SIFT ALGORITHM BASED REAL-TIME POWER SYSTEM INSPECTION BY USING UNMANNED AERIAL VEHICLES

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science, with a major in Electrical Engineering.

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This research presented a novel method for transmission and distribution lines inspection. Power lines inspection can guarantee the performance of power system stability and increase the lifetime of power lines. An advanced power lines inspection can prevent massive power outages due to line failures, which is still one of the major challenges in modern power system. Traditional method is using human squads to perform inspections. Due to the remoted locations of power lines and various geographical conditions, it is not the most efficient solution by dispatching human squads. Another popular method is using helicopters to inspect power lines, which is costly and there are limitations due to weather conditions. In this research, a combination of Scale Invariant Feature Transform (SIFT) algorithm and Unmanned Aerial Vehicles (UAVs) power lines real-time inspection system is presented. SIFT algorithm is widely used in object recognition, and it can help UAVs to reduce the vibration problems due to wind or other weather issues, while videoing power lines. The advantage of SIFT method of being invariant to image translation, scaling and rotation has been fully implemented in the proposed work. The video is processing to ground station and the final inspection analysis is performed frame by frame to locate or to recognize potential unhealthy power lines.
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CHAPTER 1

INTRODUCTION

1.1 Background

The amount of energy consummation can be used to measure how developed an area of a country is. For electrical energy, it connected with modern industry tightly. Electrical energy has participated in every single area of people’s life. Conventionally, Electrical power was generated by coal generators, gas generators, or turbine generators in power plants. Due to carbon oxide emission, noisy, and other environment impacts, power plants are built in locations which is sparsely populated areas. To transmit electrical power to consumers, transmission lines are being used. To increase the efficiency of transition, step up transformers are taken in places to increase voltage level. After using step up transformers to increase voltage level, electrical power has been transmitted to substations through transmission power lines. Substations are located closely to urban area. In order to prevent the health and living quality of civilization is impacted by high level voltage, substations have been used for decreasing voltage to distribution level. Because of that, electrical energy can be transmitted through distribution lines. Using step down transformers to decrease voltage level to customer usable level to supply customers’ need. Figure below can illustrate this process [1].
For fulfill the goal of transmitting power from power plants to consumers, power lines must across long distance. As a result of that, power lines have a great chance to face a lot of natural or manmade disturbances. Such as lines acing, tree limbs caused line to ground fault, and power lines or insulators aging.

1.2 Motivation

North American electricity system is one of the great engineering achievement of past 100 years. This electricity infrastructure represents more than one trillion US dollar in asset value, more than 200,000 miles of transmission lines operating at 230,000 volts and greater,
950,000 megawatts of generating capability, and nearly 3,500 utility organizations serving well over 100 million customers and 283 million people [2]. In Aug 2003, There was a blackout happened in United States. There are nearly 8 million people in Canada and 45 million people in 8 states in the US are impacted. It started with tree limbs touched power lines caused transmission lines overloaded. At meantime, there was a software bug in alarm system. Combined with these two main reasons, this disaster happened. After this disaster, power lines inspection is mandatory [2]. For a large system such as north American electricity system, prevent large scale blackouts and maintain system stable are especially important. Figure below can show a summary of cascading outages and related consequences [3].
Fig 1.2.1: Summary of Cascading Outages and Related Consequences

Even though, the frequencies of large scale blackouts are not much, the total number of people are impacted by these outages are huge. The economic impacted due to these blackout is enormous. Based on that, power system protection plays an important role in electric power industry. Power lines inspection is part of power system protection scheme. Power lines inspection plays an important role in maintaining power system reliability. It can also increase lifetime of power lines or other equipment served in power system. It can increase the capabilities of transmission. It can ensure employees of utilities and public safety
as well. There are four wildly used methodologies for inspecting power lines. First one is foot patrol power lines inspection. Usually a team of two people walk from pylon to pylon and inspect the power line. They use their bare eyes or with the help of binoculars, infrared cameras, and corona detection cameras [5]. The benefits of this inspection is highly accurate, and only the surface of power lines are inspected [4]. This method is limited by stamina of inspectors and the accessibility of this method is also limited by terrain. National terrain is not easy for inspectors finished easily. Due these issuers, foot patrol method is slow, tedious, monotonous and subjective, therefore larger defects can sometimes overlooked [4].

