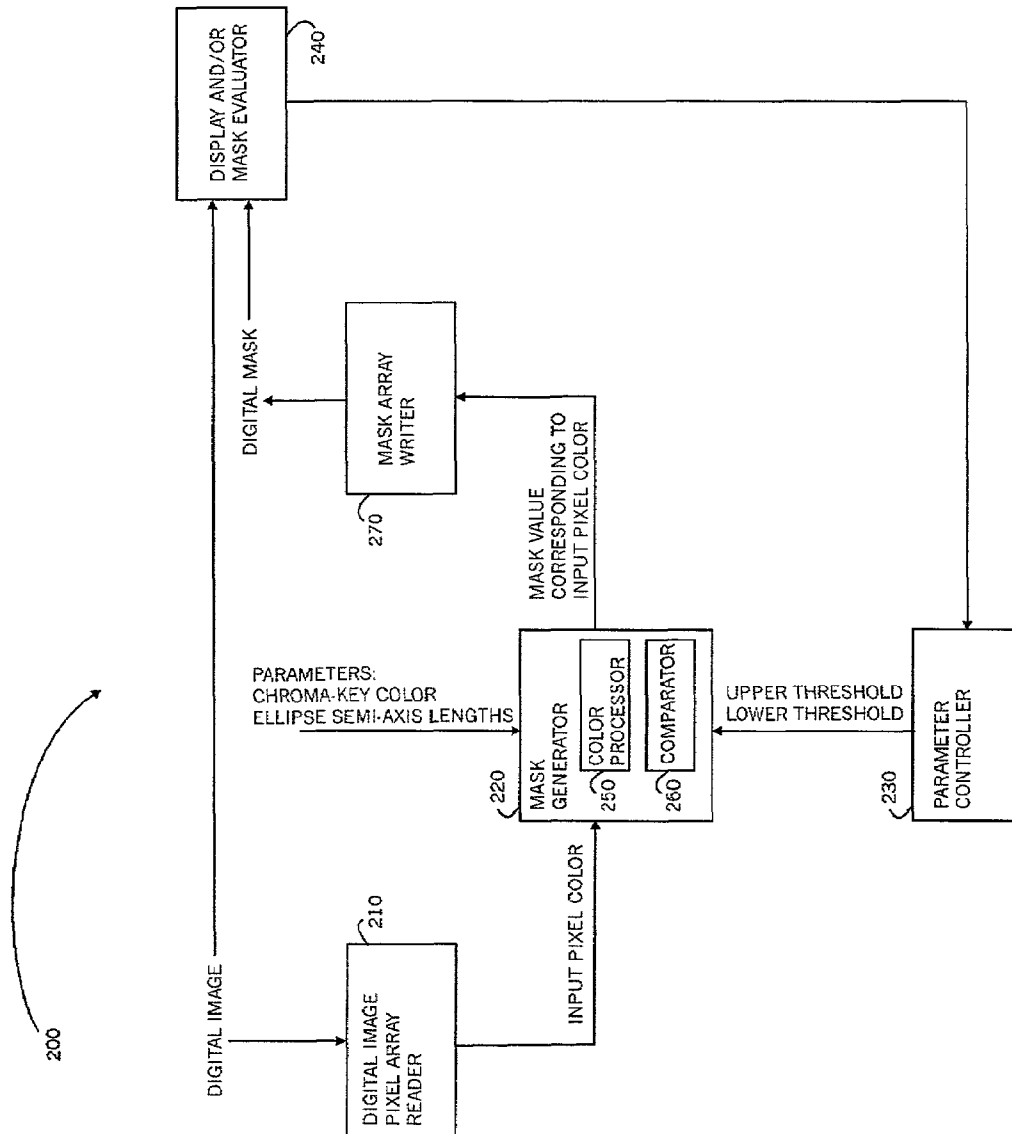


FIG. 2

METHOD AND SYSTEM FOR CHROMA KEY MASKING

FIELD OF THE INVENTION

The present invention relates generally to digital image processing, and specifically to mask generation.

BACKGROUND OF THE INVENTION

Digital color images are comprised of rectangular arrays of pixels, each pixel specifying a color. Generally, color is specified in terms of three color coordinates, such as coordinates within the familiar red-green-blue (RGB) color space. Thus a digital image of pixel dimension $m \times n$ has a representation as $\{\vec{p}_{ij} = (r_{ij}, g_{ij}, b_{ij}) : 0 \leq i < m, 0 \leq j < n\}$. The color coordinates themselves are generally 8-bit numbers, although other color depths are often used. For 24-bit RGB color values, each of r_{ij} , g_{ij} and b_{ij} take values between 0 and 255 inclusive, with (0, 0, 0) being black (absence of color) and (255, 255, 255) being white.

