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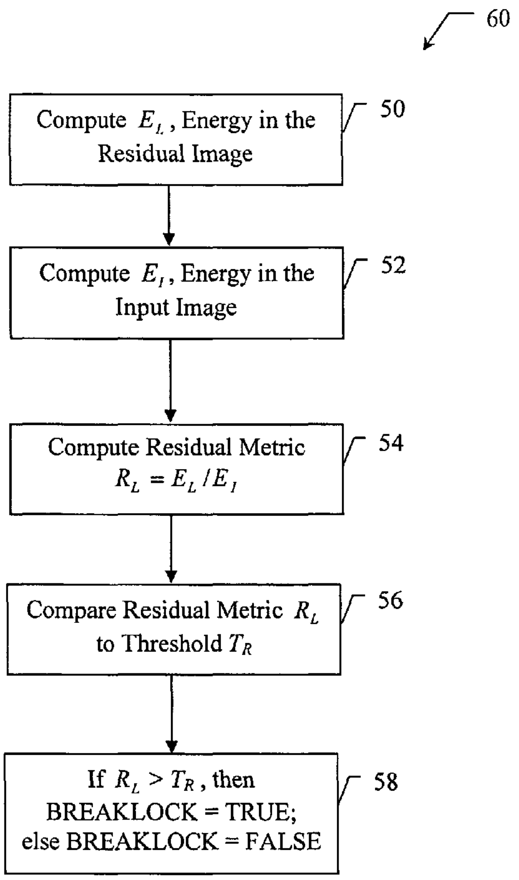

(57) Abstract: A system and method for detecting breaklock for correlation trackers. The inventive system includes a first circuit (50) for computing energy E_L in a residual image, a second circuit (52) for computing energy E_I in an input image, and a third circuit (54) for computing a residual metric R_L based on the residual image energy E_L scaled by the input image energy E_I. In the illustrative embodiment, the system further includes a fourth circuit (56) for comparing the residual metric R_L to a threshold T_R, and a fifth circuit (58) for setting a breaklock signal based on the output of the fourth circuit (56).

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CORRELATION TRACKER BREAK LOCK DETECTION

RIGHTS IN INVENTION

This invention was made with support under Government Subcontract No. E80011 Boeing Corp. under Prime Contract N00019-97-C-0009 with the Department of the Navy. The U. S. Government may have certain rights to this invention.

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to imaging systems. More specifically, the present invention relates to correlation based imaging target trackers.

Description of the Related Art:

An autotracker is a device which locates a target in each of a sequence of images and generates commands to maintain a sensor line-of-sight on the target. Correlation trackers generate servo commands based on the position of the target. The tracker measures this position by finding the shift of the input image that maximizes its cross-correlation with a reference image formed by averaging recent past input images.

During a target tracking operation, it often happens that the line-of-sight from the sensor to the target becomes temporarily obscured. For example, in an air-toground scenario, a cloud or a building may pass between the sensor and the target temporarily blocking the line-of-sight. One important function of the autotracker is to determine when the target has been obscured, thereby detecting a 'breaklock' condition. The tracker is then commanded into a 'coast mode' until the target is again visible. In coast mode the sensor is pointed open-loop at the predicted position of the target based on its recent motion. While in coast mode the tracker must continually monitor the input image to determine when the target is again visible so that closed-loop tracking may resume.

Prior attempts to detect breaklock made use of either: 1) a threshold on a statistical average of the residuals after cross-correlation (see, for example, "Developing a Real-Time, Robust, Video Tracker," K. Plakas, E. Trucco (0-7803-6551-8/00 IEEE) or 2) a threshold on the change in the difference between the input image and the correlation reference map. Unfortunately, these approaches have proven to be too sensitive to certain image disturbances which commonly occur in dynamic tracking situations. This is due to the reliance by these approaches on an assumption that the difference between the input image and reference map pixel values has a Gaussian density. While this may be true in an idealized situation, in practical tracking situations there are several types of image disturbances which cause the Gaussian assumption to falter. One such disturbance is due to a change of the sensor position relative to the tracked target which causes the target's image to change in size and shape. Another is due to uncommanded sensor line-of-sight deviations such as jitter which cause image blurring. These image disturbances will cause the existing breaklock detection methods to falsely declare a breaklock condition when continued tracking is still feasible.