Second method is manned aerial vehicles. Normally helicopters are used to assist human inspector to do inspection. Helicopters are hovering along power lines and inspectors use binoculars or other inspection tools to do inspection. Recorder in the team recording abnormal situation at that specific location. The limitation of terrain can be ignored due to high accessibility of manned aerial vehicles. This method can increase the speed of inspection, however, the cost of power lines inspection is increased as well. The use of manned aerial vehicles should be rented in quick inspection of large networks or in places where the accessibility by foot patrol inspectors present difficulties [4]. Based on reviewed [38], The price to do inspection using helicopters over a transmission line are 17.33 dollars per mile and There are 300 miles can be finished by one day. As introduced before, there are total 200,000 miles of transmission lines operated in North American electrical power system. Based on the calculation, if using this method to do inspection, the task will be finished in 1000 days and it is approximately 3 years. The cost of that is roughly three hundred and forty-six million dollars. For rural subtransmission lines, the price for inspecting one mile are
26 dollars and there are 200 miles of rural subtransmission lines can be finished a day. For Urban subtransmission lines, the price of inspecting one mile is 34.67 dollars and 150 miles of urban subtransmission lines can be finished per day. For rural distribution lines, the price for inspecting one mile of this type lines are 29.71 dollars and there are 175 miles of rural distribution lines can be finished a day. There are research works about this method, by reviewing literatures [6], [7] and [8], they are concentrating on the sensor fusion. Although manned aerial vehicles can increase the efficiency of power lines inspection, the cost of power lines inspection by applied this method is increased as well. This method endangers the human life as well. Because of these disadvantages, climbing robots and unmanned aerial vehicles are becoming hot topic for power lines inspection research.

Third method is climbing robots power lines inspection. Mobile robot can move along the conductor and conquer the obstacles such as crossarms. The advantage of this method is accuracy since climbing robots are close to power lines. One of main difficulties of this method is harmful electromagnetic field which is generated by high voltage power lines. Since the distance between climbing robots and power lines are proximity, sensors embedded in inside climbing robots are easily impacted by this harmful electromagnetic field. It is pretty hard to prevent sensors from getting harmed by electromagnetic filed generated by power lines with economic concerned. The measurement accuracy of these sensors are reduced [9], [10], and [11]. The image below can show an example of climbing robot inspection [12].
The forth method is unmanned aerial vehicles power lines inspection. This method can both reduce the risk to personal and decrease the cost. Both speed and accessibility are increased. The function of unmanned aerial vehicles is similar to helicopter. Both of them shared same problems such as camera stabilization, pole tracking and automatic defect detection [4]. Based on evaluation from [13], unmanned aerial vehicles power lines inspection is faster than foot patrol inspection. On the other hand, the accuracy of unmanned aerial vehicles can reach same level or even better than foot patrol power lines inspection. The problem of detection and tacking of power lines in complex environments is presented in [14], where a Kalman filter is used to track power lines in the Hough space, based on the continuity of a video sequence. An unmanned aerial vehicles TERCOM (terrain contour match) method of multiple route path terrain matching based on 2D plane laser radar is announced [15]. These papers mentioned only about how to make sure unmanned aerial vehicles are proximity to power lines. They did not mention how to diagnosis abnormal situation about power lines and status of power lines. In [16], a novel airborne craft carried with multiple sensors is published. The AggieAir-TIR remote sensing platform is a foam
glider carried a thermal infrared (TIR) sensor to do a fast power lines inspection. Thermal infrared sensor can recognize abnormal situations based on hotspots found. The disadvantages of this method is that foam gliders cannot inspect power lines in detail since flying function of glider have significant difference compared with drones, which means it cannot hover at a stable location.

1.3 Thesis outlines

In this thesis, a novel power lines inspection method has been introduced. There are five chapters in this thesis. First chapter was introduction. In that chapter, there are four power lines inspection methodologies have been introduced. Second chapter is literature review. In that chapter, there are three papers, which constrained inspiring ideas, are summarized. Third chapter introduced scale invariant feature transform which is main algorithm has been used in this work. There are four parts in that chapter. First one is extract scale-space extama. Second one is low contrast rejection and edge rejection. Third part is orientation assignment. The last part is keyppoint descriptor. Fourth chapter introduced simulated experiment procedure and also displayed experiment results. The last part is conclusion and future works.
CHAPTER 2

LITERATURE REVIEW

In this chapter, some pattern recognition methods and power lines inspection procedure have been introduced.

