An UAV Inspection Method for Power Line Based on Human Visual System

Field of Technology

This invention involves an UAV inspection method for power line based on human visual system, which belongs to the field of digital image processing and power line automatic inspection.

Background Technology

With the vigorous development of China's economy, there are more and more demands for electric energy. In order to meet the increasing demand of electricity in China, measures shall be taken to continue to expand in the direction of power line, high voltage and large capacity. On the one hand, with the construction of a large number of power lines, the coverage becomes much broader, terrain conditions are more complex and diverse, and it is difficult to figure out how to solve the problem of providing cross-terrain line maintenance. On the other hand, the environment of the power lines also constantly changes with the region and time. The whole power line system is complex, and the hidden danger in some key link may affect the users' power supply and system's power supply safety, resulting in immeasurable economic losses and threatening the safety of life and property, so power line inspection shall be deemed as an important part of power system equipment maintenance.

High-voltage power line, that is, overhead line, refers to the power line which erects the wires on the pole and tower with insulators and power fittings, and is an important component of the power grid and power system, which is vulnerable to external impacts and damages. At present, the overhead line accidents mainly include accidents due to external damages, wind accidents, lightning accidents and accidents caused by aging of equipment. The so-called accidents due to external damages mainly refer to accidents caused by foreign objects entering non-safe areas or

distance, such as forest trees, housing construction and power lines in other non-safe areas, which not only poses a threat to the safety of power lines, but also easily leads to electric shock in the obstacle itself, fire hazard and other accidents. According to relevant reports, accidents due to external damage account for about one-fourth of the total number of trips of the national power lines, causing enormous harm and economic loss to the society.

The traditional power line inspection mode is usually manual inspection, which requires large consumption of manpower resources, but under the circumstance with large coverage of power lines and diverse needs for the environment, manual power line inspection has low efficiency and poor timeliness, as a result of which it often cannot meet the requirements for coverage and timeliness of power line inspection. In addition, the traditional manual power line inspection mode is often based on human eye observation and determines according to the staff experience in the status of the power line. Given its excessive dependence on the staff's status and experience, it cannot give a quantitative analysis of the distance between the obstacle and the power line and tends to cause false and missed inspection, so it cannot meet the accuracy requirement for power line inspection.

Content of Invention

The technical problem to be solved by this invention is to provide an UAV inspection system for the power line with regard to the technology gap in the field of accident inspection due to external force in the current power lines, so as to improve the way of power line inspection and improve the inspection efficiency and accuracy.

To solve the said technical problem, this invention provides an UAV inspection method for power line based on human visual system, which includes the following steps:

(1) UAV video capture: It uses the UAV armed with binocular visual measuring

equipment to obtain the video image of power line distribution and power line environmental information;

The said binocular visual measuring equipment refers to two video image capture equipment with the same specifications and parameters, which are arranged in the left and right visual forms separately and acquire video image information at a fixed angle of view;

When the UAV armed with binocular visual measuring equipment is used for power line inspection, wireless remote control shall be applied to the UAV, so that the UAV can have uniform rectilinear movements on the path in parallel with the power line and above the power line, and the distribution direction of the power line in the capture video image sequence is in parallel with the flight direction of the UAV.

(2) The image preprocessing module grabs the frame of the video image sequence of the power line input system and preprocess the current frame of image, including graying processing of image and DoG edge detection;

Where the DoG edge detection uses the DoG results of different parameters to describe the image edge and applies the same treatment to the left visual image and right visual image in sequence.

(3) The power line detection module uses the mathematical morphology to deal with the image that has been preprocessed, selects the structural factors in the same direction as the power line to provide the image with repeated expansion and corrosion treatment to remove the noise in the image, and then uses the human visual connected domain attention mechanism to select the largest linear connected domain to complete segmentation of the power line in image; while human eye visual attention mechanism refers to the the fact that human eye always immediately notices the area with special shape, color and brightness within the field of view, and the attention mechanism of the connected domain of human eye vision uses the human

eye attention mechanism towards the connected domain of special shape to complete segmentation of the power lines.

Separately record the horizontal coordinate positions ($x_{dz1}, x_{dz2}...x_{dzj}$) and ($x_{dy1}, x_{dy2}...x_{dyj}$) of the power line in the left visual image and the right visual image; where $x_{dz1}, x_{dz2}...x_{dzj}$ and $x_{dy1}, x_{dy2}...x_{dyj}$ separately refer to the horizontal coordinate of the central point in the left visual image and right visual image of the connected domain of *j* power lines;

(4) The binocular image registration module provides registration for the left visual image and right visual image separately and uses SURF algorithm to find the feature points of the left and right visual edge images which have been preprocessed and obtain the descriptor of the current feature point, then provides exact match of the feature points and record the location information of the exact matching point in left and right visual images （ x_{z1}, y_{z1} ）~（ x_{y1}, y_{y1} ）, （ x_{z2}, y_{z2} ）~（ x_{y2}, y_{y2} ）...（ x_{zn}, y_{zn} ）~（ x_{yn}, y_{yn} ）, of which *n* refers to the number of all feature points included in single image, x_{zn}, y_{zn} and x_{yn}, y_{yn} refer to the position coordinates of corresponding features points in the left and right visual images, respectively;