Hence, a need exists in the art for an improved system or method for detecting breaklock for correlation trackers.

SUMMARY OF THE INVENTION

The need in the art is addressed by the system and method for detecting breaklock for correlation trackers of the present invention. The inventive system includes a first circuit for computing energy E_L in a residual image, a second circuit for computing energy E_I in an input image, and a third circuit for computing a residual metric R_L based on the residual image energy E_L scaled by the input image energy E_I.

In the illustrative embodiment, the system further includes a fourth circuit for comparing the residual metric R_L to a threshold T_R, and a fifth circuit for setting a breaklock signal based on the output of the fourth circuit.

The present invention addresses the problems associated with the prior art by comparing the residual energy to the energy in the input image, rather than the current method of comparing the residual energy to an absolute threshold. By scaling the residual energy by the input image energy, a more robust statistic is obtained which allows closed-loop tracking to continue as long as even a small amount of match exists between the input and reference images. The invention has been designed to quickly and accurately determine actual breaklock conditions such as obscurations and extreme uncommanded line-of-sight deviations while enabling continued tracking through high sensor-to-target relative position rates and sensor line-of-sight jitter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of an autotracker system.

Fig. 2 is a block diagram of the components of an autotracker designed in accordance with the teachings of the present invention.

Fig. 3 is a flow chart illustrating the breaklock detection method of the present invention.

Fig. 4 is a block diagram showing a hardware implementation of the autotracker system of the present invention.

DESCRIPTION OF THE INVENTION

Illustrative embodiments and exemplary applications will now be described with reference to the accompanying drawings to disclose the advantageous teachings of the present invention.

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the present invention would be of significant utility.

Fig. 1 is a block diagram of an autotracker system 10. A monochromatic sensor 12, mounted in a gimbal 14 generates a two dimensional image, $I(r,c)$, of the target. Example sensors are an infrared (IR) sensor or a TV camera. This image is processed by the autotracker 16, which generates commands to the servo motors 18 to maintain the sensor line-of-sight on the target. In a correlation tracker, the position of the target is measured by finding the shift of the input image that maximizes its cross-correlation with a reference image formed by averaging recent past input images.

The present invention is a system and method for breaklock detection for use in correlation autotracker systems. It uses statistics generated by the correlation process to compute a residual metric that is used to determine, while tracking, when the target is no longer present in the field of view, and, while coasting, when the target is again visible in the field of view. The invention addresses the problems of the prior art by comparing the residual energy to the energy in the input image, rather than the current method of comparing the residual energy to an absolute threshold. By scaling the residual energy by the input image energy, a more robust statistic is obtained which allows closed-loop tracking to continue as long as even a small amount of match exists between the input and reference images. The invention has been designed to quickly and accurately determine actual breaklock conditions such as obscurations and extreme uncommanded line-of-sight deviations while enabling continued tracking through high sensor-to-target relative position rates and sensor line-of-sight jitter.

Fig. 2 is a block diagram of the components of an autotracker 16 designed in accordance with the teachings of the present invention. A correlation pixel processing function 20 maintains a reference map and cross-correlates this map with each input image to determine the track errors and a residual metric. The track errors are used by the closed-loop control function 22 to compute servo commands to keep the tracked target in the center of the sensor field of view. The residual metric, the subject of this patent, is used by status processing 24 to derive a breaklock signal. This breaklock signal is used by the closed-loop control function 22 to determine when it should point the sensor based on the track errors (closed-loop mode) or when it should ignore the track errors and point using the predicted target position (coast mode).

