(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 July 2016 (28.07.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/116724 A1

(51) International Patent Classification: *G06K 9/00* (2006.01)

(21) International Application Number: PCT/GB2015/050123

(22) International Filing Date: 20 January 2015 (20.01.2015)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

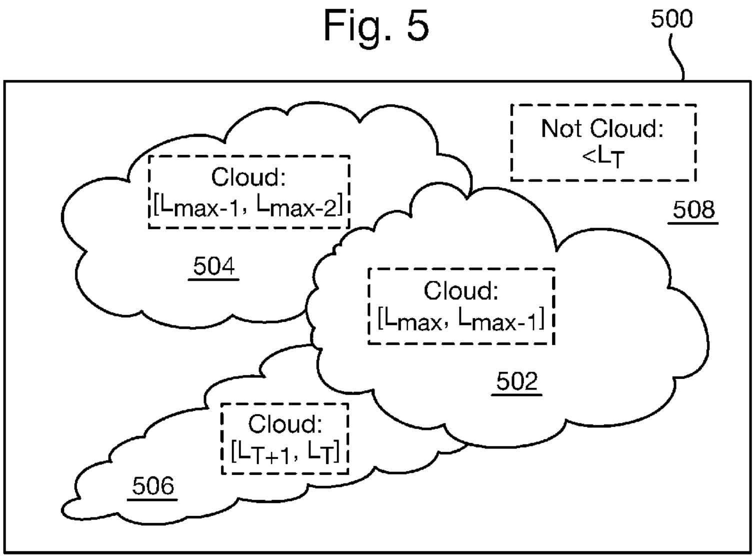
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

(54) Title: DETECTING AND RANGING CLOUD FEATURES

Fig. 5



(57) Abstract: Disclosed is a method and apparatus for detecting and ranging cloud features. The method comprises: obtaining image data(e.g. using a camera (200); classifying, as a cloud feature, an image segment (502 -508) of the image data; determining a plurality of moments of the image segment (502 -508); using the determined plurality of moments, determining a geometric representation of that image segment (502-508); and, using the geometric representation, determining a distance between the cloud feature represented by that image segment (502 -508) and an entity that obtained the image data.

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DETECTING AND RANGING CLOUD FEATURES

FIELD OF THE INVENTION

The present invention relates to the detection and ranging of cloud features.

BACKGROUND

In situations such as autonomous control of aircraft it can be desirable to automatically detect cloud features without relying on human vision/input. A system that detects cloud features can be combined with a route planner or the like to help an aircraft avoid bad weather or other crafts/objects that may not be visible through clouds. Further, obtaining range information relating to cloud features is complicated due to cloud motion and the typically small triangulation baseline.

SUMMARY OF THE INVENTION

In a first aspect, the present invention provides a method of detecting and ranging cloud features. The method comprises: obtaining image data; classifying, as a cloud feature, an image segment of the image data; determining a plurality of moments of the image segment; using the determined plurality of moments, determining a geometric representation of that image segment; and, using the geometric representation, determining a distance between the cloud feature represented by that image segment and an entity that obtained the image data.

The geometric representation may be a rectilinear or curvilinear representation. The geometric representation may be a parametric representation. The geometric representation may be a digital model. The geometric representation may be an ellipse.

Determining the geometric representation of the image segment may comprise determining a centroid of the image segment and, using the determined centroid, determining the geometric representation. Determining the geometric representation of the image segment may comprise determining major and minor axes of the image segment and, using the determined major and minor axes, determining the geometric representation.

Determining a distance may comprise determining a time-to-collision between the cloud feature represented by that image segment and an entity that obtained the image data, and, using the determined time-to-collision, determining the distance.

Determining a plurality of moments may comprise determining at least the first four moments of the image segment. The moments of the image segment may be discrete versions of Cartesian moments.

The image data may define a plurality of pixels and, for each pixel, a respective luminance value. The step of classifying may comprise: defining one or more intervals for the luminance values of the pixels; partitioning the image data into one or more image segments, each respective image segment containing pixels having a luminance value in a respective interval; and classifying, as a cloud feature, each image segment containing pixels having luminance value greater than or equal to a threshold luminance value.

Obtaining the image data may comprise capturing, using one or more cameras, an image. The camera may be mounted on an aircraft. The method may further comprise, controlling the aircraft based on the determined distance.

In a further aspect, the present invention provides apparatus for detecting and ranging cloud features. The apparatus comprises: a sensor configured to obtain image data; and one or more processors configured to: classify an image segment of the image data as a cloud feature; determine a plurality of moments of the image segment; using the determined plurality of moments, determine a geometric representation of that image segment; and, using the geometric representation, determine a distance between the cloud feature represented by that image segment and the sensor.

In a further aspect, the present invention provides an aircraft comprising apparatus according to the preceding aspect.

In a further aspect, the present invention provides a program or plurality of programs arranged such that when executed by a computer system or one or more processors it/they cause the computer system or the one or more processors to operate in accordance with the method of any of the above aspects.

In a further aspect, the present invention provides a machine readable storage medium storing a program or at least one of the plurality of programs according to the preceding aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic illustration (not to scale) of a scenario 101 in which an aircraft is flying in the vicinity of a cloud formation;

Figure 2 is a schematic illustration (not to scale) showing further details of the aircraft;

Figure 3 is a process flow chart showing certain steps of a process of controlling the aircraft;

Figure 4 is a process flow chart showing certain steps of a cloud detection process;

Figure 5 is a schematic illustration (not to scale) showing a segmented image produced during the cloud detection process;

Figure 6 is a process flow chart showing certain steps of a cloud ranging process;

Figure 7 is a schematic illustration (not to scale) illustrating an image produced during the cloud ranging process; and

Figure 8 is a schematic illustration (not to scale) illustrating an image produced during the cloud ranging process.

DETAILED DESCRIPTION

Figure 1 is a schematic illustration (not to scale) of a scenario 101 in which an aircraft 102 is flying in the vicinity of a cloud formation 104.

The aircraft 102 is an unmanned autonomous aircraft. The aircraft 102 implements a cloud detection and ranging process to facilitate navigation with respect to the cloud formation 104. An embodiment of a cloud detection and ranging process is described in more detail later below with reference to Figures 3 to 8.

Figure 2 is a schematic illustration (not to scale) showing further details of the aircraft 102.

In this embodiment, the aircraft 102 comprises a visible light detecting camera 200, a processor 202, a clock 204, an inertial measurement unit (IMU) 206, and a controller 208.

The camera 200 is a video camera capable of producing a sequence of image-based data in a suitable manner and data format. The camera 200 is configured to capture images of a scene external to the aircraft 102. In this embodiment, the camera 200 is configured to capture image in front of the aircraft 102, in the direction of travel of the aircraft 102. The camera 200 is coupled to the processor 202 such that images captured by the camera 200 may be sent from the camera 200 to the processor 202.

The clock 204 is configured to measure the time-of-day local to the aircraft 102. The clock 204 may automatically update with respect to, for example, local time zones in which the aircraft 102 is operating. This updating of the clock 204 may be performed, for example, using GPS measurements of the aircraft 102. The clock 204 is coupled to the processor 202 such that time-of-day measurements taken by the clock 204 may be sent from the clock 204 to the processor 202.