(5) The obstacle detection and early warning module, based on the horizontal coordination position of the power line in left and right visual images ($x_{dz1}, x_{dz2}...x_{dzj}$), ($x_{dy1}, x_{dy2}...x_{dyj}$) and locations of exact matching points in left and right visual images (x_{z1}, y_{z1})~(x_{y1}, y_{y1}), (x_{z2}, y_{z2})~(x_{y2}, y_{y2})...(x_{zn}, y_{zn})~(x_{yn}, y_{yn}), uses the binocular visual principle to calculate the three-dimensional space coordinates of the matching point and the power line, and calculate the vertical distance from the matching point to the power line according to the space coordinate information;

(6) The result output and feedback module back feeds the obstacle information which threatens the power line. When the space vertical distance between the matching point and the power line is lower than the given threshold, back feed

concrete information about the obstacle on the computer software interface and record the obstacle detection time and geographical location. When the space vertical distance between the matching point and the power line is higher than the given threshold, the current matching point shall not be processed and the same treatment shall be applied to all matching points in the current frame image. In addition, back feed the obstacle information about the frame images obtained in sequence to complete record of the obstacle information in the inspection process.

The beneficial effect achieved in this invention is that it uses the binocular visual technology to detect and analyze the external obstacles of the power line and it can provide a massive, rapid information search of the power lines mainly through the joint inspection of UAVs armed with binocular visual measuring equipment to obtain the image information about the power lines and equipment in real time and enable the expert system to complete the quantitative analysis of the faults and hidden dangers of the power lines. Compared to traditional manual inspection, UAV inspection is not bound by terrain, environment, state and other factors, and it can be used to monitor the distribution of power lines and the surroundings in real time and can use the binocular visual technology of human eye to provide a quantitative analysis and early warning of the power line distribution, fault and other problems, which is characterized by high inspection efficiency, versatility and good timeliness.

Description of Figures

Figure 1 is the Modular Structure Diagram of the UAV Inspection System for Power Line of this Invention;

Figure 2 is the Physical Model Diagram of the UAV Inspection System for Power Line of this Invention;

Figure 3 is the Process Flow Chart of the UAV Inspection System for Power Line of this Invention;

Figure 4 is the Dimension Diagram of the Filter in the Scale Space;

Figure 5 is the Schematic Diagram of Binocular Vision Imaging;

Figure 6 is the Diagram of Matching of Features Points in the Left and Right Visual Images;

Figure 7 is the Diagram of Annotations of Accident Points Due to External Force in the Left Visual Image.

Specific Implementation Mode

The UAV inspection method for power line based on human visual system of this invention includes the hardware work system and software operating system, and the modules of the entire system are shown in Figure 1, of which the software system includes the UAV video information capture module, while software system includes image preprocessing module, power line detection module, binocular image registration module, obstacle detection and early warning module and result output and feedback module.

Figure 2 shows the Physical Model Diagram, which first uses the UAV armed with binocular visual measuring equipment to acquire information about the power lines to be inspected and the surroundings and control the flight of the UAV, and the flight direction of UAV is in parallel with the distribution direction of power lines. It transmits the obtained binocular video sequence to the software operating system, which will extract the image frame at a certain interval from the video sequence to provide all image frames with image preprocessing, power line detection, left and right visual image registration, obstacle detection and early warning and result output and feedback in sequence to complete record and feedback of obstacle information in the process of UAV inspection.

With regard to the UAV inspection method for power line based on human visual system of this invention, the specific process is shown in Figure 3:

(1) When it is required to detect the power line in some region, be sure to first use the UAV armed with binocular visual measuring equipment to inspect the power lines and the surroundings for acquisition of relevant information, of which the binocular visual measuring equipment consists of two cameras with same specifications, the camera pixel is not lower than 500W, the parallax range b between two cameras for

fixation is 120mm and the focal length of the camera f is known as $400mm \le f \le 1000mm$, and the two cameras are used to shoot in parallel in the same direction. The UAV is controlled by the staff, whose uniform flight direction is in parallel with the distribution direction of power lines, and it is uniform and stable in the flight. The binocular visual hardware system based on dual cameras shall be installed on a stable platform of the UAV, which will save the obtained left video sequence l_z and right video sequence l_y to the storage device to the UAV, and uses mobile wireless network to transmit to the software system.

(2) In the process of UAV inspection, it will transmit the obtained left video sequence l_z and right video sequence l_y from the UAV to the software system in real time, and the software system will first backup the data obtained in the data segment and the staff will enter the shooting time and location. With regard to processing of the left video sequence l_z and right video sequence l_y, be sure to first continuously grab the frame separately from the left video sequence l_z and right video sequence l_y at a certain interval, which requires that all frames of images can be pieced together to recover the complete inspection image information and there is no information loss when adjacent frames are pieced together, so as to form the left image sequence T_z and right image sequence T_y, of which both the left image sequence T_z and right image sequence T_y contain *m* frames of images, separately are $T_{z1}, T_{z2} ... T_{zm}$ and $T_{y1}, T_{y2} ... T_{ym}$. With regard to preprocessing of corresponding left and right visual images, be sure to first process the first left visual image T_{z1} and the first right visual image T_{y1}, and then process the corresponding left and right visual images in sequence until the mth left visual image T_{zm} and the mth right visual image T_{ym} are processed.