While this method can be applied to any correlation tracker, the invention will now be described with reference to an illustrative application to the Fitts correlation pixel processing algorithm described in U.S. Patent number 4,133,004, issued January 2, 1979, entitled "Video Correlation Tracker", the teachings of which are incorporated herein by reference. In accordance with the Fitts teachings, a correlation pixel processing algorithm generates a reference map, denoted $M(r,c)$, in pixel format by averaging input images prior to the current time *t*. (It is assumed herein that all images mentioned have N_{rows} rows and N_{cols} columns of pixels for a total of $N_{pixels} = N_{rows} * N_{cols}$ pixels. Thus, the row numbers *r*, have values in the range from 1 to N_{rows} inclusive, and the column numbers, *c*, have values in the range from 1 to N_{cols} inclusive.)

The correlation pixel processing 20 correlates the reference map $M(r,c)$ with the input image at time *t*, denoted $I(r,c)$, to determine the track error, denoted $\delta = \begin{bmatrix} \delta_r \\ \delta_c \end{bmatrix}$, which is the estimated shift of the input image relative to the reference image. As described in the Fitts correlation patent, in the process of computing the track error the Fitts algorithm computes gradient images that are approximations to the image spatial derivatives in the row and column directions. The gradient image in the row direction, denoted $G_r(r,c)$, is given by:

$$G_r(r,c) = \frac{M(r+1,c) - M(r-1,c)}{2}, \qquad [1]$$

and the gradient image in the column direction, denoted $G_c(r,c)$ is given by:

$$G_c(r,c) = \frac{M(r,c+1) - M(r,c-1)}{2} \qquad [2]$$

The residual image, denoted $L(r,c)$, is defined to be the difference between the input image and the reference map shifted by δ', where $\delta' = \begin{bmatrix} \delta'_r \\ \delta'_c \end{bmatrix}$ is the computed track error before drift compensation, as described in the Fitts algorithm patent. The shifted reference map, denoted $M'(r,c)$, may be approximated using a first order Taylor expansion by:

$$M'(r,c) = M(r,c) + G_r(r,c)\delta'_r + G_c(r,c)\delta'_c \qquad [3]$$

Thus, the residual image can be approximated by:

$$L(r,c) = I(r,c) - M'(r,c) = I(r,c) - M(r,c) - G_r(r,c)\delta_r' - G_c(r,c)\delta_c', \qquad [4]$$

or

$$L(r,c) = D(r,c) - G_r(r,c)\delta_r' - G_c(r,c)\delta_c' \qquad [5]$$

where $D(r,c)$ is the difference image defined by:

$$D(r,c) = I(r,c) - M(r,c) \qquad [6]$$

The energy in the residual image, denoted E_L, gives an indication of the relative amount of unexplained variation in the residual image, and is defined as:

$$E_L = \sum_{(r,c)\in Gate} \left(L(r,c) - \bar{L}\right)^2, \qquad [7]$$

where $\bar{L}$ is the average of the residual image pixel values given by:

$$\bar{L} = \frac{1}{N_{pixels}} \cdot \sum_{(r,c)\in Gate} L(r,c) \qquad [8]$$

and *Gate* represents the set of *(r,c)* values for which $1 \le r \le N_{rows}$ and $1 \le c \le N_{cols}$.

Similarly, the energy in the input image, denoted E_I, is defined to be:

$$E_I = \sum_{(r,c)\in Gate} \left(I(r,c) - \bar{I}\right)^2, \qquad [9]$$

where $\bar{I}$ is the average of the input image pixel values and is given by:

$$\bar{I} = \frac{1}{N_{pixels}} \cdot \sum_{(r,c) \in Gate} I(r,c) \qquad [10]$$

The residual metric, denoted R_L, is then defined to be:

$$R_L = \frac{E_L}{E_I} \qquad [11]$$

and represents the relative amount of the energy in the input image that is not explained by modeling it as the shifted reference image.

