Abstract—Using aerial images captured by a web cam on board on an unmanned aerial vehicle (UAV) provides potential application in network assets (power lines, power poles, conductors etc) surveillances. In this paper, a novel algorithm is proposed for power line detection system - using Gabor Filter to extract and enhanced power line features and texture and Hough Transform to detect Power Lines. The results found proved to be effective in detecting power lines and can be used as a building block to implement a more sophisticated system for detecting Power Lines.

Keywords: UAV, Gabor Filter, Hough Transform, Power Lines

I. INTRODUCTION

Unison Networks, the local electrical distribution company in New Zealand have vast networks assets (power poles, switchgear etc) in regions Hawkes Bay, Taupo and Rotorua. Inspection and maintenance of these network assets are costly and proved to be a critical issue. These issues are locations of networks assets are unknown and some network assets are difficult to access or inaccessible. Cost is a major issue and Australian companies like Ergon Energy have spent approximately $80 million on inspection and maintenance on their network asset alone [4]. Maintenance usually involves preventing encroachment of vegetation on power lines which induces damages. Due to their vast network in different regions, they are not able to keep effective maintenance on all their network assets. For companies like Ergon Energy, this lead to loss of reliability of electricity transmission and result to serious hazards. These hazards are unstable network assets such as power outages in Canada and in the USA [1], [2]. For companies like Unison Network who currently deploy periodic based ground patrol [3](sending ground patrols to network assets in a periodic schedule). This proves to be labour intensive, costly and time consuming. Furthermore, inspection on some zones where inspected more frequently than others.

Unison Network is investigating and researching the use of UAV (unmanned aerial vehicle), the quad-copter to inspect their network assets shown Figure 1.

For this project, we will be developing a system that will detect power lines using a web cam. The web cam will be hovering over a dummy model comprising of strings attached to pringle cans that will simulate a UAV navigating along power lines.

Section 2 briefly introduces Related Research on power line detection and section 3 entails the proposed method in detecting power lines.

II. RELATED WORKS

Power line detection is not a new field as it provides many practical applications. Electrical Distribution companies and Universities such as Queensland University of Technology in Australia have explored the use of Pulse Coupled Neural Network (PCNN)[4] in conjuction with Hough Transform. PCNN[5] has the ability to extract relevant information such as edge information and texture information. The process is followed up by segmenting the image. The Hough Transform is then used to detect the power lines. Furthermore, the combination of these two methods also limits the detection of linear features. Furthermore, it also limits image noises. The results of using these methods are shown in Figure 2.

Alternate methods explored by Wuham University of China is the Gabor Filter in combination with Hough Transform [9]. The result is shown in Figure 3.

As shown in Figure 2 and 3, both methods were effective in detecting power lines. However they both posed limitations. The research concluded that it also detected linear features that were parallel to the power lines as shown Figure 4. Figure 4a shows four sets of lines. The first line on the right is the fence, the last three are the power lines. As shown in Figure 4b, both methods detected all four lines rather than just the power lines.
III. PROPOSED METHOD

For this project, the Gabor filter and Hough transform will be used to detect the power lines rather than using the PCNN method due to the complexity of the method and limited time. Furthermore, the characteristics of power lines will be used for profile analysis to aid in distinguishing itself from other linear features. This will eliminate the issue previous papers have encounter - detecting linear features that were parallel to the power lines.

To test out system, we will use a scaled model to simulate power lines and power poles - using strings attached to a base (Pringle cans) shown in Figure 5.

![Fig. 5. Scaled Model of the Network Asset](image)

A web cam will be hovering above the strings to model a UAV navigating along power lines. The system will be developed using Visual Studio 2010 environment. The language used is OpenCv C++ as it provides collections of functions for image processing. The Overall system for Power Line Detection is seperated into subsystem shown in Figure 6. These are Power Lines Enhancement using Gabor Filter which is followed up by Power Lines Extraction using Hough Transform and lastly, Power Lines Profile Analysis.

A. Power Line Enhancement using Gabor Filter

The Gabor Filter which is a band pass Filter [6] is used because of their ability to extract features and texture analysis. The Gabor Filter which was presented by Daugman (1980) is a complex oscillation multiplied by Gaussian envelope function. The oscillation comprises of a sinusoidal plane wave of a particular frequency and orientation. The Gabor Filter over the image domain (X, Y) is represented by Eqn. 1

\[
g(x, y) = \frac{1}{2\pi \delta x \delta y} \exp \left\{ -\frac{1}{2} \left[ \left( \frac{x}{\delta x} \right)^2 + \left( \frac{y}{\delta y} \right)^2 \right] \right\} \exp(-2\pi j f x)
\]

(1)

Where \( \delta x, \delta y \) (standard deviations) are Gaussian envelope function respectively along x-axis and y-axis, \( f \) is the frequency. Based upon Eqn. 1, the two-dimensional Gabor filter is a band-pass in the x-axis direction and low-pass in the y-axis direction. Therefore the power lines information can be greatly enhanced when the filter direction is the same direction with the power lines. Any information that is perpendicular to the filter direction is weakened. Eqn. 1 is derived into two components - even and odd function shown in Eqn. 2 and 3 respectively.