Preprocess the first left visual image T_{z1} and the first right visual image T_{y1}, including image grayscale processing and DoG (Difference of Gaussian) edge detection:

Grayscale processing of the said image turns color image into the single-channel grayscale image H_{z1} of the first left visual image and the single-channel grayscale image of the first right visual image H_{y1};

In the said DoG edge detection, Difference of Gaussian (DoG) is the difference of Gaussian function, which obtains the LPF results of a frame of image through convolution of the image of Gaussian function. Same as the Gaussian in the Gaussian low pass filter, the said Gaussian is a function, that is, normal distribution function. Difference of Gaussian, namely, difference of Gaussian function, is the difference of two Gaussian images. When it is specific to image processing, that is, subtract the results of Gaussian filter of the same frame of image under different parameters to obtain DoG image, that is, the edge detection result. In addition, DoG operation is defined as:

$$D = \frac{1}{2\pi}\left[\frac{1}{\sigma_1^2}e^{-\frac{(x^2+y^2)}{2\sigma_1^2}} - \frac{1}{\sigma_2^2}e^{-\frac{(x^2+y^2)}{2\sigma_2^2}}\right] * H$$
$$= [G(x,y,\sigma_1) - G(x,y,\sigma_2)] * H$$

Where, D refers to the image result after processing, the first constant $\sigma_1 = 0.6$ and the second constant $\sigma_2 = 0.9$, x and y separately refer to the horizontal and vertical coordinates of the current pixel point in the image, the window size of the Gaussian filter function is 5×5, $G(x,y,\sigma_1)$ and $G(x,y,\sigma_2)$ separately refer to the Gaussian filter function of different parameters, H refers to grayscale image, "*" stands for the processing of the treatment of moving filter toward the whole frame of image, and the preprocessed images separately are the left visual edge image D_{z1} and the right visual edge image D_{y1}.

(3) With regard to segmentation of the power line in the left visual edge image D_{z1} and the right visual edge image D_{y1}, first use the loop erosion and dilation operation in mathematical morphology to process the left visual edge image D_{z1} and the right visual edge image D_{y1}; the video capture direction is in parallel with the distribution direction of power lines, and the direction of power line in the image is in

parallel with the direction of 90° of the image. Image processing in morphology is to move a structural element in the image, and then apply intersection, union and other set operations to the left visual edge image D_{z1} and the right visual edge image D_{y1} with the structural element, of which structural element is the most important and fundamental concept, where $B(x)$ stands for the structural element, and the erosion and dilation operation of each point $A(x, y)$ in the work space E is defined as:

$$\text{Erosion: } X = E \otimes B = \{A(x, y) : B(x) \subset E\}$$

$$\text{Dilation: } Y = E \oplus B = \{A(x, y) : B(y) \cap E \neq \Phi\}$$

Where, $\subset$ stands for "included in", $\cap$ stands for "intersection operation" and Φ stands for null set. If the structural element $B(x)$ is used to apply erosion to the work space E, the result is the set consisting of all points of the structural element $B(x)$ included in the work space E after translation of the structural element $B(x)$. If the structural element $B(x)$ is used to apply dilation to the work space E, the result is the set consisting of all non-null set points of the structural element B included in the work space E after translation of the structural element B. Select the linear structure factor with the length of 3 pixel points and the angle of 90°, apply erosion and dilation operation to the left visual edge image D_{z1} and the right visual edge image D_{y1}, during which one loop operation includes two erosion operations and one dilation operation, which lasts for 20 times.

With regard to the image which has completed the loop erosion and dilation operation, measure the area and length of the area of the connected domain in the image, retain the line segment whose linear shape and area of the connected domain meet the threshold requirements, that is, the power line, remove the noise in the image, complete segmentation of the power line in the image and separately record the horizontal coordinate positions of $(x_{dz1}, x_{dz2} \ldots x_{dzj})$ and $(x_{dz1}, x_{dz2} \ldots x_{dzj})$ of the power line in the left visual edge image D_{z1} and the right visual edge image D_{y1}, where the left visual edge image D_{z1} and the right visual edge image D_{y1} separately contain *n*

power lines and record *j* horizontal coordinate positions.

(4) Use SURF algorithm to detect the feature points of the left visual edge image D_{z1} and the right visual edge image D_{y1}. To make the registration feature have scale invariance, key points of the image shall be detected in the scale space. In addition, SURF algorithm is to filter boxes of different sizes on the original image to form the image pyramid of different scales.

(41) Use the rapid Hessian detector to extract the feature points, and Hessian matrix has good computing time and precision performance. With regard to certain point, the Hessian matrix under scale can be defined as shown in the formula below, while with regard to certain point (x, y) in the left visual edge image D_{z1} and the right visual edge image D_{y1}, when the scale is σ, the Hessian matrix at the point shall be expressed as:

$$H(x,\sigma)=\begin{bmatrix} L_{xx}(x,\sigma) & L_{xy}(x,\sigma) \\ L_{xy}(x,\sigma) & L_{yy}(x,\sigma) \end{bmatrix}$$

Where, the function $L_{xx}(x,\sigma)$ refers to the second partial derivative of the Gaussian function on X-coordinate and the convolution of the left visual edge image D_{z1} and the right visual edge image D_{y1} at the point (x, y), and the formula is shown below:

$$L_{xx}(x,\sigma)=D*\frac{\partial^2}{\partial x^2}g(\sigma)$$

Description of $L_{xy}(x,\sigma)$ and $L_{yy}(x,\sigma)$ is separately shown in the formula below:

$$L_{xy}(x,\sigma) = D * \frac{\partial^2}{\partial x \partial y} g(\sigma)$$

$L_{yy}(x,\sigma) = D * \frac{\partial^2}{\partial y^2} g(\sigma)$, ∂ refers to the operation to obtain the partial derivative,

Where, the scale space of SURF algorithm is divided by group, images in each group are obtained after convolution of filters of different sizes, and the filter size will gradually increase. Assuming that the size is $N \times N$, and the corresponding size is $\sigma = 1.2 \times N / 9$. In addition, the sizes of filters in different groups in the scale space are shown in Figure 4, where horizontal coordinate stands for the changes in filter size while vertical coordinate stands for different groups.