The IMU 206 is an electronic device configured to measure the position, orientation, and velocity of the aircraft 102. In this embodiment, the position of the aircraft 102 is a global positioning system (GPS) measurement of the aircraft's location. The IMU 206 is coupled to the processor 202 such that measurements of the aircraft's position, orientation, and velocity taken by the IMU 206 may be sent from the IMU 206 to the processor 202.

The processor 202 is configured to receive and process measurements received from the camera 200, the clock 204 and the IMU 206, as described in more detail later below with reference to Figure 3 to 8. An output of the processor 202 is a control signal for controlling operation of the aircraft 102. The processor 202 is coupled to the controller 208 such that the control signal determined by the processor 202 may be sent from the processor 202 to the controller 208.

The controller 208 is configured to control the aircraft 102 in accordance with the control signal received from the processor 202.

Figure 3 is a process flow chart showing certain steps of a process of controlling the aircraft 102 in which an embodiment of the cloud detection and ranging process is implemented.

At step s2, a process of detecting clouds is performed. The cloud detection process is described in more detail later below with reference to Figure 4.

At step s4, respective ranges between the aircraft 102 and the clouds detected at step s2 are determined. The cloud ranging process is described in more detail later below with reference to Figure 6.

At step s6, using the output from the cloud detection process and the cloud ranging process performed at step s2 and s4 respectively, the processor 202 determines a control signal for controlling the aircraft 102, and sends the determined control signal to the controller 208. The controller 208 controls the aircraft 102 in accordance with the received control signal, for example so as to avoid the clouds of the cloud formation 104.

Returning to the description of step s2, Figure 4 is a process flow chart showing certain steps of an embodiment of the cloud detection process. Although the cloud detection process of Figure 4 is described below as being performed based on a single image captured by the camera 200, it will be appreciated by the skilled person that, in practice, the camera 200 captures a video or image sequence and that the process of Figure 4 may be continuously performed or updated as new images are captured.

At step s8, the camera 200 captures an image of a scene in front of the aircraft 102. In particular, the camera 200 captures an image along a direction of travel of the aircraft 102. The camera 200 captures an image of the cloud formation 104.

In this embodiment, the image captured by the camera 200 is in a red-green-blue (RGB) format, i.e. each pixel in an image is assigned a coordinate [R, G, B] representative of its colour in the RGB colour space.

The camera 200 sends the captured image of the scene to the processor 202. In some embodiments, the camera 200 acquires and sends 5megapixel images to the processor 202 at a rate of 15Hz.

At step s10, the processor 202 converts the received image into the hue-saturation-luminance (or hue-saturation-lightness) (HSL) coordinate system. The HSL coordinate system is a cylindrical coordinate representation of the RGB colour space. Any appropriate process may be used by the processor 202 to convert the received image from the RGB coordinate system into the HSL coordinate system.

After conversion into the HSL format, each pixel in the captured image is assigned a coordinate [H, S, L] in the HSL space.

At step s12, the clock 204 measures the time-of-day local to the aircraft 102 at which the image was captured. The clock 204 then sends the time-of-day measurement to the processor 202.

At step s14, the IMU 206 measures the orientation of the aircraft 102 when the image was taken. In other words, the heading or facing of the aircraft 102 when the image was captured is measured. The IMU 206 then sends the orientation measurement to the processor 202. In some embodiments, the IMU 206 sends navigation data (including orientation measurements) to the processor 202 at a rate of 50Hz.

In this embodiment, the camera 200 has a fixed facing relative to the aircraft 102. Thus, a measured orientation of the aircraft 102 at the point in time at which the image was captured by the camera 200 specify a direction in which that image was captured by the camera 200. In some embodiments, a camera mounted to a steerable turret may be used to capture image data, and measurements of the cameras facing may be taken.

At step s15, the processor 202 analyses the HSL-format image to determine a maximum luminance value L_{max} in that image.

In this embodiment, maximum luminance value L_{max} in an image is the maximum of the luminance (L) coordinate of all the pixels in that image.

At step s16, using the time-of-day measurement taken at step s12, and the aircraft orientation measurement taken at step s14, the processor 202 determines a luminance threshold value L_T. L_T is less than L_{max}.

Use of the luminance threshold value L_T is described in more detail later below.

In this embodiment, the L_T is a function of the time-of-day measurement and the aircraft orientation measurement. In other embodiments, L_T is a function of only one of the time-of-day measurement and the aircraft orientation measurement. In other embodiments, L_T is a function of one or more further parameters instead of or in addition to one or both of the time-of-day measurement and the aircraft orientation measurement. For example, in some embodiments, L_T is a function of a measurement of ambient light level in which the aircraft 102 is flying. In some embodiments, L_T is a heuristic which may be learnt or based upon, for example, previous aircraft sorties and operations.

In some embodiments, determining the value of L_T comprises looking up the L_T value in a look-up table using the time-of-day measurement and/or the aircraft orientation measurement.

At step s18, using the time-of-day measurement taken at step s12, and the aircraft orientation measurement taken at step s14, the processor 202 determines a luminance interval value L_{int}.

Use of the luminance threshold value L_T is described in more detail later below.

In this embodiment, the L_{int} is a function of the time-of-day measurement and the aircraft orientation measurement. In other embodiments, L_{int} is a function of only one of the time-of-day measurement and the aircraft orientation measurement. In other embodiments, L_{int} is a function of one or more further parameters instead of or in addition to one or both of the time-of-day measurement and the aircraft orientation measurement. For example, in some embodiments, L_{int} is a function of the computational power of the processor 202 available for performing the cloud detection process. In some embodiments, L_{int} is a heuristic which may be learnt or based upon, for example, previous aircraft sorties and operations.

In some embodiments, determining the value of L_{int} comprises looking up the L_{int} value in a look-up table using the time-of-day measurement and/or the aircraft orientation measurement.

At step s20, the processor 202 segments the HSL-format image of the scene in-front of the aircraft 102 into separate regions using the determined maximum luminance value L_{max}, the luminance threshold value L_T, and the luminance interval value L_{int}.

In this embodiment, the segmentation of the image is performed as follows.

Firstly, an interval space between L_{max} and L_T is defined. The interval space comprises a plurality of intervals between L_{max} and L_T, i.e.

$$[L_{max}, L_{max-1}], [L_{max-1}, L_{max-2}], \ldots, [L_{T+2}, L_{T+1}], [L_{T+1}, L_T],$$

where $[L_{i+1}, L_i]$ includes all luminance values less than or equal to L_{i+1} and greater than L_i. In some embodiments, the interval $[L_{T+1}, L_T]$ includes all luminance values less than or equal to L_{T+1} and greater than or equal to L_T.

In this embodiment, the size of each interval within the interval space is equal to L_{int}. In other words, for each interval $[L_{i+1}, L_i]$ in the interval space, $L_{i+1} - L_i = L_{int}$.

Secondly, each pixel in the HSL-format image is assigned to an interval in the interval space (or to a further interval $[L_T, 0]$ which contains all luminance values less than L_T and greater than or equal to zero) depending upon its luminance coordinate value L. Thus, in effect, each pixel in the image is assigned a label.

Thirdly, adjacent pixels in the image that are assigned to the same interval in the interval space (i.e. have been assigned the same label), are grouped together to form image segments.

Thus, the HSL-format image is segmented into groups of pixels having similar luminance characteristics.