An important operation in digital image compositing is masking, also referred to as silhouetting. Masking is the process of "cutting out" a desired subject from within a digital image. Visually, masking corresponds to cutting out a subject from a photograph with a scissors; for example, cutting out the part of a photograph containing one or more people. In the digital world, where images are always rectangular, the "cutting out" is generally performed by generating an appropriate digital mask.

A "digital mask," also referred to simply as a "mask," is a rectangular array of transparency values, generally ranging between 0 and 255 inclusive. A mask value of 0 corresponds to full opacity, a mask value of 255 corresponds to full transparency, and a mask value in between corresponds to partial transparency. A digital mask is superimposed upon a digital image of the same pixel dimensions in order to cut out the desired subject. Pixel locations where a digital mask is fully opaque are blocked out of the digital image. Thus opacity is used to block out portions that are not part of the desired subject. Similarly, colors of the digital image at pixel locations where a digital mask is fully transparent are retained. Mask values intermediate between 0 and 255 are used to fade between transparent and opaque areas of the digital image.

Numerically, masks are generally applied to digital images by multiplying color coordinates by a normalized mask value. Thus an $m \times n$ mask $\{\alpha_{ij} : 0 \leq i < m, 0 \leq j < n\}$ applied to an $m \times n$ digital image $\{(r_{ij}, g_{ij}, b_{ij}) : 0 \leq i < m, 0 \leq j < n\}$ generally produces an $m \times n$ masked digital image

$$\left\{ \left(\frac{\alpha_{ij} r_{ij}}{255}, \frac{\alpha_{ij} g_{ij}}{255}, \frac{\alpha_{ij} b_{ij}}{255} \right) : 0 \leq i < m, 0 \leq j < n \right\}.$$

Applications of digital masking include replacing a background in a digital image with a substitute background, and, more generally, compositing a desired subject with one or more additional image layers.

There are several conventional approaches to mask generation. Some approaches require more manual work on the part of a user, and some require less or no manual work. A popular approach used currently to generate a mask is highlighting, where a user designates an approximate boundary around a desired subject using nodes and simple lines and curves, and a digital imaging software application

automatically refines the boundary and generates a mask with values zero at pixel locations inside of the boundary and values 255 at pixel locations outside of the boundary. Highlighting programs often include a partially transparent zone between the inside and the outside of the boundary, so that the mask generates a smooth fade at the boundary of the desired subject.

Another popular approach is chroma keying. Use of a chroma key provides a more automated mask generation than does highlighting, at the cost of more manual work in preparation of the digital image. To prepare a digital image for chroma key processing, a subject is photographed against a homogeneous background, the color of which is referred to as a chroma key. Optimal colors for chroma keys are blues, since natural colors of human subjects tend to have low blue color components. For such images with homogenous backgrounds, automatic mask generation is generally performed by assigning opaque mask values to pixels with colors that match the chroma key, and transparent mask values to pixels with colors that do not match the chroma key.

A general reference on chroma keying is Jack, K., *Video Demystified: A Handbook for the Digital Engineer*, 2nd Edition, HighText Publications, San Diego, 1995, pages 404-412.

Conventional chroma key masking programs do not perform well with backgrounds that are not homogenous in color. Such programs tend to generate inaccurate masks, which include parts of a background with the desired foreground subject. In turn, when such programs try to compensate for heterogeneous background coloration, they tend to over-compensate and generate masks that block out parts of the desired foreground subject.

U.S. Pat. No. 6,201,581 to Moriwake et al. describes the use of concentric spheres in a color space centered about a chroma key color, for mask generation. However, for backgrounds with non-homogenous coloration, one does not obtain sufficiently good background/foreground discrimination using concentric spheres. Consider, for example, a background that is painted uniformly but lit unevenly. Expanding a sphere to include all such background pixels typically has the disadvantage of inadvertently also including pixels of quite different colors, thereby causing portions of the desired foreground subject to disappear.

Thus there is a need for a robust chroma key process that accurately masks out backgrounds with non-homogenous colorations.

SUMMARY OF THE INVENTION

The present invention provides a robust method and system for mask generation based on a chroma key. The present invention is advantageous over prior art methods and systems in that it yields good background/foreground discrimination for backgrounds that are not professionally lit. In a preferred embodiment, the present invention uses only two user adjustable parameters.

The present invention uses two ellipsoids in color space centered about a chroma key color, for generating masks. For a given pixel color, the present invention preferably determines a mask value based on the location of the pixel color in color space, relative to the two ellipsoids. Sizes of the two ellipsoids are adjustable by a user.