In practice the energy in the residual image can be approximated by the energy in the difference image because the image shifts are relatively small, and the change they induce can often be neglected. Let the energy in the difference image, denoted E_D, be defined as:

$$E_D = \sum_{(r,c) \in Gate} \left(D(r,c) - \bar{D}\right)^2 \qquad [12]$$

where $\bar{D}$ is the average of the difference image pixel values given by:

$$\bar{D} = \frac{1}{N_{pixels}} \cdot \sum_{(r,c) \in Gate} D(r,c) \qquad [13]$$

The difference residual metric, denoted R_D, is then defined to be:

$$R_D = \frac{E_D}{E_I} \qquad [14]$$

The residual metric, either R_D or R_L, is used by the status processing function

24 to determine the value of the breaklock signal. If the shifted reference image exactly matches the input image then the residual metric will very nearly equal zero. As the degree of match decreases the residual metric grows in size. Values of this metric close to or greater than one indicate a complete mismatch between the reference image and the input image. Therefore, a threshold, T_R, on the residual metric is used to derive the breaklock signal. If the residual metric is less than or equal to T_R, the match between the reference image and the input image is considered good enough to continue tracking and the breaklock signal is set to FALSE indicating that closed-loop tracking is to continue. If the residual metric is greater than T_R, then the match has significantly degraded and the breaklock signal is set to TRUE indicating that the closed-loop control should enter coast mode. Empirical experience has shown that tracking can reliably continue with T_R values up to 0.9.

Fig. 3 is a flow chart illustrating the breaklock detection method 60 of the present invention. First, the energy E_L in the residual image is determined (50), and the energy E_I in the input image is determined (52). In the illustrative embodiment, E_L is computed using Eqn. 7, or estimated using Eqn. 12. In the illustrative embodiment, E_I is computed using Eqn. 9. Next, the residual metric $R_L = E_L / E_I$ is computed (54). Then, the residual metric R_L is compared to a threshold T_R (56). Finally, if the residual metric R_L was greater than the threshold T_R , then the Breaklock Signal is set to TRUE; otherwise, it is set to FALSE (58).

Fig. 4 is a block diagram showing a hardware implementation of the autotracker system 10 of the present invention. A sensor 12 mounted in a gimbal 14 receives visible or infrared images which are then processed by a video processor 30. The video processor 30 formats the received images into digital video and, for infrared, performs non-uniformity correction and dead cell replacement. The digital images are then sent to an image processor 32 which computes the track errors and the residual metric. The track errors are used by a servo control processor 34 to generate the torque commands for the sensor gimbal hardware 14 to keep the tracked target in the center of the sensor field of view. The residual metric is used by a system control processor 36 to derive a breaklock signal. This breaklock signal is used by the servo control processor 34 to determine when it should point the sensor based on the track errors (closed-loop mode) or when it should ignore the track errors and point using the predicted target position (coast mode). The system control processor 36 controls the operation of the entire autotracker system and may interface to an aircraft.

Thus, the present invention has been described herein with reference to a particular embodiment for a particular application. Those having ordinary skill in the art and access to the present teachings will recognize additional modifications, applications and embodiments within the scope thereof.

It is therefore intended by the appended claims to cover any and all such applications, modifications and embodiments within the scope of the present invention.

Accordingly,

WHAT IS CLAIMED IS:

EUROSTYLE CLAIMS

1. A system (60) for detecting breaklock for correlation trackers characterized by:

a first circuit (50) for computing the energy E_L in a residual image;

a second circuit (52) for computing the energy E_I in an input image; and

a third circuit (54) for computing a residual metric R_L based on the residual image energy E_L scaled by the input image energy E_I.

2. The invention of Claim 1 wherein said system further includes a fourth circuit (56) for comparing said residual metric R_L to a threshold T_R.

3. The invention of Claim 2 wherein said system further includes a fifth circuit (58) for setting a breaklock signal based on the output of said fourth circuit (56).

4. The invention of Claim 2 wherein said breaklock signal is set to TRUE if the residual metric R_L is greater than the threshold T_R and FALSE otherwise.