To make the algorithm have the feature of invariant direction, SURF algorithm will re-specify the only direction for each interest point according to the information about the pixel point around the feature points, and the specific steps are as follows:

a) Take feature points as center to calculate the horizontal and vertical responses of Harr wavelet in the circular field with a radius of 6σ, of which the sampling step length is σ and the wavelet size is 4σ;

b) Take feature points as center to apply Gaussian weighting (2σ) to wavelet response, so that the weight value close to the feature point is large and that away from the feature point is small, and the new horizontal and vertical responses are obtained;

c) Finally, use a fan-shaped window with an angle of 60° to traverse the entire circle until the total response within the fan-shaped window is the strongest, at this

time the direction within the fan-shaped window is the principal direction of the interest point.

(42) Set the feature point as the central point and construct a box with the size of 20σ along the principal direction of the central point, then divide the region into 16 small regions, calculate the wavelet response within each subregion ($5\sigma \times 5\sigma$) and obtain the direction of $0°$ and the vector $\sum dx$, direction of $90°$ and the vector $\sum dy$, direction of $180°$ and the vector $\sum d|x|$ and direction of $180°$ and the vector $\sum d|y|$, and then construct the 4D feature vector $v = (\sum dx, \sum |dx|, \sum dy, \sum |dy|)$ to express each subregion, and finally form the 64D descriptor of the point.

Assuming that the size of the left visual edge image D_{z1} and the right visual edge image D_{y1} are both M×N, and the images are placed horizontally at the same coordinate axis to form the image with the size of $M \times 2N$, and the matching of feature points in the left edge image and the right visual edge image are shown in Figure 6. In addition, the set of feature points of the left visual edge image D_{z1} and the right visual edge image D_{y1} detected by the SURF method can be expressed as:

$$Pos1 = \{(x_1^{'}, y_1^{'}), (x_2^{'}, y_2^{'}), ..., (x_p^{'}, y_p^{'})\}$$

$$Pos2 = \{(x_1, y_1), (x_2, y_2), ..., (x_q, y_q)\},$$

Where, *p* and *q* separately refer to the number of feature points of the left visual edge image D_{z1} and the right visual edge image D_{y1}; according to to the priori knowledge about the consistency of slope direction between the final correct matching points, the steps of the matching methods of the feature points of this

invention are as follows:

a) With regard to each point i in the feature point set $Pos1$ of the left visual edge image, calculate the Euclidean distance of it from all points in the feature point set $Pos2$ of the right visual edge image, and select the corresponding point of the minimum Euclidean distance as the rough matching point of Point i;

b) Calculate the Euclidean distance of all rough matching point pair, sort the matching point pairs by the Euclidean distance in ascending order and delete the point pair with multiple points towards one point, at this time the feature points in the left visual edge image D_{z1} and the right visual edge image D_{y1} can be separately expressed as the feature point set $Pos1'$ of the fixed left visual edge image and the feature point set $Pos2'$ of the fixed right visual edge image;

c) Select the first K_1 pairs of matching points in the feature point set $Pos1'$ of the fixed left visual edge image and the feature point set $Pos2'$ of the fixed right visual edge image to express as

$Pos_K_1 = \{\{(x_1', y_1'), (x_1, y_1)\}, \{(x_2', y_2'), (x_2, y_2)\}, ..., \{(x_n', y_n'), (x_n, y_n)\}\}$, which is called Set 1;

Select the first K_2 pairs of matching points in the feature point set $Pos1'$ of the fixed left visual edge image and the feature point set $Pos2'$ of the fixed right visual edge image to express as Pos_K_2, where $Pos_K_2 = \{\{(x_1', y_1'), (x_1, y_1)\}, \{(x_2', y_2'), (x_2, y_2)\}, ..., \{(x_{K_2}', y_{K_2}'), (x_{K_2}, y_{K_2})\}\}$, is called as Set 2, where $K_1 < K_2$;

With regard to all the point pairs in Set 2, calculate the slope between two points

as shown in the formula below, and round it to form Slope Set $k: k = \{k_1, k_2, ..., k_w\}$,

$$k_w = \frac{y_w}{x_w - x_w^{'}}, 1 \le w \le K_2 \text{;}$$

e) Calculate the frequency of each slope in Slope Set k, screen the slope with the frequency of greater than and equal to 2 to form a new set $k_new = \{k_1, k_2, ..., k_t\}$, where *t* refers to the total quantity of feature points obtained; if the frequency of each slop in Slope Set k is 1, select the slope of the first $2K_2/3$ pairs of points to form a new set k_new;

f) Traverse and calculate the slope of all point pairs in the feature point set $Pos1^{'}$ of the fixed left visual edge image and the feature point set $Pos2^{'}$ of the fixed right visual edge image, and screen all the point pairs with the slope falling between the interval of $[k_t - 0.5, k_t + 0.5]$ to form the point pair set