2.1 Hough Transformation

Hough transform is a feature extraction method which is extensively used in pattern recognition, image analysis, digital image processing, and computer vision. It has been used for isolating features of different shapes in an image. It was conventionally that Hough transform was used to detect typical curves, for instance, lines, circles, and ellipses.

Hough transform was first claimed by Hough in 1959 in [17]. In 1962, Hough transform had been announced as U.S. Patent 3,069,654 [18]. It was improved by Duda, R.O and P.E. Hart in [19], the well-known and extensively used rho-theta parametrization was explained [20].

Hough transform has unique advantage in finding lines within an image or edges detection. Hough transform has been approached in three steps. First step, applied edge detection for an input image and figures below results.
Second step, using result of output from edge detection to generate Hough accumulator matrix. In this step, each white pixel in edge detection result created a one-pixel sine wave in
Hough accumulator matrix. Third step, defined a threshold and compare this threshold with Hough accumulator matrix elements to find hot point. The figure below can show the result [23].

Fig 2.1.3: Result from Hough line detection. Red lines are detected results

Some road tracking or planning research applied Hough transformation [21]. For power lines inspection, Hough transform is not an ideal algorithm to apply. Although power lines are sufficient to recognize as lines, the background of power lines are complicated most times. Power lines are easily cluster in background [22].

2.2 Image histogram

In 2.1, Hough transform has been introduced. It is a good technique to apply when the background is not complicated. In this part, another image analysis method will be introduced.
Image histogram is one of histogram which can be used to represent digital image by separate tonal. Total numbers of pixel are plotted for each color. Researchers can figure out all tonal distribution by observing histograms [24]. Images below can show results [25].

Fig 2.2.1: Figure on the left is an image of sunflower, Image on the left is HoG of it

Histogram of image has been applied in power lines inspection. By studying [26], this paper introduced a method which used charged coupled device to do power lines monitoring. Histogram of graphic has been applied to analysis of these images. Because human eyes can be influenced by fatigue or emotional issues, using computer to judge whether power system in good condition or not is more reliable. The information contained within images are digitalized by image histogram, and use results of image histogram to train support vector machine to separate abnormal situations from normal situations. These two flow charts can illustrate main idea of that [26].
From reviewing this literature, this method has better performance to inspect power system equipment such as current transformers, voltage transformers, and arresters. Due to the thin lines structure of power lines, other tonal of images taken by charge couple devices will impact results. The pixels of power lines are easily clustered in background. Signal transmitted from charged couple devices to control center can be affected by intensive electromagnetic field which is generated by high level voltage. Compared with unmanned aerial vehicles, the accessibility and mobility are low. When the image of power system suffered extremely weather, charge coupled devices are easily distorted. In this scenario, cost of power lines maintenance increased.

2.3 Power lines detection with color and near-infrared images

In previous two parts, 2.1 and 2.2, two image analysis method have been introduced.
In this part, methodology of power lines detection with color and near-infrared images will be introduced. The aim of this methodology is to extract all potential information and reduce negatives impacts of abnormal situations. There are three steps for completed this method. First step of this methodology, consider power lines profiles in pixels from RGB and near-infrared images. Second step, filter the candidates with low reign-based intensity of special material characteristics in near-infrared images. Third step, validate the power lines according to the color features in RGB images. The flow chart below can illustrate how is object-aware of power lines based on image feature is defined and the working procedure can be illustrated in figure 7 [27].

Flow Chart 2.3.1: Object-aware definition of power line based on image feature illustration
Figure 2.3.2: Working procedure of power lines detecting system

By reviewing literature [27], simple line property of power lines is trivial and scattered because of the weak visual appearance of power lines’ small size and thin structure. As a result of that, line segments in the cluttered background can cause false alarm. For the aim of better performance in cluster background. Using both RGB image and near-infrared image as inputs. As a result of that, the computation time of power lines detection was slowed down in this method. It is 2s to detect a pair of 1024*650 RGB and near-infrared images.
CHAPTER 3

Scale Invariant Feature Transform

In this chapter, the main algorithm which has been applied to this research work will be introduced. Compare with those two image analysis method in chapter 2, scale invariant feature transform is more stable due to its special characteristics. Scale invariant feature transform is the main algorithm employed to assist to inspect power lines.