5. The invention of Claim 1 wherein said residual image energy E_L is computed using the equation $E_L = \sum_{(r,c)\in Gate} \left(L(r,c) - \overline{L}\right)^2$, where $L(r,c)$ is the residual image, $\overline{L}$ is the average of the residual image pixel values, and *Gate* represents the set of *(r,c)* values in the image.

6. The invention of Claim 1 wherein said residual image energy E_L is approximated by the energy E_D in a difference image $D(r,c)$.

7. The invention of Claim 6 wherein said difference image energy E_D is computed using the equation $E_D = \sum_{(r,c)\in Gate} \left(D(r,c) - \overline{D}\right)^2$, where $\overline{D}$ is the average of the difference image pixel values, and *Gate* represents the set of *(r,c)* values in the image.

8. The invention of Claim 1 wherein said input image energy E_I is computed using the equation $E_I = \sum_{(r,c)\in Gate} \left(I(r,c) - \bar{I}\right)^2$, where $I(r,c)$ is the input image, $\bar{I}$ is the average of the input image pixel values, and *Gate* represents the set of *(r,c)* values in the image.

9. The invention of Claim 1 wherein said residual metric R_L is computed using the equation $R_L = E_L / E_I$.

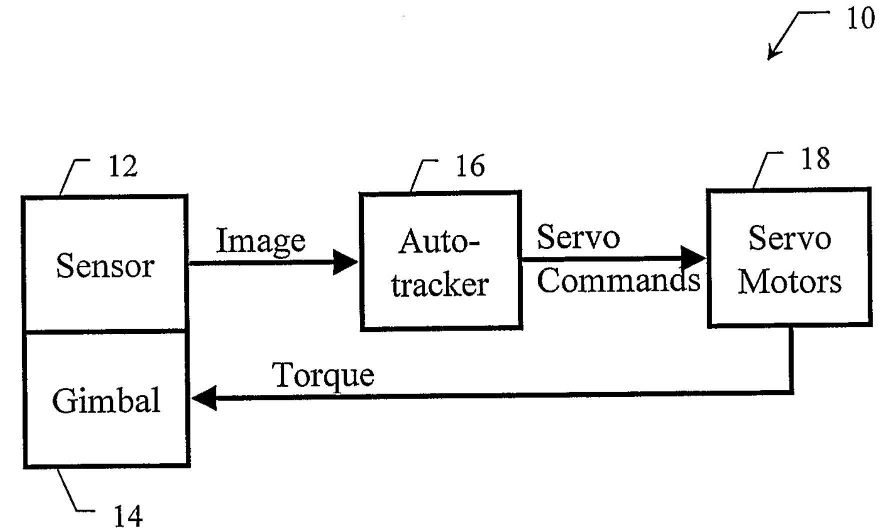
10
12
Sensor
Gimbal
14
Image
16
Auto-
tracker
Servo
Commands
18
Servo
Motors
Torque

Fig. 1

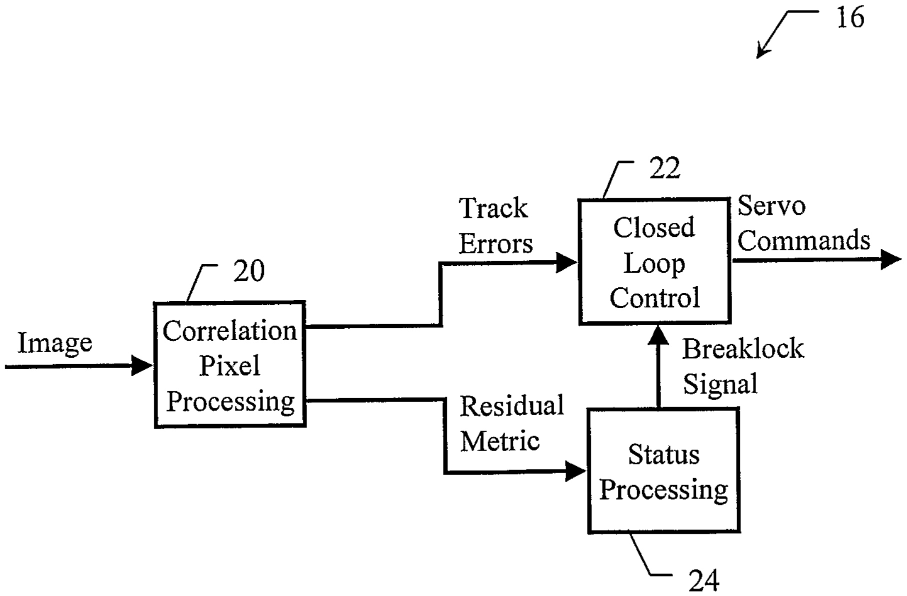
16
Image
20
Correlation
Pixel
Processing
Track
Errors
Residual
Metric
22
Closed
Loop
Control
Servo
Commands
Breaklock
Signal
Status
Processing
24