$Pos_K_3 = \{\{(x_{z1}, y_{z1}), (x_{y1}, y_{y1})\}, \{(x_{z2}, y_{z2}), (x_{y2}, y_{y2})\}, ..., \{(x_{zn}, y_{zn}), (x_{yn}, y_{yn})\}\}$, where $k_t \in k_new$;

(5)The binocular visual imaging principle is as shown in Figure 5, the known focal length of the binocular visual camera is $b = 120mm$ and the known focal length of the camera is f ($400mm \le f \le 1000mm$), and the parallax d is defined as the position difference of certain point between the corresponding points in two images:

$$d = (x_{zn} - x_{yn})$$

Where, x_{zn}、x_{yn} separately refer to the horizontal coordinates of the matching point in the left visual image and right visual image, so as to calculate the space coordinates of certain point *P* in the left camera coordinate system as:

$$\begin{cases} x^c = \dfrac{b \cdot x_{zn}}{d} \\ y^c = \dfrac{b \cdot y_{zn}}{d} \\ z^c = \dfrac{b \cdot f}{d} \end{cases}$$

Where, (x^c, y^c, z^c) is the position information about the current matching point in the space coordinate and y_{zn} is the vertical coordinate of the matching point in the left and right visual images. Calculate the coordinates of all matching points in the left camera coordinate system according to the formula above, and then calculate the space coordinate of the point on the power line with the minimum Euclidean distance from the space of the matching point according to the formula above and the obtained horizontal coordinate positions of the power line $(x_{dz1}, x_{dz2} \ldots x_{dzn})$ and $(x_{dy1}, x_{dy2} \ldots x_{dyn})$; where the points defined on the 2D coordinate system with the same vertical coordinate have the minimum Euclidean distance from the space of the matching point, then directly give the vertical coordinate of the matching point to the corresponding point on the power line to form a corresponding point of the power line $Pos_D = \{\{(x_{dz1}, y_{z1}), (x_{dy1}, y_{y1})\}, \{(x_{dz2}, y_{z2}), (x_{dy2}, y_{y2})\}, \ldots, \{(x_{dzn}, y_{zn}), (x_{dyn}, y_{yn})\}\}$ with the point pair set $Pos_K_3 = \{\{(x_{z1}, y_{z1}), (x_{y1}, y_{y1})\}, \{(x_{z2}, y_{z2}), (x_{y2}, y_{y2})\}, \ldots, \{(x_{zn}, y_{zn}), (x_{yn}, y_{yn})\}\}$, thus to calculate the space coordinate (x^d, y^d, z^d) of certain point *D* on the power line in the left camera coordinate system;

(6) Calculate the Euclidean distance *J* of the matching point from the space of the power line after the space coordinates of Point *P* and Point *D* are obtained, and *J* is defined as

$$J = \sqrt{(x^c - x^d)^2 + (y^c - y^d)^2 + (z^c - z^d)^2}$$

Calculate the Euclidean distance of all matching points in the current frame of image from the space of the power line in sequence and compare with the predetermined distance empirical threshold. If *J* is greater than the threshold, complete the annotation of the point in the left visual image, complete feedback of

the information about the obstacle which poses a threat to the power line, back feed the specific information about the obstacle on the computer software interface, record the obstacle detection time and geographical location. When the space vertical distance between the matching point and the power line is lower than the given threshold, the current matching point shall not be processed and the same treatment shall be applied to all matching points in the current frame image. In addition, process the frames of images in the sequence frame image in all videos in sequence and complete record of the obstacle annotation and information in the inspection process.

1. As an UAV inspection method for power line based on human visual system, it has such characteristics and includes the following steps:

(1) UAV video capture: UAV armed with binocular visual measuring equipment is used to obtain the video image of distribution of the power line and the environmental information about the power line;

(2) The image preprocessing module grabs the frame of the video image sequence of the power line input system and preprocess the current frame of image, including graying processing of image and DoG edge detection; the DoG edge detection as described uses the DoG results of different parameters to describe the image edge and applies the same treatment to the left visual image and right visual image in sequence;

(3) The power line detection module uses the mathematical morphology to deal with the image that has been preprocessed, selects the structural factors in the same direction as the power line to provide the image with repeated expansion and corrosion treatment to remove the noise in the image, and then uses the human visual connected domain attention mechanism to select the largest linear connected domain to complete segmentation of the power line in image;

Separately record the horizontal coordinate positions ($x_{dz1}, x_{dz2}...x_{dzj}$) and ($x_{dy1}, x_{dy2}...x_{dyj}$) of the power line in left visual image and right visual image; where $x_{dz1}, x_{dz2}...x_{dzj}$ and $x_{dy1}, x_{dy2}...x_{dyj}$ separately refer to the horizontal coordinate of the central point in the left visual image and right visual image of the connected domain of *j* power lines;

(4) The binocular image registration module provides registration for the left visual image and right visual image separately and uses SURF algorithm to find the

feature points of the left and right visual edge images which have been preprocessed and obtain the descriptor of the current feature point, then provides exact match of the feature points and record the location information of the exact matching point in left and right visual images （x_{z1}, y_{z1}）~（x_{y1}, y_{y1}）,（x_{z2}, y_{z2}）~（x_{y2}, y_{y2}）...（x_{zn}, y_{zn}）~（x_{yn}, y_{yn}）, of which *n* refers to the number of all feature points included in single image, x_{zn}, y_{zn} and x_{yn}, y_{yn} refer to the position coordinates of corresponding features points in the left and right visual images, respectively;