At step s22, the processor 202 classifies as “cloud” each segment in the image that contains pixels that have been assigned to an interval in the interval space between L_{max} and L_T.

Also, the processor 202 classifies as “not a cloud” each segment in the image that contains pixels that have not been assigned to an interval in the interval space between L_{max} and L_T, i.e. pixels that are assigned to $[L_T, 0]$. In this embodiment, the segments that contain pixels that have not been assigned to an interval in the interval space between L_{max} and L_T contain only those pixels that have a luminance value that is less than L_T. In some embodiments, the segments that contain pixels that have not been assigned to an interval in the interval space between L_{max} and L_T may be assigned a different label or be classified in a different way, for example, those segments may be classified as “sky” or “ground”.

Figure 5 is a schematic illustration (not to scale) showing the segmented image 500 produced by the processor 202 at step s22.

In this embodiment, the image 500 comprises a plurality of image segments, namely a first segment 502, a second segment 504, a third segment 506, and a fourth segment 508.

The first segment 502 comprises pixels that have been assigned to the interval $[L_{max}, L_{max-1}]$. As the pixels in the first segment 502 have been assigned to an interval in the interval space between L_{max} and L_T, the first segment 502 is assigned the label “CLOUD”. The “CLOUD” label and the $[L_{max}, L_{max-1}]$ interval that have been assigned to the first segment 502 are shown in Figure 5, in a dotted box located in the first segment 502.

The second segment 504 comprises pixels that have been assigned to the interval [L_{max-1}, L_{max-2}]. As the pixels in the second segment 504 have been assigned to an interval in the interval space between L_{max} and L_T, the second segment 504 is assigned the label “CLOUD”. The “CLOUD” label and the [L_{max-1}, L_{max-2}] interval that have been assigned to the second segment 504 are shown in Figure 5, in a dotted box located in the second segment 504.

The third segment 506 comprises pixels that have been assigned to the interval [L_{T+1}, L_T]. As the pixels in the third segment 506 have been assigned to an interval in the interval space between L_{max} and L_T, the third segment 506 is assigned the label “CLOUD”. The “CLOUD” label and the [L_{T+1}, L_T] interval that have been assigned to the third segment 506 are shown in Figure 5, in a dotted box located in the third segment 506.

The fourth segment 508 comprises pixels that have a luminance coordinate value less than L_T. Thus, the pixels in the fourth segment 508 are not assigned to an interval in the interval space between L_{max} and L_T, and so the fourth segment 508 is assigned the label “NOT CLOUD”. The “NOT CLOUD” label that has been assigned to the fourth segment 508 is shown in Figure 5, in a dotted box located in the fourth segment 508.

Thus, the processor 202 detects the presence of clouds in the images captured by the camera 200.

In some embodiments, the segments in the image that are classified as “CLOUD” may be further classified depending upon the luminance interval assigned to the pixels in that segment.

In some embodiments, one or more segment in the segmented image may be labelled as a particular type of cloud depending upon the luminance interval assigned to that segment. For example, a segment may be further classified as a stratus cloud, and assigned a “STRATUS” label by the processor 202, if it contains pixels assigned to any of the intervals [L_i, L_{i+1}], [L_{i+1}, L_{i+2}], or [L_{i+2}, L_{i+3}].

In some embodiments, one or more segments in the segmented image may be labelled as having certain cloud characteristics or properties depending upon the luminance interval assigned to that segment. For example, a segment may be further classified as a cloud associated with an increased risk of aircraft icing, and assigned an "ICE RISK" label by the processor 202, if it contains pixels assigned to the interval $[L_j, L_{j+1}]$ or $[L_{j+1}, L_{j+2}]$. Also for example, a segment may be further classified as a cloud associated with an increased lightning strike risk, and assigned a "LIGHTNING RISK" label by the processor 202, if it contains pixels assigned to the intervals $[L_k, L_{k+1}]$.

Thus, the cloud detection process of step s2 is provided.

Returning to the description of step s4, Figure 6 is a process flow chart showing certain steps of an embodiment of the cloud ranging process for determining a range between the aircraft 102 and the clouds detected at step s2 (which correspond to the image segments 502, 504, 506). Although the cloud ranging process of Figure 6 is described below as being performed based on the single image 500 captured by the camera 200, it will be appreciated by the skilled person that, in practice, the camera 200 captures a video or image sequence and that the process of Figure 3 may be continuously performed or updated as new images are captured.

At step s24, for each segment of the image 500 that has been classified as "cloud", the processor 202 determines the centroid of that segment. Any appropriate centroid determination process may be used.

Thus, in this embodiment, the processor 202 determines a respective centroids for the first, second, and third image segments 502, 504, 506.

In this embodiment, the centroid, or geometric centre, of a two-dimensional image segment is the arithmetic mean ("average") position of all the pixels in that image segment.

At step s26, for each segment of the image 500 that has been classified as "cloud", the processor 202 determines the major and minor axes of that segment. Any appropriate axes determination process may be used. For example, in some embodiments, the covariance matrix of an image segment may be determined, and the eigenvectors of that covariance matrix determined. The eigenvalues of the covariance matrix of an image segment may correspond to the lengths of the major and minor axes of that image segment. The eigenvectors of the covariance matrix of an image segment may correspond to the orientations of the major and minor axes of that image segment.

Figure 7 is a schematic illustration (not to scale) illustrating the information determined by the processor 202 at step s26.

The first image segment 502 has previously been labelled as “CLOUD”. Thus a centroid of the first image segment 502, which is hereinafter referred to as the “first centroid” and indicated in Figure 7 by the reference numeral 702, has been determined. Also, major and minor axes of the first image segment 502, which are hereinafter referred to as the “first major axis” 703a and the “first minor axis” 703b, have also been determined.

The second image segment 504 has previously been labelled as “CLOUD”. Thus a centroid of the second image segment 504, which is hereinafter referred to as the “second centroid” and indicated in Figure 7 by the reference numeral 704, has been determined. Also, major and minor axes of the second image segment 504, which are hereinafter referred to as the “second major axis” 705a and the “second minor axis” 705b, have also been determined.

The third image segment 506 has previously been labelled as “CLOUD”. Thus a centroid of the third image segment 506, which is hereinafter referred to as the “third centroid” and indicated in Figure 7 by the reference numeral 706, has been determined. Also, major and minor axes of the third image segment 506, which are hereinafter referred to as the “third major axis” 707a and the “third minor axis” 705b, have also been determined.

The fourth image segment 508 is not labelled as “CLOUD”. Thus, in this embodiment, a centroid and major/minor axes are not determined for this segment 508.

At step s28, for each segment of the image 500 that has been classified as “cloud”, the processor 202 determines a plurality of image moments of that segment.

In this embodiment, a plurality of discrete versions of Cartesian moments are determined for each of the image segments that have been classified as "cloud". Preferably, discrete versions of at least the first four Cartesian moments, I_1, I_2, I_3, and I_4 are determined for each of the image segments that have been classified as "cloud". For example, the discrete versions of the first five Cartesian moments, I_1, I_2, I_3, I_4, and I_5 may be determined. In some embodiments, for one or more of the image segments, one or more different image moments instead of or in addition to the discrete versions of the Cartesian moments may be determined, for example, central moments. The first moment I_1 of an image segment may be a moment of inertia of that image segment.