\[
h(x, y, \theta, f) = \exp \left\{ -\frac{1}{2} \left[ \left( \frac{x \cos \theta + y \sin \theta}{\delta x^2} \right)^2 + \left( \frac{-x \sin \theta + y \cos \theta}{\delta y^2} \right)^2 \right] \right\} \cos[2\pi f(x \cos \theta + y \sin \theta)]
\]

(2)

\[
h(x, y, \theta, f) = \exp \left\{ -\frac{1}{2} \left[ \left( \frac{x \cos \theta + y \sin \theta}{\delta x^2} \right)^2 + \left( \frac{-x \sin \theta + y \cos \theta}{\delta y^2} \right)^2 \right] \right\} \sin[2\pi f(x \cos \theta + y \sin \theta)]
\]

(3)

In this paper, we will be using the even component (Eqn. 2) of the Gabor filter because it enhances straight line features. In contrast, the odd function of the Gabor filter enhances the object edges. Figure 7 shows the Even intensity level of the even component of the Gabor Filter.

B. Power Line Extraction using Hough Transform

Hough transform is a common technique for detecting parameterized shapes such as lines and circles [7] which in this
The Hough Transform for detecting straight lines (or linear features) is represented by Eqn. 4.

\[ x \cos \theta + y \sin \theta = \rho \]  

Hough Transform maps each point in a parameter space in which its shape is determined by its orientation and location as shown in Figure 8.

When distinguishing a straight line in an image, the Hough Transform parameterises a line in a Cartesian coordinate to a point in the polar coordinate \((\theta, \rho)\) [10] shown Figure 8a. The points for each line shown in Figure 8a which lies in the \((\rho, \theta)\) plane creates a curve characteristics - Hough Space shown in Figure 8b. This determines the distance and the angle for the line detected.

**C. Power Lines Analysis**

We will be treating the strings as actual power lines to ensure they exhibit the characteristics of power lines. These characteristics are:

1. The colour of the strings are fixed in colour (white). Actual power lines owned by Unison Networks are black. However it is important to note that they vary in intensity due to lighting conditions.
2. The strings approximates to a straight line. In actuality, power lines often sag losing their linearity feature.
3. The strings are parallel to each other. However this is not the case in real life situations as the wires are sometimes off by an angle or so.

These characteristics will be used for Power Line Analysis. In this paper, we will only be considering a primitive method for Power Line Analysis due to limited time. Profile analysis involves using the width of the pixel of the string in the image. This is then used to match lines detected after applying Gabor filter and Hough Transform.

To measure the width of the pixel of the string, a single string is analyzed. Basic algorithm such as converting an image to grayscale and using Adaptive thresholding is used to give a clear resolution of the image. Adaptive thresholding is process of segmenting an image by setting the intensity values to foreground that are above thresholding [11]. The remaining pixels is set to background. This form of thresholding eliminates any variations in intensity levels in an image [12]. Take an image for an example shown in Figure 9a which shows an uneven level of intensity level. The image is then converted to gray scale image shown in Figure 9b.
Adaptive Thresholding is then applied shown in Figure 10.

As shown in Figure 10, Adaptive Thresholding eliminates any intensity variations in the image. Adaptive Thresholding is used for this project to prevent any variations in intensity levels when measuring the pixel width. A relatively straightforward method is taken to measure the width of the pixel - direct access of the pixel itself and record the pixel width at a fixed height. The pixel width of the lines detected in the image is then compared to the recorded pixel width.

For this paper, we will only be concerned with power line detection. Objects such as power poles and vegetation encroachment will be ignored. Furthermore, we will also be ignoring different lighting conditions - the experiment will be in a fixed lighting condition. This will provide better detection of the strings by the web cam and to minimise the variations in intensity of the strings.

IV. RESULTS

A. Power Line Detection

All images captured are in real time using a Logitech web cam. The experiment was taken place in non-cluttered environment where it contained minimal linear features. Initially, the Even Gabor Filter and Hough Transform is tested to measure its effectiveness and reliability of detecting the strings. Three types of test were performed. The first test consisted of only strings attached to a pringle can shown in Figure 11. The second test involved inserting linear objects in the images. These are books and rulers shown in 12. In the last test involved inserting many linear objects such as books, rulers, and pens. Furthermore, we also added the same type of string but was not connected to the pringle can. It also lay slightly parallel to the strings that were attached to the pringle can shown in Figure 13.