(5) The obstacle detection and early warning module, based on the horizontal coordination position of the power line in left and right visual images ($x_{dz1}, x_{dz2}...x_{dzj}$), ($x_{dy1}, x_{dy2}...x_{dyj}$) and locations of exact matching points in left and right visual images (x_{z1}, y_{z1})~(x_{y1}, y_{y1}), (x_{z2}, y_{z2})~(x_{y2}, y_{y2})...(x_{zn}, y_{zn})~(x_{yn}, y_{yn}), uses the binocular visual principle to calculate the three-dimensional space coordinates of the matching point and the power line, and calculate the vertical distance from the matching point to the power line according to the space coordinate information;

(6) The result output and feedback module back feeds the obstacle information which threatens the power line. When the space vertical distance between the matching point and the power line is lower than the given threshold, back feed concrete information about the obstacle on the computer software interface and record the obstacle detection time and geographical location. When the space vertical distance between the matching point and the power line is higher than the given threshold, the current matching point shall not be processed and the same treatment shall be applied to all matching points in the current frame image. In addition, back feed the obstacle information about the frame images obtained in sequence to complete record of the obstacle information in the inspection process.

2. According to the UAV inspection method of the power line based on human visual system as stated in Claim 1, the characteristics are as follows: In Step (1) as described, the binocular visual measuring equipment as described refers to two video

image capture equipment with the same specifications and parameters, which are arranged in the left and right visual forms separately and acquire video image information at a fixed angle of view;

When the UAV armed with binocular visual measuring equipment is used for power line inspection, wireless remote control shall be applied to the UAV, so that the UAV can have uniform rectilinear movements on the path in parallel with the power line and above the power line, and the distribution direction of the power line in the capture video image sequence is in parallel with the flight direction of the UAV;

The power line video image captured includes the left video sequence l_z and right video sequence l_y, and stores the data of the left video sequence l_z and the right video sequence l_y in a storage device installed on the UAV, which shall be transmitted to the image preprocessing module of the software system via the mobile wireless network.

3. According to the UAV inspection method of the power line based on human visual system as stated in Claim 1, the characteristics are as follows: In Step (2) as described, the image preprocessing module processes the left video sequence l_z and the right video sequence l_y, which first grabs the frame continuously from the left video sequence l_z and the right video sequence l_y separately at a certain interval, which requires that all frame images can be pieced together to recover the complete inspection image information and there is no information gap when adjacent frames are pieced together, so as to form the left image sequence T_z and right image sequence T_y, of which the left image sequence T_z and right image sequence T_y contain *m* frames of images, separately are $T_{z1}, T_{z2} ... T_{zm}$ and $T_{y1}, T_{y2} ... T_{ym}$; preprocess the corresponding frames of left and right visual images, and first process the first frame of left visual image T_{z1} and right visual image T_{y1}, and then process the corresponding frame of the left and right visual images in sequence until the end of processing of *m* frame of left visual image T_{zm} and *m* frame of left visual image T_{ym}.

4. According to the UAV inspection method of the power line based on human

visual system as stated in Claim 3, the characteristics are as follows: Preprocess the first frame of left visual image T_{z1} and the first image of right visual image T_{y1}, including image grayscale processing and DoG edge detection:

Grayscale processing of the said image turns color image into the single-channel grayscale image H_{z1} of the first left visual image and the single-channel grayscale image of the first right visual image H_{y1};

In the said DoG edge detection, DoG operation was defined as:

$$D = \frac{1}{2\pi}\left[\frac{1}{\sigma_1^2}e^{-\frac{(x^2+y^2)}{2\sigma_1^2}} - \frac{1}{\sigma_2^2}e^{-\frac{(x^2+y^2)}{2\sigma_2^2}}\right] * H$$
$$= [G(x,y,\sigma_1) - G(x,y,\sigma_2)] * H$$

Where, D refers to the image result after processing, σ_1 is the first constant while σ_2 is the second constant, x and y separately refer to the horizontal and vertical coordinates of the current pixel point in the image, $G(x,y,\sigma_1)$ and $G(x,y,\sigma_2)$ separately refer to the Gaussian filter function of different parameters, H refers to the grayscale image, "*" refers to treatment of moving filter toward the whole frame of image, and the preprocessed images separately are the left visual edge image D_{z1} and the right visual edge image D_{y1}.

5. According to the UAV inspection method of the power line based on human visual system as stated in Claim 4, the characteristics are as follows: In the said Step (3), segment the power line in the left visual edge image D_{z1} and the right visual edge image D_{y1}, $B(x)$ refers to structural element, and erosion and dilation operation of each point $A(x,y)$ in the work space E can be defined as:

$$\text{Erosion: } X = E \otimes B = \{A(x,y) : B(x) \subset E\}$$

$$\text{Dilation: } Y = E \oplus B = \{A(x,y) : B(y) \cap E \neq \Phi\}$$

Where, $\subset$ stands for "included in", $\cap$ stands for "intersection operation" and Φ stands for null set. If the structural element $B(x)$ is used to apply erosion to the work space E, the result is the set consisting of all points of the structural element

$B(x)$ included in the work space E after translation of the structural element $B(x)$. If the structural element $B(x)$ is used to apply dilation to the work space E, the result is the set consisting of all non-null set points of the structural element B included in the work space E after translation of the structural element B.