At step s30, for each segment of the image 500 that has been classified as "cloud", using the centroid, the major and minor axes, and the image moments of that image segment, the processor 202 determines an ellipse that best represents that image segment.

In other words, in this embodiment, using the first centroid 702, the first major and minor axes 703a, 703b, and image moments of the first image segment 502, the processor determines a first ellipse that is representative of the first image segment 502. The processor 202 also determines a second ellipse that is representative of the second image segment 504 in the same way *mutatis mutandis*. The processor 202 also determines a third ellipse that is representative of the third image segment 506 in the same way *mutatis mutandis*.

Figure 8 is a schematic illustration (not to scale) illustrating the first ellipse 802, the second ellipse 804, and the third ellipse 806 that are representative of the first image segment 502, the second image segment 504, and the third image segment 506 respectively.

In this embodiment, any appropriate method of determining the ellipses 802, 804, 806 may be implemented.

The first centroid 702 is the centre of the first ellipse 802. The first major and minor axes 703a, 703b are the major and minor axes respectively of the first ellipse 802. Similarly, the second centroid 704 is the centre of the second ellipse 804, and the second major and minor axes 705a, 705b are the major and minor axes respectively of the second ellipse 804. Similarly, the third centroid 706 is the centre of the third ellipse 806, and the third major and minor axes 707a, 707b are the major and minor axes respectively of the third ellipse 806.

The ellipses 802, 804, 806 are geometric parametric models of the “cloud” image segment that are generated using the moments extracted from those image segments.

In this embodiment, the ellipses 802, 804, 806 are curvilinear models of the “cloud” image segments. Also, the ellipses are digital models representative of the “cloud” image segments. In other embodiments, different models of one or more of the image segments may be determined instead of or in addition to an ellipse. For example, in some embodiments, a different curvilinear geometric representation of an image segment, e.g. a circle or an oval, may be used. In some embodiments, a rectilinear geometric representation of an image segment, e.g. a polygonal representation, may be used. Preferably image segments are represented by geometric models or representations formed by, or characterized by, points, lines, curves, or surfaces. More preferably, the geometric representations of image segments are in the form of relatively simple geometric forms, such as circles, ellipses, rectangles, and triangles.

Advantageously, the ellipses 802, 804, 806 tend to be very stable representations of the cloud segments.

In some embodiments, the ellipses 802, 804, 806 are maximally stable extremal regions (MSER). Further information on MSER and the extraction/detection of MSER from images may be found, for example, in J. Matas, O. Chum, M. Urban, and T. Pajdla. "Robust wide baseline stereo from maximally stable extremal regions.", Proc. of British Machine Vision Conference, pages 384-396, 2002, which is incorporated herein by reference in its entirety.

Advantageously, as more images of the scene are captured and the image segmentation and the ellipses 802, 804, 806 are updated, the ellipses

802, 804, 806 tend to exhibit similar properties to each other and the clouds that they represent (e.g. motion due to wind etc.).

At step s32, the IMU 206 measures the position and velocity of the aircraft 102. The measurements of the aircraft's position and velocity taken by the IMU 206 are sent from the IMU 206 to the processor 202.

At step s34, using the measured position and velocity of the aircraft 102, for each of the determined ellipses 802, 804, 806, the processor 202 determines a "time-to-collision" between the aircraft 102 and the cloud represented by that ellipse 802, 804, 806.

To calculate the time to collision for an ellipse 802, 804, 806, the processor 202 may calculate the rate of change of the size of that ellipse in the image 500, and use the aircraft's position and velocity.

In some embodiments, the processor 202 assumes that the ellipses (i.e. the clouds) are stationary, and that only the aircraft 102 is moving. However, in other embodiments, a velocity of a cloud/ellipse may be calculated, for example, using measurements of the wind speed and direction relative to the aircraft 102, which may be taken by one or more appropriate sensors mounted on the aircraft 102.

At step s36, for each of the ellipses 802, 804, 806, using the "time-to-collision" determined for that ellipse 802, 804, 806, the processor 202 determines a range between the aircraft 102 and the cloud represented by that ellipse 802, 804, 806. Measurements of the velocity of the aircraft 102 may be used to determine the cloud ranges.

In some embodiments, the major and minor axes of an ellipse may be converted into azimuth and elevation coordinates, for example, from an origin located at a current position of the aircraft 102. Cloud ranges and angular extents from the point of view of the aircraft 102 may be in the form of azimuth, elevation, and range coordinates.

Thus, the cloud ranging process of step s4 is provided.

Returning to the description of step s6 of Figure 3, control signal for controlling the aircraft 102 may be determined using the azimuth, elevation, and range properties of the detected clouds. The aircraft 102 may be controlled so as to avoid the detected clouds. In some embodiments, only those clouds having been assigned certain labels are avoided, for example, in some embodiments, only clouds having been labelled as ICE RISK or LIGHTNING RISK are actively avoided.

Using the above described cloud detection process, different cloud structures within a region of cloud may be detected. Thus, different parts of a cloud formation having different properties and characteristics may be detected. Thus, it tends to be possible to differentiate areas of cloud that may be hazardous to the aircraft from those that are relatively safe, and the aircraft may be controlled accordingly. Thus, the above described method and apparatus tends to reduce or eliminate the unnecessary avoidance of cloud.

Advantageously, the parametric representations of the clouds used in the above described cloud ranging process tend to be stable, i.e. unchanging over time. Thus, the cloud ranging process tends to be advantageously robust.

Advantageously, the above described method allows for the autonomous operation of an aircraft. In particular, the autonomous navigation of an aircraft through or within the vicinity of a cloud formation is facilitated. The aircraft may avoid at least the most hazardous regions of cloud.

The above described cloud detection and cloud ranging processes tend to be relatively simple and relatively computationally inexpensive to perform compared to conventional cloud detection/ranging techniques.

The appearance of clouds (e.g. the colours of the clouds) tends to change depending on, for example, the time of day, the time of year, and the weather. For example, clouds and the sky tend to appear redder at dawn and dusk. Advantageously, the above described method tends to be robust to such changes in the colours of clouds. This may, for example, be as a result of performing image segmentation based on luminance measurements, as opposed to on a colour basis as is typically used in conventional cloud detection/ranging processes in which images tend to be in the RGB format.

Obtaining range information to cloud features tends to be difficult, for example, due to cloud motion and the typically small triangulation baseline. The above described methods advantageously tend to traverse these difficulties.

Apparatus, including the processor 202, for implementing the above arrangement, and performing the method steps to be described later below, may be provided by configuring or adapting any suitable apparatus, for example one or more computers or other processing apparatus or processors, and/or providing additional modules. The apparatus may comprise a computer, a network of computers, or one or more processors, for implementing instructions and using data, including instructions and data in the form of a computer program or plurality of computer programs stored in or on a machine readable storage medium such as computer memory, a computer disk, ROM, PROM etc., or any combination of these or other storage media.

It should be noted that certain of the process steps depicted in the flowcharts of Figures 3, 4, and 6 and described above may be omitted or such process steps may be performed in differing order to that presented above and shown in the Figures. Furthermore, although all the process steps have, for convenience and ease of understanding, been depicted as discrete temporally-sequential steps, nevertheless some of the process steps may in fact be performed simultaneously or at least overlapping to some extent temporally.