The present invention is advantageous over the above mentioned U.S. Pat. No. 6,201,581 to Moriwake et al., in that use of concentric ellipsoids oriented along a chroma key color enables one to discriminate in a non-uniform way

between brightness variation and hue variation when separating background colors from foreground colors. Specifically, using the present invention, one can generate a keyed region that includes pixel colors that differ from the chroma key color mainly in their brightness components.

There is thus provided in accordance with a preferred embodiment of the present invention a method for chroma key masking including for a given pixel color, calculating a quadratic function of the pixel color coordinates based on a prescribed chroma key color, the quadratic function corresponding to an ellipsoid in a color space, generating a substantially transparent mask value for the given pixel color, if the quadratic function is less than a prescribed lower threshold, generating a substantially opaque mask value for the given pixel color, if the quadratic function is greater than a prescribed upper threshold, and generating a partially transparent mask value for the given pixel color, based on the value of the quadratic function, if the quadratic function is between the prescribed lower threshold and the prescribed upper threshold.

There is further provided in accordance with a preferred embodiment of the present invention a chroma key masking system including a mask generator for calculating a mask value corresponding to an input pixel color, based on a prescribed chroma key color, including a color processor calculating a quadratic function of the input pixel color coordinates, based on the prescribed chroma key color, the quadratic function corresponding to an ellipsoid in a color space, and a comparator comparing the value of the quadratic function to at least one prescribed threshold, a pixel array processor for extracting individual pixel colors from a digital image and transmitting them to the mask generator, and a digital mask processor for receiving individual mask values from the mask generator and incorporating them within a digital mask.

There is yet further provided in accordance with a preferred embodiment of the present invention a method for chroma key masking including adjusting a first parameter representing a size of a first ellipsoid in a color space, the first ellipsoid being centered about a prescribed chroma key color, adjusting a second parameter representing a size of a second ellipsoid in the color space, the second ellipsoid also being centered about the prescribed chroma key color and surrounding the first ellipsoid in the color space, and generating a mask value for a given pixel color based on the location of the given pixel color in the color space, relative to the first and second ellipsoids.

There is moreover provided in accordance with a preferred embodiment of the present invention a chroma key masking system including a parameter controller adjusting first and second parameters representing sizes of a first and a second ellipsoid in a color space, respectively, the first and second ellipsoids being centered about a prescribed chroma key color, and the second ellipsoid surrounding the first ellipsoid in the color space, and a mask processor for generating a mask value corresponding to a given pixel color based on the location of the given pixel color in the color space, relative to the first and second ellipsoids.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood and appreciated from the following detailed description, taken in conjunction with the drawings in which:

FIG. 1 is an illustration of calculation of a mask value for a pixel color based on a given chroma key, in accordance with a preferred embodiment of the present invention; and

FIG. 2 is a mask generation system operative in accordance with a preferred embodiment of the present invention.

LIST OF APPENDICES

Appendix A is a listing of exemplary software, in the form of C++ code, for implementing mask generation in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

The present invention provides a robust method and system for mask generation based on a chroma key.

For purposes of clarity the present invention is described with respect to the three-dimensional RGB color space, although it is apparent to those skilled in the art that it applies to other color spaces of arbitrary dimensions as well. Similarly, the present invention is described with respect to 8-bit color values, although it is apparent to those skilled in the art that it applies to other color depths as well.

In a preferred embodiment, the present invention generates a mask value, α , based on a pixel color $\vec{p}=(r, g, b)$ and a given chroma key $\vec{k}=(k_r, k_g, k_b)$. That is, α is preferably determined as a function $\alpha=\alpha(\vec{p}, \vec{k})$. Correspondingly, mask generation for a digital image $\{p_{ij}:0\leq i<m, 0\leq j<n\}$ is performed by generating the mask $\{\alpha_{ij}=\alpha(\vec{p}_{ij}, \vec{k}):0\leq i<m, 0\leq j<n\}$.

Reference is now made to FIG. 1, which illustrates calculation of a mask value for a pixel color based on a given chroma key, in accordance with a preferred embodiment of the present invention.

In a preferred embodiment of the present invention, mask generation is based on a geometry of two concentric ellipsoids of revolution in color space. Specifically, an inner planar ellipse **10** centered about a key color **K** in three-dimensional color space is rotated about the vector \vec{OK} from the origin to **K**, to generate an inner ellipsoid of revolution. An outer ellipse **20**, co-planar with inner ellipse **10** and also centered about **K**, and preferably having the same eccentricity as inner ellipse **10**, is also rotated about the vector \vec{OK} to generate an outer ellipsoid of revolution.