6. According to the UAV inspection method of the power line based on human visual system as stated in Claim 5, the characteristics are as follows: Select the linear structure factor with the length of 3 pixel points and the angle of 90°, apply erosion and dilation operation to the left visual edge image D_{z1} and the right visual edge image D_{y1}, during which one loop operation includes two erosion operations and one dilation operation, which lasts for 20 times.

7. According to the UAV inspection method of the power line based on human visual system as stated in Claim 5, the characteristics are as follows: With regard to the image which has completed the loop erosion and dilation operation, measure the area and length of the area of the connected domain in the image, retain the line segment whose linear shape and area of the connected domain meet the threshold requirements, that is, the power line, remove the noise in the image, complete segmentation of the power line in the image and separately record the horizontal coordinate positions of $(x_{dz1}, x_{dz2}...x_{dzj})$ and $(x_{dz1}, x_{dz2}...x_{dzj})$ of the power line in the left visual edge image D_{z1} and the right visual edge image D_{y1}, where the left visual edge image D_{z1} and the right visual edge image D_{y1} separately contain *j* power lines and record *j* horizontal coordinate positions.

8. According to the UAV inspection method of the power line based on human visual system as stated in Claim 5, the characteristics are as follows: In the said Step (4), use SURF algorithm to detect the feature points of the left visual edge image D_{z1} and the right visual edge image D_{y1}, and the specific steps are as follows:

(41) Use the rapid Hessian detector to extract the feature points, with regard to

certain point in the left visual edge image D_{z1} and the right visual edge image D_{y1}, when the scale is σ, the Hessian matrix at the point shall be expressed as:

$$H(x,\sigma)=\begin{bmatrix} L_{xx}(x,\sigma) & L_{xy}(x,\sigma) \\ L_{xy}(x,\sigma) & L_{yy}(x,\sigma) \end{bmatrix}$$

Where, the function $L_{xx}(x,\sigma)$ refers to the second partial derivative of the Gaussian function on X-coordinate and the convolution of the left visual edge image D_{z1} and the right visual edge image D_{y1} at the point (x,y), and the formula is shown below:

$$L_{xx}(x,\sigma)=D*\frac{\partial^2}{\partial x^2}g(\sigma)$$

Description of $L_{xy}(x,\sigma)$ and $L_{yy}(x,\sigma)$ is separately shown in the formula below:

$$L_{xy}(x,\sigma)=D*\frac{\partial^2}{\partial x\partial y}g(\sigma)$$

$L_{yy}(x,\sigma)=D*\frac{\partial^2}{\partial y^2}g(\sigma)$, ∂ refers to the operation to obtain the partial derivative,

Where, the scale space of SURF algorithm is divided by group, images in each group are obtained after convolution of filters of different sizes, and the filter size will gradually increase;

(42) Set the feature point as the central point and construct a box with the size of 20σ along the principal direction of the central point, then divide the region into 16 small regions, calculate the wavelet response within each subregion ($5\sigma\times5\sigma$) and obtain the direction of $0°$ and the vector $\sum dx$, direction of $90°$ and the vector $\sum dy$,

direction of $180°$ and the vector $\sum d|x|$ and direction of $180°$ and the vector $\sum d|y|$, and then construct the 4D feature vector $v=(\sum dx,\sum|dx|,\sum dy,\sum|dy|)$ to express each subregion, and finally form the 64D descriptor of the point;

Assuming that the size of the left visual edge image D_{z1} and the right visual edge image D_{y1} are both $M\times N$, and the images are placed horizontally at the same coordinate axis to form the image with the size of $M\times 2N$, and the set of feature points of the left visual edge image D_{z1} and the right visual edge image D_{y1} detected by the SURF method can be expressed as:

$$Pos1=\{(x_1^{'},y_1^{'}),(x_2^{'},y_2^{'}),...,(x_p^{'},y_p^{'})\}$$

$$Pos2=\{(x_1,y_1),(x_2,y_2),...,(x_q,y_q)\},$$

Where, p and q separately refer to the number of feature points of the left visual edge image D_{z1} and the right visual edge image D_{y1};

Feature point matching method includes the following steps:

a) With regard to each point i in the feature point set $Pos1$ of the left visual edge image, calculate the Euclidean distance of it from all points in the feature point set $Pos2$ of the right visual edge image, and select the corresponding point of the minimum Euclidean distance as the rough matching point of Point i;

b) Calculate the Euclidean distance of all rough matching point pair, sort the matching point pairs by the Euclidean distance in ascending order and delete the point pair with multiple points towards one point, at this time the feature points in the left visual edge image D_{z1} and the right visual edge image D_{y1} can be separately expressed as the feature point set $Pos1^{'}$ of the fixed left visual edge image and the

feature point set $Pos2'$ of the fixed right visual edge image;

c) Select the first K_1 pairs of matching points in the feature point set $Pos1'$ of the fixed left visual edge image and the feature point set $Pos2'$ of the fixed right visual edge image to express as

$Pos_K_1 = \{\{(x_1', y_1'), (x_1, y_1)\}, \{(x_2', y_2'), (x_2, y_2)\}, ..., \{(x_n', y_n'), (x_n, y_n)\}\}$, which is called Set 1;