In the above embodiments, the aircraft is an unmanned autonomous aircraft. However, in other embodiments, the aircraft is a manned aircraft. Also, in some embodiments, the aircraft may be a semi-autonomous aircraft or controlled by a human pilot (e.g. a human located at a ground-base). In embodiments in which the aircraft is controlled by a navigator or pilot, a display device can be used to display the detected clouds and/or range information to help the navigator or pilot fly the aircraft. For example, a display may be produced that shows the images of any of Figures 5, 7, and/or 8 providing information regarding the positions of detected clouds.

In the above embodiments, the cloud detection and cloud ranging processes run in an on-line to navigate the aircraft. However, in other embodiments, systems may run in off-line modes. In some off-line embodiments, the processor may receive input from a data source in the form of a video and navigation logfile.

In the above embodiments, aircraft position, orientation, and velocity measurements are provided by the IMU to the processor for use in the cloud detection and ranging processes. In some embodiments, other data instead of or in addition to the aircraft position, orientation, and/or velocity measurements may be used by the processor. Examples of such data include but are not limited to latitude, longitude, altitude, pan, tilt, roll and rates data. Such data may be provided to the processor by the IMU or a different system on-board or remote from the aircraft.

In the above embodiment, the cloud detection and ranging process is used to navigate an aircraft. However, in other embodiments, the cloud detection process and/or the cloud ranging process may be used for a different appropriate purpose, for example, an output of the detection process and/or the cloud ranging process may be transmitted from the aircraft to an entity remote from the aircraft for the purpose of, e.g., navigating one or more further aircraft or forecasting weather.

In the above embodiments, clouds are detected using the cloud detection process described above with reference to Figure 4. However, in other embodiments, a different appropriate cloud detection process is used.

CLAIMS

1. A method of detecting and ranging cloud features, the method comprising:

obtaining image data;

classifying, as a cloud feature, an image segment (502 - 508) of the image data;

determining a plurality of moments of the image segment (502 - 508);

using the determined plurality of moments, determining a geometric representation of that image segment (502 - 508); and,

using the geometric representation, determining a distance between the cloud feature represented by that image segment (502 - 508) and an entity that obtained the image data.

2. A method according to claim 1, wherein the geometric representation is a rectilinear or curvilinear representation.

3. A method according to claim 1 or 2, wherein the geometric representation is a parametric representation.

4. A method according to any of claims 1 to 3, wherein the geometric representation is a digital model.

5. A method according to any of claims 1 to 4, wherein the geometric representation is an ellipse (802 – 806).

6. A method according to any of claims 1 to 5, wherein determining the geometric representation of the image segment (502 - 508) comprises determining a centroid (702 – 706) of the image segment (502 - 508) and, using the determined centroid (702 – 706), determining the geometric representation.

7. A method according to any of claims 1 to 6, wherein determining the geometric representation of the image segment (502 - 508) comprises determining major and minor axes (703 – 707) of the image segment (502 - 508) and, using the determined major and minor axes (703 – 707), determining the geometric representation.

8. A method according to any of claims 1 to 7, wherein determining a distance comprises determining a time-to-collision between the cloud feature represented by that image segment (502 - 508) and an entity that obtained the image data, and, using the determined time-to-collision, determining the distance.

9. A method according to any of claims 1 to 8, wherein determining a plurality of moments comprises determining at least the first four moments of the image segment (502 - 508).

10. A method according to any of claims 1 to 9, wherein the moments of the image segment (502 - 508) are discrete versions of Cartesian moments.

11. A method according to any of claims 1 to 10, wherein:

the image data defines a plurality of pixels and, for each pixel, a respective luminance value; and

the step of classifying comprises:

defining one or more intervals for the luminance values of the pixels;

partitioning the image data into one or more image segment (502 - 508)s, each respective image segment (502 - 508) containing pixels having a luminance value in a respective interval; and classifying, as a cloud feature, each image segment (502 - 508) containing pixels having luminance value greater than or equal to a threshold luminance value (L_T).

12. A method according to any of claims 1 to 11, wherein:

obtaining the image data comprises capturing, using one or more cameras (200), an image (500);

the camera (200) is mounted on an aircraft (102); and

the method further comprises, controlling the aircraft (102) based on the determined distance.

13. Apparatus for detecting and ranging cloud features, the apparatus comprising:

a sensor (200) configured to obtain image data; and

one or more processors (202) configured to:

classify an image segment (502 - 508) of the image data as a cloud feature;

determine a plurality of moments of the image segment (502 - 508);

using the determined plurality of moments, determine a geometric representation of that image segment (502 - 508); and,

using the geometric representation, determine a distance between the cloud feature represented by that image segment (502 - 508) and the sensor.

14. An aircraft (102) comprising apparatus according to claim 13.

15. A program or plurality of programs arranged such that when executed by a computer system or one or more processors it/they cause the computer system or the one or more processors to operate in accordance with the method of any of claims 1 to 12.

16. A machine readable storage medium storing a program or at least one of the plurality of programs according to claim 15.