Fig. 2

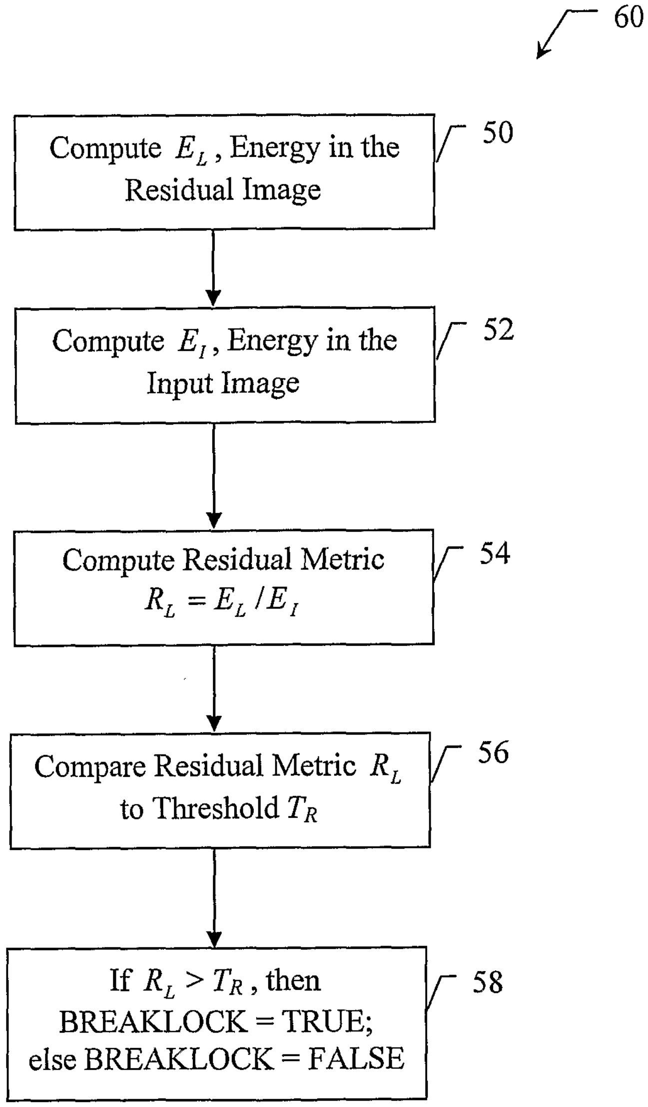
60
Compute E_L, Energy in the Residual Image
50
Compute E_I, Energy in the Input Image
52
Compute Residual Metric $R_L = E_L / E_I$
54
Compare Residual Metric R_L to Threshold T_R
56
If $R_L > T_R$, then BREAKLOCK = TRUE; else BREAKLOCK = FALSE
58