Preferably, mask values are generated as follows:

1. For pixel colors falling within the inner ellipsoid, the mask value is 0.
2. For pixel color falling outside the outer ellipsoid, the mask value is 255.
3. For pixel values in the ellipsoidal annulus between the inner and outer ellipsoids, the mask value is set to an integer between 0 and 255, based on an interpolation calculation as described hereinbelow.

An advantage of the present invention is the ease with which the mask values can be calculated. The present invention takes advantage of the rotational symmetry of the inner and outer ellipsoids of revolution to reduce the calculations to simple planar vector arithmetic.

Indeed, given a pixel color **P** in three-dimensional color space, the mask value for **P** can be determined by considering the planar cross-section with the plane determined by the three points **O**, **K** and **P**. Such a plane is illustrated in FIG. 1. Let *b* denote the semi-axis length of ellipse **10** along the direction of the vector \vec{OK} and let *h* denote the semi-axis

length along the orthogonal direction within the plane. Relative to these axes and relative to an origin located at K,

the coordinates of P are given by $P=(x, y)$, where $x=|\vec{KP}|\cos\theta$, $y=|\vec{KP}|\sin\theta$, and θ is the angle between the vectors

\vec{OK} and \vec{KP} . Thus the determination of whether P is inside of ellipse **10**, outside of ellipse **20** or between the ellipsi, can be made by calculating the value of

$$d = \frac{x^2}{b^2} + \frac{y^2}{h^2} \tag{1}$$

Specifically, for an inner ellipse threshold T_1 and an outer ellipse threshold T_2 , the mask value for P is given by

$$\alpha = \begin{cases} 0, & \text{if } d \leq T_1 \\ 255, & \text{if } d \geq T_2 \\ \frac{d - T_1}{T_2 - T_1} 255, & \text{if } T_1 < d < T_2 \end{cases} \tag{2}$$

Reference is now made to Appendix A, which is a listing of exemplary software, in the form of C++ code, for implementing mask generation in accordance with a preferred embodiment of the present invention. Described in Appendix A is a method chromaMask_fc () from a C++ class AlphaMask. The method chromamask_fc () has as input: a digital image specified as an array of RGB values, denoted *pixels; color coordinates of a chroma key, denoted red, green, blue; and ellipse semi-axis lengths (in pixels), denoted brightTol and hueTol. The output of chromaMask_fc () is a filled-in array of mask values, denoted m_alphaMask, which is a member of the class AlphaMask.

As can be seen from the listing in Appendix A, the angle θ is computed through the vector dot-product,

$$\cos\theta = \frac{\vec{OK} \cdot \vec{KP}}{\|\vec{OK}\| \cdot \|\vec{KP}\|}$$

As can also be seen from the listing in Appendix A, the calculation of d is circumvented if

$$|\vec{KP}|^2 < T_1 \min(b^2, h^2),$$

in which case α is set to 0; or if

$$|\vec{KP}|^2 > T_2 \max(b^2, h^2),$$

in which case α is set to 255. Geometrically, referring to FIG. 1, the former condition corresponds to P lying in the circle inscribed within ellipse **10** and concentric therewith. Similarly, the latter condition corresponds to P lying outside of the circle circumscribed about ellipse **20** and concentric therewith.

Regarding setting of the semi-axis parameters b and h, it may be appreciated that adjustments along the direction of the vector \vec{OK} correspond generally to adjustments of chroma key brightness, and adjustments along directions orthogonal to \vec{OK} correspond generally to adjustments of chroma key hue. It has been found that a ratio of

$$\frac{b}{h} \approx 2,$$

corresponding to an eccentricity of

$$\frac{\sqrt{3}}{2},$$

yields accurate mask values for backgrounds having low color saturation and high brightness variation.

Reference is now made to FIG. 2, which is a mask generation system **200** operative in accordance with a preferred embodiment of the present invention. System **200** serves to derive a digital mask for cutting out a desired subject from a digital image, based on a given chroma key. Shown in FIG. 2 is a pixel array reader **210** that reads individual pixel colors from a digital image and transmits them for processing to a mask generator **220**. Mask generator **220** accepts individual pixel colors as input and derives corresponding individual mask values as output. Chroma key color values and elliptical semi-axis lengths are provided to mask generator **220** as parameters.

It may be appreciated by those skilled in the art that ellipse eccentricity may be specified by setting semi-axis lengths, or by setting a major axis to minor axis length ratio, or by setting an eccentricity.