Select the first K_2 pairs of matching points in the feature point set $Pos1'$ of the fixed left visual edge image and the feature point set $Pos2'$ of the fixed right visual edge image to express as Pos_K_2, where

$Pos_K_2 = \{\{(x_1', y_1'), (x_1, y_1)\}, \{(x_2', y_2'), (x_2, y_2)\}, ..., \{(x_{K_2}', y_{K_2}'), (x_{K_2}, y_{K_2})\}\}$, is called as Set 2, where $K_1 < K_2$;

d) With regard to all the point pairs in Set 2, calculate the slope between two points as shown in the formula below, and round it to form Slope Set $k : k = \{k_1, k_2, ..., k_w\}$,

$$k_w = \frac{y_w}{x_w - x_w'}, 1 \le w \le K_2;$$

e) Calculate the frequency of each slope in Slope Set k, screen the slope with the frequency of greater than and equal to 2 to form a new set $k_new = \{k_1, k_2, ..., k_t\}$, where *t* refers to the total quantity of feature points obtained; if the frequency of each slop in Slope Set k is 1, select the slope of the first $2K_2/3$ pairs of points to form a new set k_new;

f) Traverse and calculate the slope of all point pairs in the feature point set $Pos1'$ of the fixed left visual edge image and the feature point set $Pos2'$ of the fixed

right visual edge image, and screen all the point pairs with the slope falling between the interval of $[k_t - 0.5, k_t + 0.5]$ to form the point pair set

$Pos_K_3 = \{\{(x_{z1}, y_{z1}), (x_{y1}, y_{y1})\}, \{(x_{z2}, y_{z2}), (x_{y2}, y_{y2})\}, ..., \{(x_{zn}, y_{zn}), (x_{yn}, y_{yn})\}\}$, where $k_t \in k_new$.

9. According to the UAV inspection method of the power line based on human visual system as stated in Claim 8, the characteristics are as follows: In the said Step 41), SURF algorithm re-specifies the only direction for each interest point according to the information about the pixel point around the feature points, and the specific steps are as follows:

a) Take feature points as center to calculate the horizontal and vertical responses of Harr wavelet in the circular field with a radius of 6σ, of which the sampling step length is σ and the wavelet size is 4σ;

b) Take feature points as center to apply Gaussian weighting to wavelet response, so that the weight value close to the feature point is large and that away from the feature point is small, and the new horizontal and vertical responses are obtained;

c) Finally, use a fan-shaped window with an angle of 60° to traverse the entire circle until the total response within the fan-shaped window is the strongest, at this time the direction within the fan-shaped window is the principal direction of the interest point.

10. According to the UAV inspection method of the power line based on human visual system as stated in Claim 8, the characteristics are as follows: In the said Step

(5), the parallax range between binocular visual cameras is b, the known focal length of camera is f and parallax d is defined as the position difference of certain point between the corresponding points in two images;

$$d = (x_{zn} - x_{yn})$$

Where, x_{zn}、x_{yn} separately refer to the horizontal coordinates of the matching point in the left visual image and right visual image, so as to calculate the space coordinates of certain point *P* in the left camera coordinate system as:

$$\begin{cases} x^c = \dfrac{b \cdot x_{zn}}{d} \\ y^c = \dfrac{b \cdot y_{zn}}{d} \\ z^c = \dfrac{b \cdot f}{d} \end{cases}$$

Where, (x^c, y^c, z^c) is the position information about the current matching point in the space coordinate and y_{zn} is the vertical coordinate of the matching point in the left and right visual images. Calculate the coordinates of all matching points in the left camera coordinate system according to the formula above, and then calculate the space coordinate of the point on the power line with the minimum Euclidean distance from the space of the matching point according to the formula above and the obtained horizontal coordinate positions of the power line $(x_{dz1}, x_{dz2} ... x_{dzn})$ and $(x_{dy1}, x_{dy2} ... x_{dyn})$; where the points defined on the 2D coordinate system with the same vertical coordinate have the minimum Euclidean distance from the space of the matching point, then directly give the vertical coordinate of the matching point to the corresponding point on the power line to form a corresponding point of the power line $Pos_D = \{\{(x_{dz1}, y_{z1}), (x_{dy1}, y_{y1})\}, \{(x_{dz2}, y_{z2}), (x_{dy2}, y_{y2})\}, ..., \{(x_{dzn}, y_{zn}), (x_{dyn}, y_{yn})\}\}$ with the point pair set $Pos_K_3 = \{\{(x_{z1}, y_{z1}), (x_{y1}, y_{y1})\}, \{(x_{z2}, y_{z2}), (x_{y2}, y_{y2})\}, ..., \{(x_{zn}, y_{zn}), (x_{yn}, y_{yn})\}\}$, thus to calculate the space coordinate (x^d, y^d, z^d) of certain point *D* on the power line in the left camera coordinate system.

11. According to the UAV inspection method of the power line based on human visual system as stated in Claim 10, the characteristics are as follows: In the said Step (6), calculate the Euclidean distance *J* of the matching point from the space of the power line after the space coordinates of Point *P* and Point *D* are obtained, and *J* is defined as:

$$J = \sqrt{(x^c - x^d)^2 + (y^c - y^d)^2 + (z^c - z^d)^2} \quad .$$