In 1999, Dr. D. Lowe firstly published Scale invariant feature transform [28]. Because of the wind or other environmental issues, the flight path of UAVs inspection is not perfectly stable. There are chances that UAVs might shake around the designed flight path. As a result of that, the pictures or videos obtained by RGB cameras or IR cameras will be added unintentional zoom-in or zoom out effects. SIFT algorithm is suitable for these situations. According to [28], SIFT can extract key features. Those key features are invariant to scale changes and rotation. The SIFT features can be extract in three steps.

3.1 Extract Scale-Space Extrama

SIFT image features are extracted by cascade filtering approach in scale space. Scale space is first claimed by Wikin in 1983. Scale space is a frame which allowed multi-scale signal representation [30]. The figures below are examples for same image in different scales.
The kernel is applied is Gaussian kernel, according to [31], it is the only possible kernel. Because of that, the image scale space can be defined as a function of $x$, $y$, and $\sigma$. It can be got from convoluting variable-scale Gaussians and input images. For example, input image is $I(x, y)$ and variable-scale Gaussian is $G(x, y, \sigma)$. The image scale space function is:

$$L(x,y,\sigma) = G(x,y,\sigma) \ast I(x,y)$$  \hspace{1cm} (3.1.1)

where $\ast$ is the convolution operator between $x$ and $y$. Gaussian function can be defined as:

$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}}$$  \hspace{1cm} (3.1.2)

where $\sigma$ is the number of octaves in scale space.
To find the stable key point locations, the method in [32] has been proved sufficient. The difference-of-Gaussian scale-space extrema, $D(x, y, \sigma)$, is calculated by the difference of smoothed images, $L(x, y, \sigma)$, in different scale spaces.

$$D(x,y,\sigma) = L(x,y,k\sigma) - L(x,y,\sigma)$$ \hspace{1cm} (3.1.3)

The figures below can illuminate how it works.

![Diagram](image)

**Fig 3.1.2:** Adjacent Gaussian images are subtracted to get Difference of Gaussian

The scale space extrema are maxima or minima points in their adjacent difference of Gaussian images. Compare with the selected point which is marked by “X” in the figure below, with its 26 neighboring points [32].
3.2 Low Contrast Rejection and Edge Rejection

After extracted scale-space extrama from DoG. The candidate points are not all suitable to be selected as key point. Some of them have low contrast. Points with low contrast is sensitive to noise. From [32], using Tylor expansion of difference of Gaussian function can be used to eliminated point with low contrast.

\[ D(x) = D + \frac{\partial D}{\partial x} x + \frac{1}{2} x^T \frac{\partial^2 D}{\partial x^2} x \]  

Equation three is the form of Tylor expansion of difference of Gaussian function. It was evaluated and derivated at the sample point. Its offset point is \( x = (x, y, \sigma)^T \). The location of maximum or minimum can be produced by taking derivative of the fourth Tylor expansion of difference of Gaussian function with respect to \( x \) and setting it to zero. The equation showed below [32]:

\[ \hat{x} = -\frac{\partial^2 D^{-1}}{\partial x^2} \frac{\partial D}{\partial x} \]  

Only reject candidate points with low contrast is not sufficient. The edges will impact the difference of Gaussian function easily. Based on [14], a poorly defined peak in the
difference of Gaussian function will have a large principal curvature across the edge but a small one in the perpendicular direction. Because of that, Hessian matrix is applied at the location and scale of key point.

Hessian matrix is a 2*2 matrix and it is computed at the location and scale of key point:

\[ H = \begin{bmatrix} D_{xx} & D_{xy} \\ D_{xy} & D_{yy} \end{bmatrix} \]  

(3.2.3)

Based on reviewed on [33], the eigenvalues of Hessian matrix is proportional to the principal curvatures of difference of Gaussian functions. In order to avoiding complicated calculation, only the ratio of eigenvalues was concerned. Assigned, \( \alpha \), as the largest magnitude, in the other hand, \( \beta \) was assigned as smaller one. By computing trace of Hessian matrix and determinant of Hessian matrix, the summation of \( \alpha \) and \( \beta \) can be found and production of \( \alpha \) and \( \beta \) can be found as well. The following equations can show this procedure:

\[ \text{Tr}(H) = D_{xx} + D_{xy} = \alpha + \beta \]  