Fig. 1

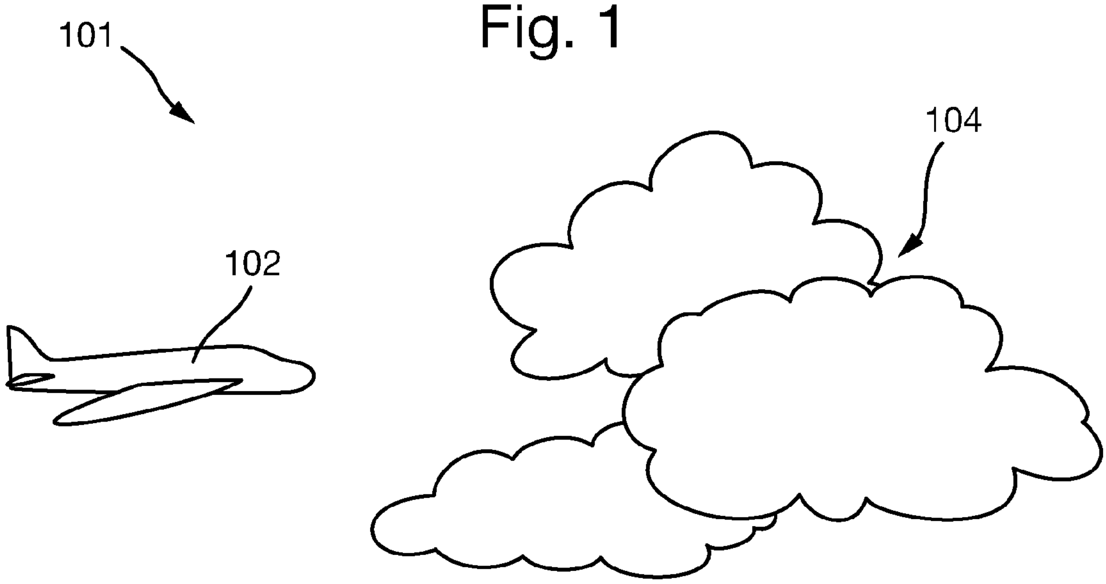


Fig. 2

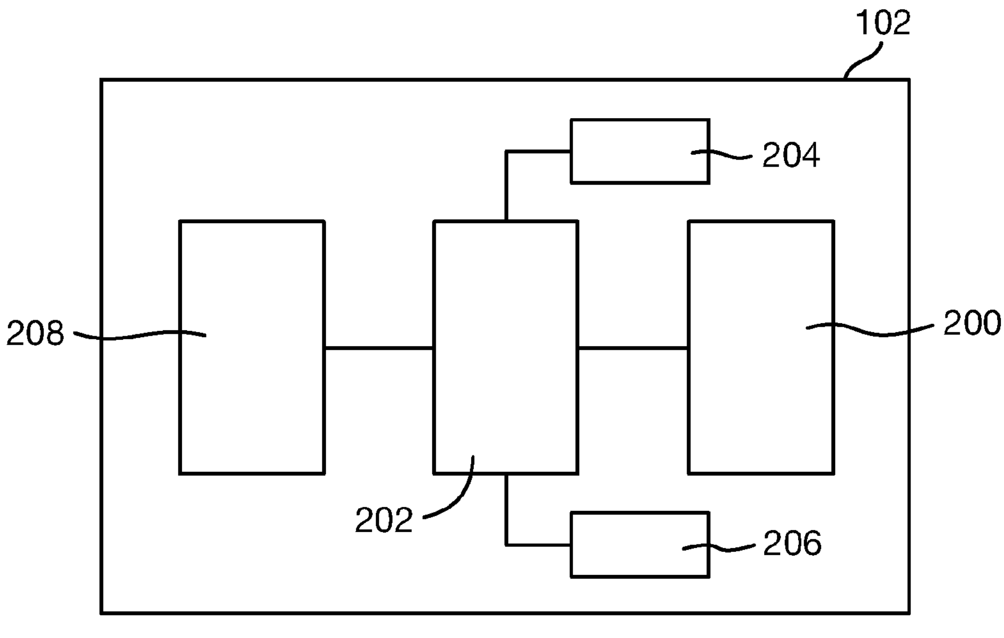


Fig.3

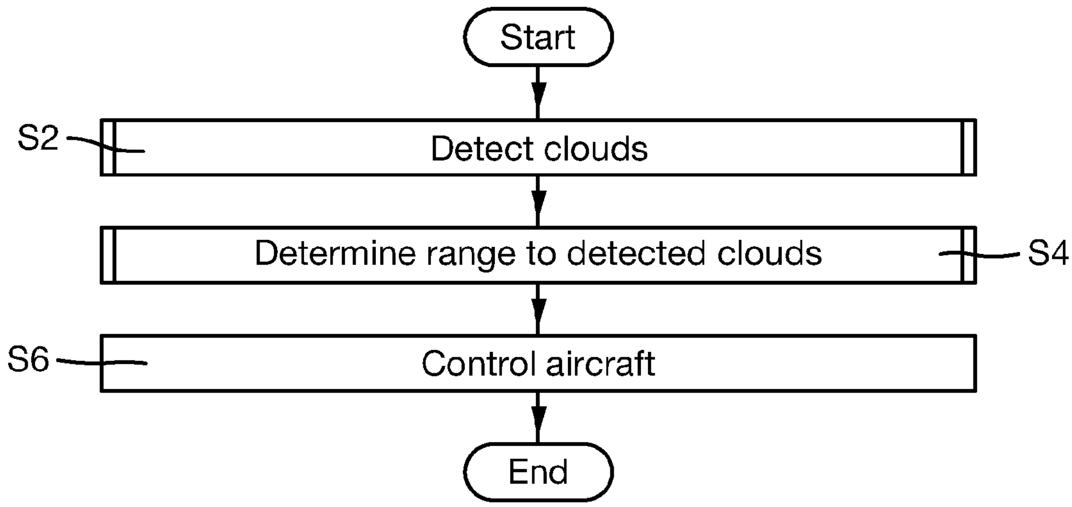

Start
S2
Detect clouds
Determine range to detected clouds
S4
S6
Control aircraft
End

Fig. 4

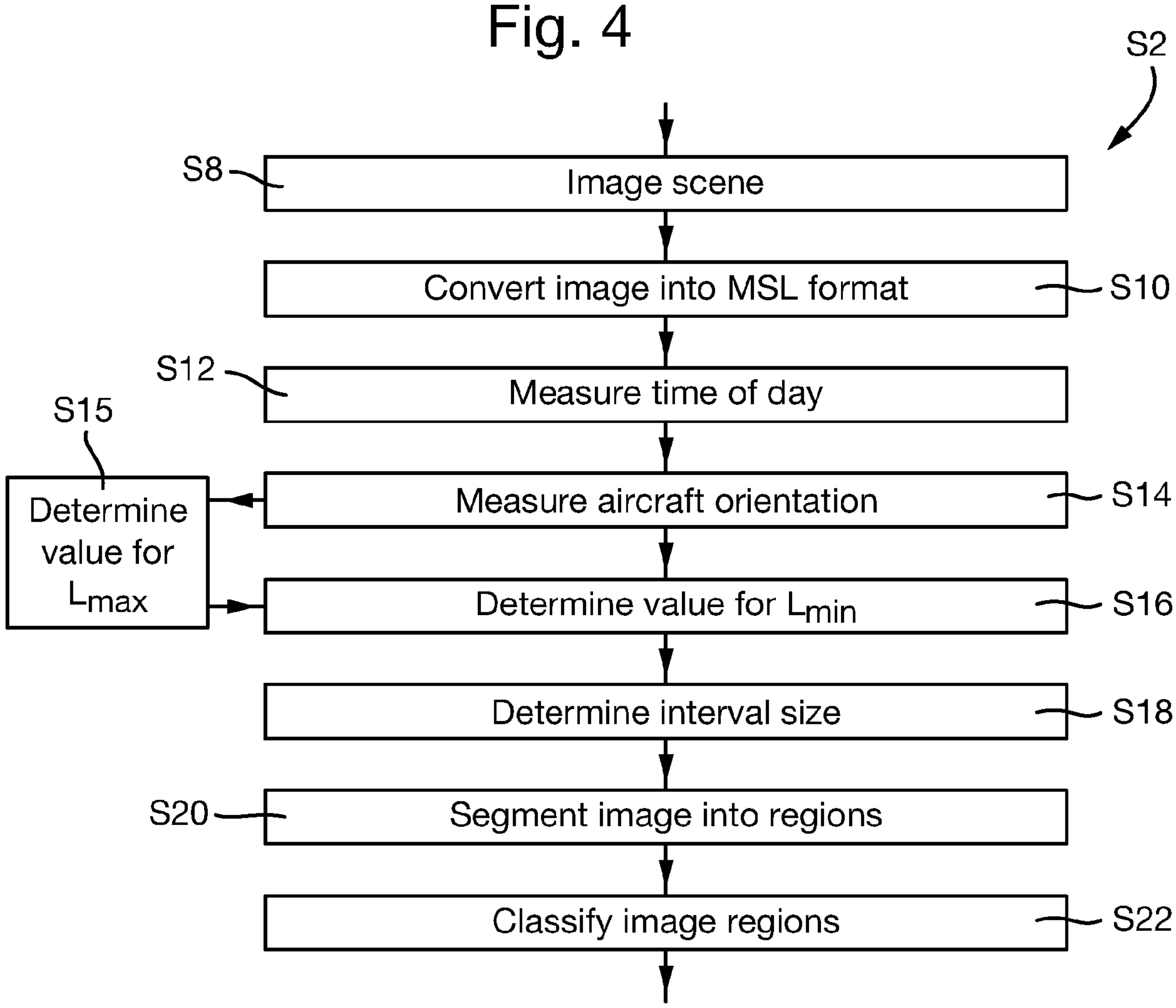

S2
S8
Image scene
Convert image into MSL format
S10
S12
Measure time of day
S15
Determine value for L_{max}
Measure aircraft orientation
S14
Determine value for L_{min}
S16
Determine interval size
S18
S20
Segment image into regions
Classify image regions
S22