Fig. 3

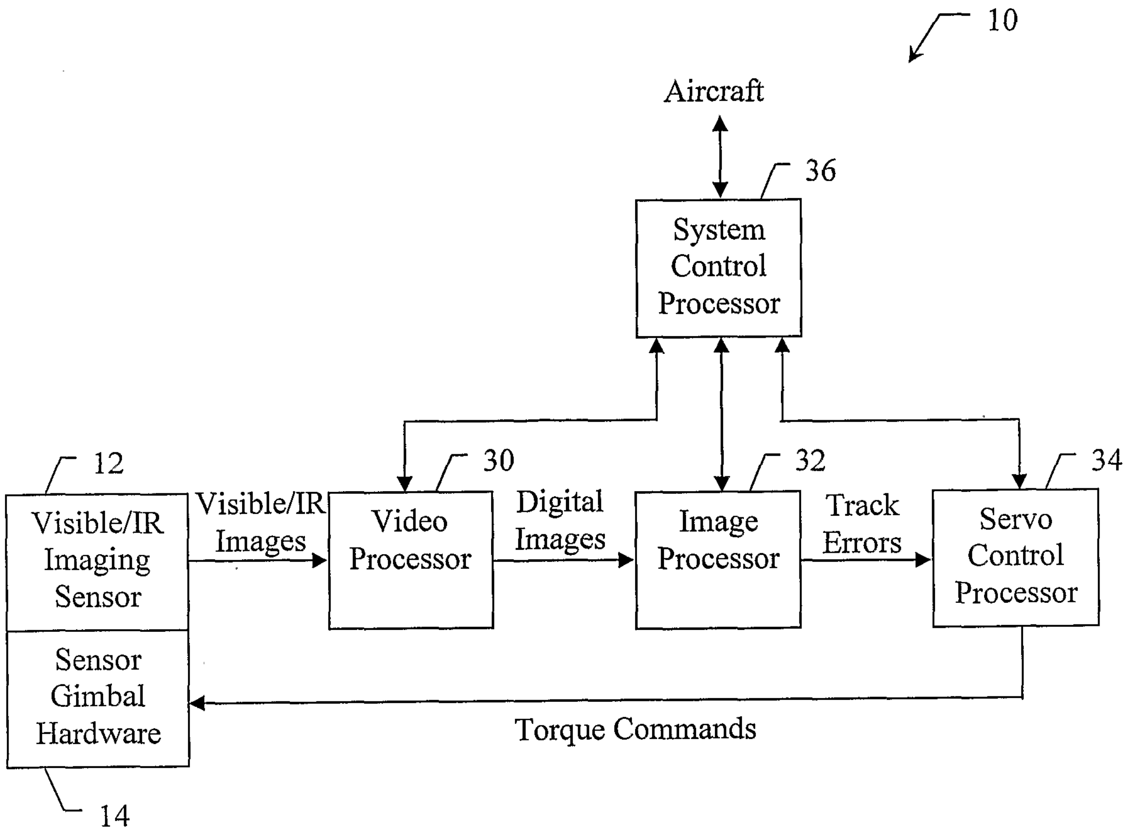
10
Aircraft
36
System Control Processor
12
Visible/IR Imaging Sensor
Visible/IR Images
30
Video Processor
Digital Images
32
Image Processor
Track Errors
34
Servo Control Processor
Sensor Gimbal Hardware
Torque Commands
14

Fig. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 03/23548

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01S3/786

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)
IPC 7 G01S

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 practical, search terms used)

INSPEC, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 666 545 A (HUGHES AIRCRAFT CO) 9 August 1995 (1995-08-09) abstract column 5, line 55 -column 7, line 46; figure 6 column 8, line 46 - line 52 ---	1
A	US 6 330 371 B1 (CHEN HAI-WEN ET AL) 11 December 2001 (2001-12-11) column 2, line 44 -column 3, line 23 column 5, line 29 - line 46 ---	1
A	US 5 947 413 A (MAHALANOBIS ABHIJIT) 7 September 1999 (1999-09-07) column 5, line 27 -column 8, line 17 --- -/--	1

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

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
27 November 2003	13/01/2004

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, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Mercier, F

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 03/23548

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

In[redacted]tion on patent family members

International Application No
PCT/US 03/23548

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