Based on Figure 11, 12 and 13, the Gabor Filter and Hough Transform alone was successfully in detecting power lines. Furthermore, each test was run 10 times at different heights to measure its reliability. The results are given in Table I, II and III. Furthermore, the parameters \((\theta, frequency)\) is constant throughout the experiment (without any adjustment to the parameters) to allow consistency in results given.
TABLE I  
INITIAL EXPERIMENT - HEIGHT AT 50 CM

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Confidence Level (Power Line Detection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1. Contained no objects. Refer to Fig. 11.</td>
<td>100%. Successfully detected lines.</td>
</tr>
<tr>
<td>Test 2. Contained linear features. Refer to Fig. 12.</td>
<td>100%. Successfully detected lines.</td>
</tr>
<tr>
<td>Test 3. Contained linear features and loose wires. Refer to Fig. 13.</td>
<td>90%</td>
</tr>
</tbody>
</table>

TABLE II  
CONFIDENCE LEVEL IN POWER LINE DETECTION AT A HEIGHT OF 1 METER

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Confidence Level (Power Line Detection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1. Contained no objects. Refer to Fig. 11.</td>
<td>100%. Successfully detected lines.</td>
</tr>
<tr>
<td>Test 2. Contained linear features. Refer to Fig. 12.</td>
<td>80%</td>
</tr>
<tr>
<td>Test 3. Contained linear features and loose wires. Refer to Fig. 13.</td>
<td>80%</td>
</tr>
</tbody>
</table>

TABLE III  
CONFIDENCE LEVEL IN POWER LINES DETECTION AT A HEIGHT OF 1.5 METER

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Confidence Level (Power Line Detection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1. Contained no objects. Refer to Fig. 11.</td>
<td>90%</td>
</tr>
<tr>
<td>Test 2. Contained linear features. Refer to Fig. 12.</td>
<td>80%</td>
</tr>
<tr>
<td>Test 3. Contained linear features and loose wires. Refer to Fig. 13.</td>
<td>80%</td>
</tr>
</tbody>
</table>

Based on the table, the Gabor Filter used in conjunction with Hough Transform was successful in detecting the strings at a closer distance. It is shown that its confidence level decreased as the height increased. However it is found that when the parameters are adjusted, the web cam successfully detected the strings at greater distances. This proved that the height can only vary within certain tolerances to prevent the web cam from failing to detect the power lines.

B. Power Line Profile Analysis

The pixel width of the string is approximately about 3 pixels at a height of 50cm. The Power Line Profile Analysis is used after the Gabor Filter and Hough Transform is applied to a fixed image - image captured is not real time. This is because the Gabor Filter and Hough Transform eliminates all irrelevant features (including linear features that are parallel to the strings) making it difficult to test the Power Line Profile Analysis method. Regardless that the Gabor Filter and Hough Transform is successful detecting the strings without detecting any linear features that is parallel to the strings, we know that this is not the case when applied to real power lines. The image used for Profile Analysis is taken from [9] which is shown in Figure 14a. The result of applying Power Line Profile Analysis is shown in Figure 14b.

![Original Image](a) Original Image  ![Applying Power Line Profile Analysis](b) Applying Power Line Profile Analysis

Fig. 14. Power Line Profile Analysis

The results are promising. However the result can not deduct on how reliable or effective when applied to real time images. But the concept does prove that it was effective in distinguishing the power lines from other linear features that is parallel to the power lines.

C. Discussion

The use of Gabor Filter and Hough Transform was an effective combination in detecting strings (power lines). However it is found that when the strings lay horizontal (in x axis), the system failed to detect the strings. The parameters had to be changed in order for the system to detect the strings. This implies that the web camera on the UAV must stay parallel to the power lines. Furthermore, the parameters of the Gabor Filter ($\theta, frequency$) had to be changed constantly when the height varied for more than a meter.

The concept for Power Line Profile Analysis proved effective even though the method used was primitive. However its reliability can not be determined when applied to real time images. The captured image for Power Line Profile Analysis was an image taken from a research paper. Real time images was not used as the Gabor Filter eliminated linear features that were parallel the power lines. This limited from testing the Power Line Profile Analysis on real time images.

V. Conclusion

In this paper, Power Line Profile Analysis method in conjunction with Gabor Filter and Hough Transform is used for Power Line Detection. The result of the using the proposed method was successful in detecting power lines. It improved past projects where it detected linear features such as a fence that was parallel to the power lines. However there were limitations. These are that the System for power line detection failed when the power line was perpendicular to the Gabor Filter. The web cam had to be kept parallel to the direction of the Gabor Filter. Furthermore, the system’s confidence level for detecting power lines decreased as the height varied more than 50cm.
The concept for Power Line Profile Analysis proved to be effective. However, its reliability cannot be measured against real-time images. The concept can be used as a building foundation for future research for eliminating linear features that are parallel to the power lines. A research paper similar to Profile Analysis but at a more advanced stage is using a robust Gaussian Model [13]. Its design processes consist of three stages - Pre-processing (noise elimination/reduction), Line Discrimination using Profile Analysis and Post Processing (thresholding). In the Profile Analysis stage, based upon Steger's proposed method [14] they proposed the use of a robust Gaussian model to approximate the gray scale distribution to model the profile of the power lines. This aids in eliminating different linear patterns detected. Past results have proven that Gaussian models are effective in image segmentation [15] and background modeling [16]. The research paper regarding the Profile Analysis method concluded that the method they proposed outperformed previous detection methods.

For future research, candidates can focus on using Gaussian Modelling in conjunction with the Gabor filter and Hough Transform in power line detection. This will aid in discriminating between wires and other linear features that are parallel to the power lines.

REFERENCES

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