Fig. 5

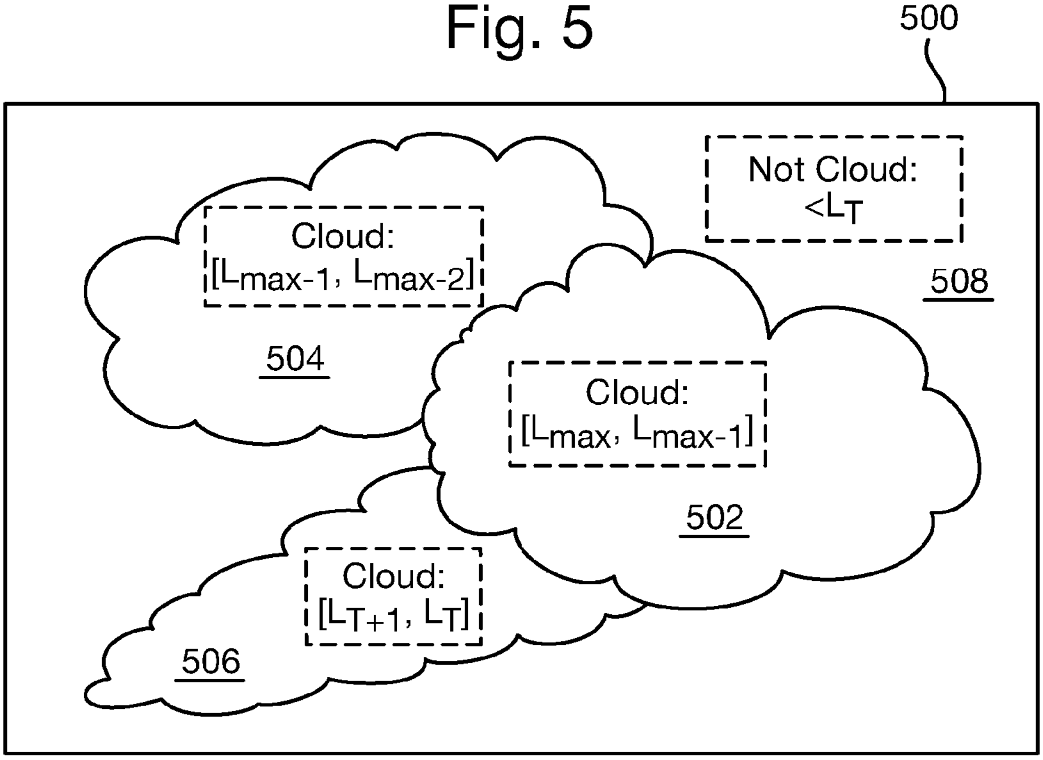

500
Not Cloud:
<LT
Cloud:
[Lmax-1, Lmax-2]
508
504
Cloud:
[Lmax, Lmax-1]
502
Cloud:
[LT+1, LT]
506

Fig. 7

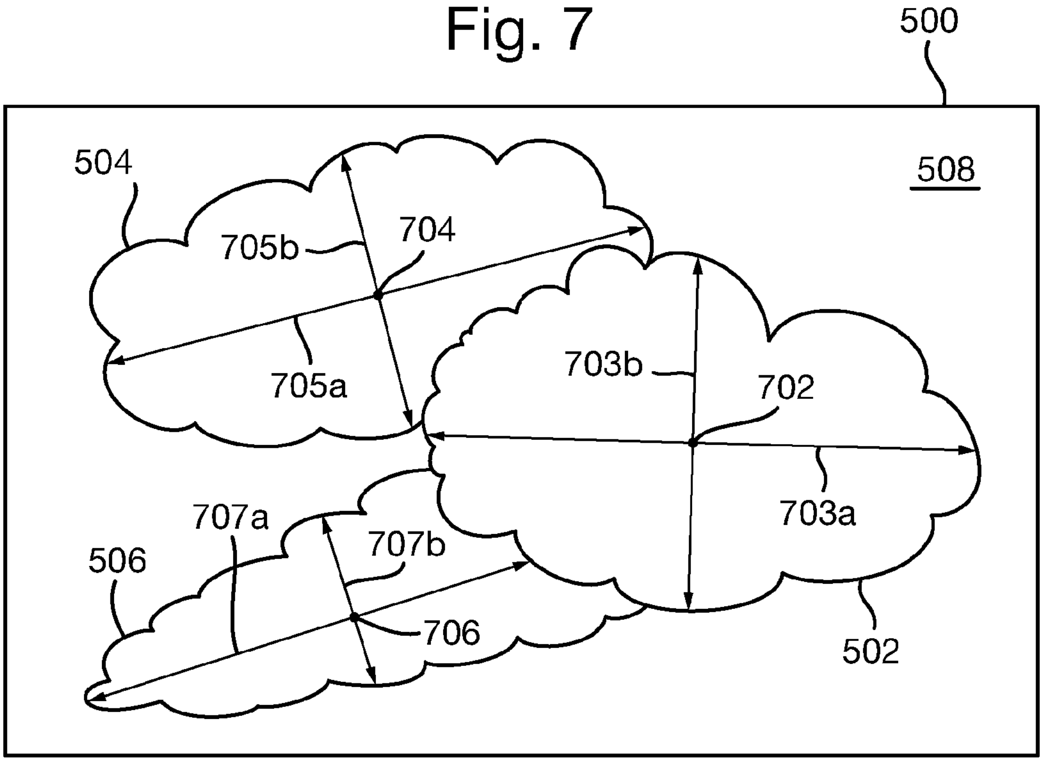

500
504
508
705b
704
703b
702
705a
707a
707b
703a
506
706
502

Fig. 6

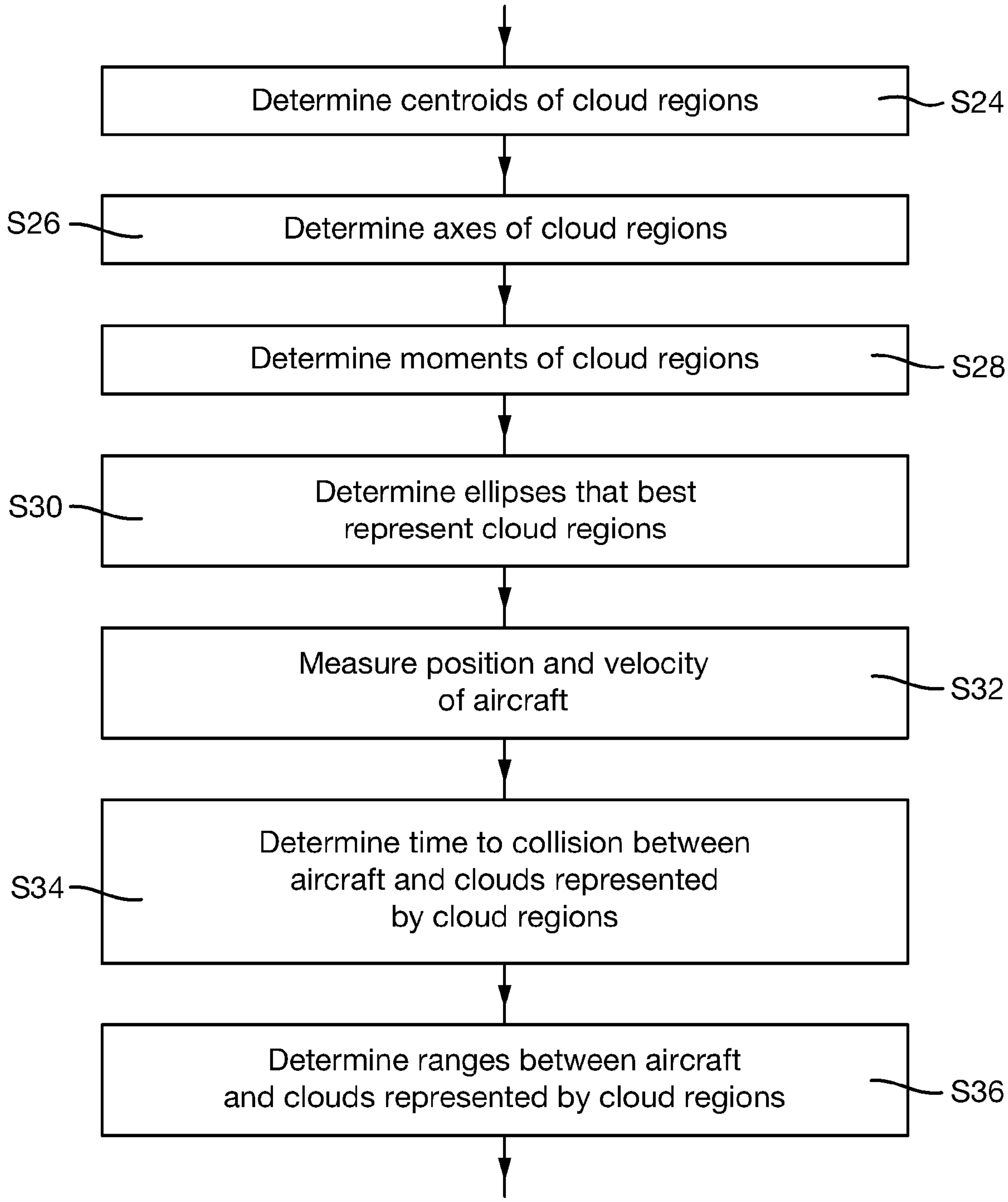
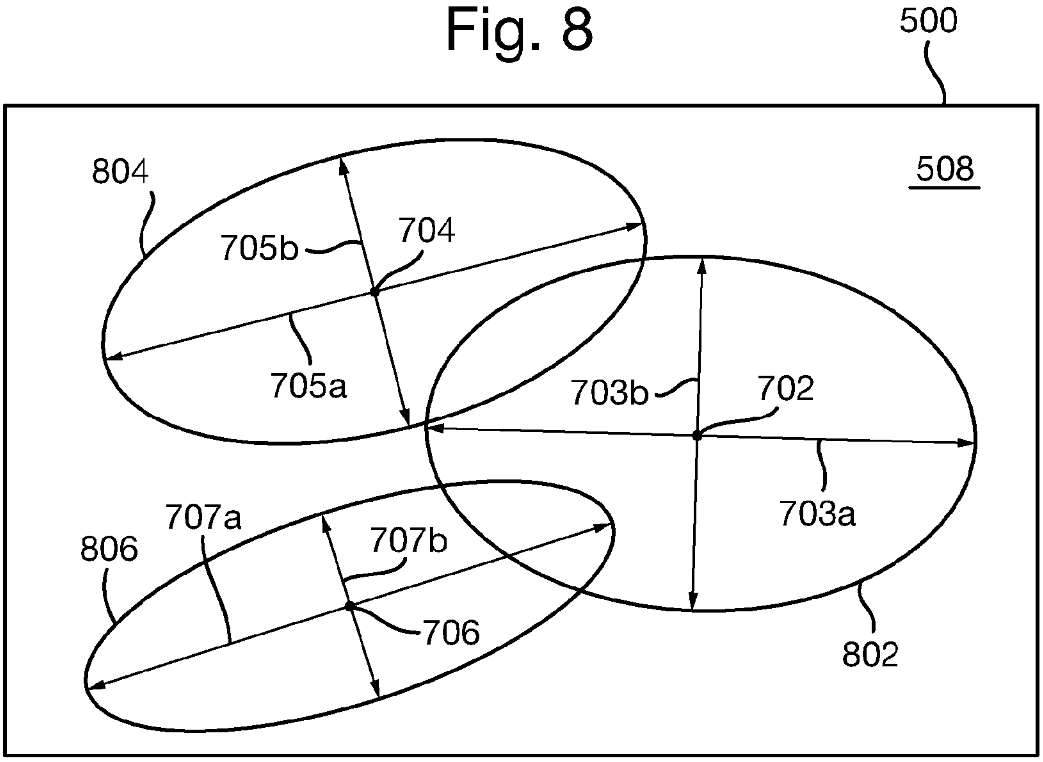

Determine centroids of cloud regions
S24
S26
Determine axes of cloud regions
Determine moments of cloud regions
S28
S30
Determine ellipses that best represent cloud regions
Measure position and velocity of aircraft
S32
S34
Determine time to collision between aircraft and clouds represented by cloud regions
Determine ranges between aircraft and clouds represented by cloud regions
S36

Fig. 8



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2015/050123

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 03/069558 A1 (UNIV SINGAPORE [SG]; LI MIN [SG]; LIEW SOO CHIN [SG]; KWOH LEONG KEONG) 21 August 2003 (2003-08-21) page 8, line 10 - line 25; figure 1 -----	1,3,5-7, 9-14
Y	LEE R ET AL: "MOMENT PRESERVING DETECTION OF ELLIPTICAL SHAPES IN GRAY-SCALE IMAGES", PATTERN RECOGNITION LETTERS, ELSEVIER, AMSTERDAM, NL, vol. 11, no. 6, 1 June 1990 (1990-06-01), pages 405-414, XP000128317, ISSN: 0167-8655, DOI: 10.1016/0167-8655(90)90111-E page 408, left-hand column, line 9 - page 410, right-hand column, paragraph 4 page 408, left-hand column, line 3 -----	1,3,5-7, 9-11,13

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 July 2015	27/07/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Chateau, Jean-Pierre

1

International application No
PCT/GB2015/050123

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 2 731 050 A1 (BAE SYSTEMS PLC [GB]) 14 May 2014 (2014-05-14) the whole document -----	12,14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2015/050123

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		CN 1623171 A	01-06-2005
		EP 1476850 A1	17-11-2004
		US 2005175253 A1	11-08-2005
		WO 03069558 A1	21-08-2003
EP 2731050 A1	14-05-2014	NONE	