(3.2.4)

\[ \text{Det}(H) = D_{xx}D_{xy} - (D_{xy})^2 = \alpha \beta \]  

(3.2.5)

From equation (3.2.4) and (3.2.5), ratio of eigenvalues can be found. The equations below can show the procedure and ratio was assigned as \( r \).

\[ \frac{\text{Tr}(H)^2}{\text{Det}(H)} = \frac{(\alpha + \beta)^2}{\alpha \beta} = \frac{(r+1)^2}{r} \]  

(3.2.6)

Based on these mathematical procedure, complicated calculation for eigenvalues is eliminated. Only make sure:

\[ \frac{\text{Tr}(H)^2}{\text{Det}(H)} < \frac{(r+1)^2}{r} \]  

(3.2.7)

Then, key point candidates on the edge can be filtrated [32].

3.3 Assign Orientation

To achieve invariance to image rotation, each qualified keypoint is assigned a consistent orientation. The orientation is based on local image properties. Compared with
previously work [34], scale invariant feature transform can generate more useable descriptors and accept image information by taking measurement based on a consistent rotation. To achieve most stable results, the method below has been employed. The keypoint’s scale is used to detect qualified Gaussian image, L. After this selection, all candidates are scale invariant. For each image L(x,y), the gradient magnitude, m(x,y), and orientation, θ (x,y), is precomputed using pixel differences:

\[
m(x, y) = \sqrt{(L(x + 1, y) - L(x - 1, y))^2 + ((L(x, y + 1) - L(x, y - 1))^2}
\]

\[
\theta(x, y) = \tan^{-1}\left(\frac{(L(x, y + 1) - L(x, y - 1))}{(L(x + 1, y) - L(x - 1, y))}\right)
\]

(3.3.1)

(3.3.2)

3.4 Keypoint Descriptor

In this paper, SIFT algorithm has been applied to analysis and diagnose abnormal situations. It has been used to recognized crossarm of poles as well. UAVs carried with RGB camera and IR camera monitors and records alone power lines. While the power lines are in good situation, the video recorded can be used as a reference. As the inspection system operating, the real-time video can be transmitted to ground station. The video recorded can be sampled by frames. Each frame is an images with time and geological position data. SIFT match algorithm is used to match sampled images with reference images.

SIFT descriptors are created by local gradient data of an image. The figure below can show the key descriptors [32].
Fig 3.4.1: Key point descriptors typically use a set of 16 histograms, aligned in a 4x4 grid, each with 8 orientation bins, one for each of the main compass directions and one for each of the mid-points of these directions. This results in a feature vector containing 128 elements.

SIFT match algorithm can be used to match key descriptors from different images. The key descriptors are extracted from each image by applying SIFT algorithm. Key descriptors are highly distinctive. When three or more keys agree on the model parameters this model is evident in the image with high probability [32].
CHAPTER 4

System Design and Experiment Results

4.1 System Design

In this chapter, scale invariant feature transform applied power lines inspection with assisted by unmanned aerial vehicles system will be introduced. The simulation experiment procedure and results are also presented in this part.

In this paper, some simulation experiments are involved. A Sony α6000 camera is used. It has 24MP quality [35]. FILR 2 IR camera is used as IR camera. IR sensor of that is 80*60 and total 4,800 measurement pixels. Thermal Sensitivity of that is less than 0.10 Celsius degree. The field of view is 41° * 31°. Minimum focus distance is 0.15 m for thermal. Image frequency is 9 Hz. The spectral range of that is 7.5-14 µm. It has auto orientation function [36]. Because of these special characteristic and cost-efficient. It has been selected. Images were taking in Wichita, Kansas. Matlab is the software has been used to simulate and do analysis.

Global geographical data is applied. The data extracted form google earth. An assigned route was given to the drone. The drone was assigned to flight along this given route. The figure below can show the route [37].
The drone can recognize the crossarm of poles. If there is not recognizable crossarm in 15 meters, then drones sent losing track signal to control center. The recognition is based on SIFT algorithm. The figures below showed matched results.