In a preferred embodiment of the present invention, upper and lower thresholds are adjustable by parameter controller **230**. Adjusting the upper and lower thresholds serves to fine tune the mask generation on an image-by image basis. Based on visual results, a user can adjust the thresholds to reduce the opaque portion and/or to enlarge the transparent portion. Shown in FIG. 2 is an optional display **240**, through which a user can view a masked digital image resulting from application a derived mask and adjust the thresholds in a feedback loop.

It may be appreciated by those skilled in the art that feedback from a masked digital image to parameter controller **230** may be manual, by a user, or automatic, by a computer, or partially manual and partially automatic. For automatic feedback, display **240** is preferably replaced by or augmented with a mask evaluator that analyzes a mask and a digital image to score the goodness of a specific mask, and to determine how to further adjust the upper and lower thresholds to improve the score.

In a first alternate embodiment of the present invention, upper and lower thresholds are also provided to mask generator **220** as parameters. In a second alternate embodiment of the present invention chroma key color values and/or elliptical semi-axis lengths are also adjusted by parameter controller **230**.

Preferably, mask generator **220** derives mask values according to Equation (2) hereinabove. As shown in FIG. 2, preferably mask generator **220** includes a color processor **250** for calculating the value of d, as indicated above in Equation (1) hereinabove, and a comparator **260** for comparing the value of d with the thresholds as indicated in Equation (2) hereinabove. Mask values derived by mask generator **220** are transmitted to a mask array writer **270**, for incorporation within a digital mask.

In the foregoing specification the invention has been described with reference to specific exemplary embodiments

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thereof. It will, however, be evident that various modifications and changes may be made to the specific exemplary embodiments without departing from the broader spirit and scope of the invention as set forth in the appended claims. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A method for chroma key masking comprising:
 for a given pixel color, calculating a quadratic function of the given pixel color coordinates based on a prescribed chroma key color, the quadratic function corresponding to an ellipsoid in a color space;
 generating a substantially transparent mask value for the given pixel color, if the quadratic function is less than a prescribed lower threshold;
 generating a substantially opaque mask value for the given pixel color, if the quadratic function is greater than a prescribed upper threshold; And
 generating a partially transparent mask value for the given pixel color based on a value of the quadratic function, if the quadratic function is between the prescribed lower threshold and the prescribed upper threshold.
2. The method of claim 1 wherein the color space is three-dimensional and the prescribed chroma key color and the given pixel color are each represented by three color coordinates.
3. The method of claim 2 wherein the three color coordinates are red, green, blue (RGB) color coordinates.
4. The method of claim 1 further comprising adjusting the prescribed lower and upper thresholds.
5. The method of claim 4 further comprising displaying a visual result of applying a mask to a digital image, and wherein the adjusting is preformed based on the visual result.
6. The method of claim 5 wherein the adjusting is performed manually by a user.
7. The method of claim 5 wherein the adjusting is performed automatically by a computer.
8. The method of claim 7 further comprising analyzing the mask and the digital image comprising:
 calculating at least one score for the mask; and
 calculating adjustments for upper and lower thresholds so as to improve the at least one score.
9. The method of claim 5 wherein the adjusting is performed in conjunction, manually by a user and automatically by a computer.

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10. The method of claim 4 wherein the operation of adjusting the prescribed lower and upper thresholds is performed by a parameter controller.

11. The method of claim 10 wherein the parameter controller adjusts the prescribed lower and upper thresholds based on a visual result of applying a mask to a digital image.

12. The method of claim 1 wherein the generating a partially transparent mask value uses an interpolation based on the value of the quadratic function.

13. The method of claim 1 wherein the ellipsoid is an ellipsoid of revolution having an axis of revolution along a vector representing the prescribed chroma key color.

14. The method of claim 1 further comprising:
 displaying a visual result of applying a mask to a digital image.

15. A method for chroma key masking comprising:
 calculating a quadratic function of a given pixel color coordinates for a given pixel color based on a prescribed chroma key color, the quadratic function corresponding to an ellipsoid in a three-dimensional color space;

if the quadratic function is less than a prescribed lower threshold, generating a substantially transparent mask value for the given pixel color;

if the quadratic function is greater than a prescribed upper threshold, generating a substantially opaque mask value for the given pixel color;

if the quadratic function is between the prescribed lower threshold and the prescribed upper threshold, generating a partially transparent mask value for the given pixel color based on a value of the quadratic function; and

adjusting the prescribed lower and upper thresholds.

16. The method of claim 15 wherein the prescribed chroma key color and the given pixel color are each represented by three color coordinates.

17. The method of claim 16 wherein the three color coordinates are RGB color coordinates.

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