Fig 4.1.1: Location is at Wichita, KS

Fig 4.1.2: A matched example of crossarm, total 356 key points are matched
The experiment procedure is listed below. The input images collected from cameras named A and the reference images named B. First step, convert both A and B into grayscale images using Matlab embedded function. Second step, extract key descriptors and locations from both A and B. SIFT key descriptors are K-by-128 matrixes. Each row of those matrixes gives an invariant descriptor for one of the K key points. The descriptor is a vector of 128 values normalized to unit length. Locations are K-by-4 matrixes. Each element in each row of those matrixes represent row, column, scale, and orientation. The orientation is in the range of negative pi to positive pi. Third step, calculate the matched key points for a pair of images. For example, Image A (1) is an image from image set A and image B (1) is an image from image set B. The number inside parenthesis is index numbers. After the calculation of second step, there are n numbers of key points are found in image A (1) and there are m numbers of key points are found in image B (1). The key descriptor n (1) is a vector with 128 elements. Calculate the Euclidean distances between n (1) and m (1) to m (m). The m inside the parenthesis is the last key points. The pair of two key points is matched only if the smallest
Euclidean distance between these two vector is less than distratio times the distance to the second closet match. DistRatio is a threshold. In this paper, based one experiments, distRatio is selected as 0.75 to fit thin structural of power lines. Fourth step, repeat third steps for all key points of image A. Fifth step, display the lines connection between matched points and display the number of matched points. Last step, if the matched point is less than three, there will be an alarm. That part of power lines showed in the image need a further inspection. The mismatch image will be saved.

Experiment results displayed in next. These results include images took in the same places, images took in difference places, and images took to simulate drone’s shaking. Flow chart below can show this methodology as well.
4.2 Simulated Experiment Results

Experiment results displayed in next. These results include images took in the same places, images took in difference places, and images took to simulate drone’s shaking.

First experiment result simulated power lines are in good situation. Input images is an 850*477-pixels image. It taken by RGB camera. There are 349 key points found in that image. The matched key points are 349. The figure below can show the result. The image on
the left is input image and right one is considered as reference image.

Fig 4.2.1: First experiment result, all keypoints are matched

The second experiment simulated drone shaking situation 1. For a three phase power lines, because of shaking, experimental images zoomed into a smaller version. The image on the left is a 700*392-pixel image and the image on the left is an 850*392-pixel image. There are 379 key points are found in the left one and there 349 key points are found in the right one. There are 27 matched key points are found. The figure below can show the result.
The third experiment simulated another shaking situation of drone. When the drones zoomed the image into a bigger vision due to shake. The input image is a 1024*768-pixel image one the left and the reference one the right is an 850*477-pixel image. There 614 key points are found in the left image and there are 349 key points are found in the right image. The total matched points are 26. The figure below can show the result.
The fourth experiment simulated a fault condition. The experiment assumed an extremely environment. Three phase power lines are iced. The input image is an 850*478 pixel artificial simulated iced lines image. There are 544 key points are found in the left image and there are 349 key points are found in the right image. There are no matched key points are found. Figure below can show this example.

Fig 4.2.4: Fourth experiment result, there are no matched key points

This method can process with IR camera as well. IR camera can provide better results with images which background are clutter. If the input images are infrared images, then the reference image should be infrared images. The fifth experiment used infrared images as input. The input image is a 372*273-pixels image. There are 148 key points are found. The total found matched key points are 148. The figure 8 can illustrate results.
Fig 4.2.5: Experiment on IR image, there are 148 key points matched
CHAPTER 5
CONCLUSION

In this paper, explained how objective recognition algorithm applied in power line inspection by using unmanned aerial vehicles. Due to SFIT key points are invariant to scale changes, it is a suitable for UVAs monitoring applications to do practical tasks. UAVs monitoring is hard to maintain a stable position while hoovering or flying. Because of that, the images taken are easily zoomed in or zoomed out passively. In this approach, SIFT algorithm can match the power lines with in simulated UVAs shaking environment. SIFT algorithm can be also used to recognized the crossarm of poles or structure of pylon. This can help to track power lines and feed back to ground station whether flight route is correct.

From this approach, the outstanding advantages of SIFT algorithm in object recognition has been showed. Combined these advantages of SIFT algorithm with high speed, comparably cost-efficient UAVs, the SIFT applied power lines inspection can contribute to power system stability.

Future study can be carried in building database about failure or abnormal situations. The images which are not matched with reference can be used to save as examples of abnormal situations. Those saved images can be used to train machine learning model to improve efficiency of diagnosis.
REFERENCES
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