Proceedings of the 1st International Conference on Unmanned Vehicle Systems (UVS), Muscat, Oman, 5-7 February, 2019

Automatic Fault Detection of Power Lines using Unmanned Aerial Vehicle (UAV)

Mehdi Korki
School of Software and Electrical Engineering
Swinburne University of Technology
Melbourne, Australia
mkorki@swin.edu.au

Nikhil Dwarakanath Shankar
School of Software and Electrical Engineering
Swinburne University of Technology
Melbourne, Australia
nikhil.shankar2311@gmail.com

Raj Naymeshbhai Shah
School of Software and Electrical Engineering
Swinburne University of Technology
Melbourne, Australia
raj.shah20@yahoo.com

Syed Muhammad Waseem
School of Software and Electrical Engineering
Swinburne University of Technology
Melbourne, Australia
waseemmoazzam580@gmail.com

Steven Hodges
Innovation Manager
Zinfra
Melbourne, Australia
steven.hodges@zinfra.com.au

***Abstract*—Safety and automation are the two major challenges in the application of Unmanned Aerial Vehicle (UAV), commonly known as drone, to the power lines inspection and fault detection. While current state-of-the-art UAVs are equipped with collision avoidance features, there is less attention to the automatic and real-time fault detection of power lines using UAVs. This paper presents the architecture of three drone-oriented concept designs for automatic and real-time fault detection of power lines using UAVs. The proposed systems could be potential candidates for replacing traditional inspection methods of power lines, which are risky and costly. By incorporating a robust neural network, i.e., Artificial Intelligence (AI), and using appropriate and efficient sensors, the systems can automatically detect various faults and defects on power lines with high precision. We propose three concept design options comprised of different hardware/software components and their feasibility factors. For instance, FLIR Duo Pro R as a thermal sensor and Zenmuse XT for thermal vision have been proposed to be used in the concept designs. For data communication, the proposed designs use cloud-based virtual private network (VPN) for a secure connection between remote control (RC) of the UAV and the server. Based on the advantages and disadvantages of the three proposed design options, the most efficient design is also discussed. This design proposes a system with lightweight sensors, which could increase the flight time of the UAV. Further, the AI interface is coded on to the RC, making it economical, without any database for big data storage. The back-end of the neural network is stored in a cloud server. With the help of GSM antenna, the AI can run on the tablet if there is an available cellular network.**

***Index Terms*—Unmanned Aerial Vehicle (UAV), Artificial Intelligence (AI), Convolutional Neural Network (CNN), Power lines, Automatic Fault Detection**

I. Introduction

Unmanned Aerial Vehicle (UAV), commonly known as drone, is an aircraft without a pilot, which flies either autonomously or with a remote control (RC). UAVs have variety of applications such as photography, warfare, entertainment, delivery, etc. According to [1], sales of UAVs are expected to rise from 2.5 millions in 2016 to 7 millions in 2020, a staggering 180% increase.

PricewaterhouseCoopers (PwC) has recently reported that, operational safety and automation are the two major challenges in the application of UAVs to the power lines inspection and fault detection. Globally, there is an estimated loss of $169 billion annually related to power network outages [2]. Recent drones are equipped with collision avoidance features, however, the automated detection and avoidance of power lines in real-time has not been incorporated in the system [3]. This work focuses on using these two rapidly growing technologies, i.e., Artificial Intelligence (AI) and UAV to develop a solution to utility sectors such as Zinfra [4] that can eliminate the risk of involving humans by automating the entire process of fault detection of power lines. Traditionally, technicians climbed onto pole structures to conduct inspection and fault detection, which would be risky and expensive regarding safety equipment. Recently, the usage of UAVs in surveying difficult terrains has been promising [5]. Combining the UAVs technology for surveying with AI will enhance the fault detection process of power lines by eliminating human intervention during a survey and inspection. By automating routine asset inspections, service providers can reduce the risk of human errors, can increase the frequency of inspections, can access remote locations which are not easily accessible by humans, can provide a safer working environment for employees, can reduce client outlay for safety equipment, and can provide higher quality of usable and measurable data.

In this paper, we propose three feasible automatic, real-time, and autonomous vision-based power line inspection concept designs that use UAVs as the main inspection system, thermal images as the primary data source, and Deep Learning (DL), i.e., convolutional neural network (CNN)-based approaches as the backbone of data analysis and inspection. The benefit of this research, would be the safety of the inspecting officer and the accurate detection using a real time monitoring. Further, the project manager could also inspect remotely and track the progress of the project. Thus, time saving during inspection

978-1-5386-9368-1/19/$31.00 ©2019 IEEE

(a)

(b)

Fig. 1. Common faults on:(a) power lines (from left to right): trees growing too close to power lines, trees lying across power lines, icing on power lines. (b) power lines components (from left to right): broken poles, broken crossarms, missing toppads [20].

visits, long term data maintenance and better efficiency would be the results.

II. Literature Review

UAVs have been utilized in several applications including search and rescue [9]– [12], active classifications [13], [14], aerial surveillance [15], [16], and agriculture [17]. The conventional methods to inspect and detect possible faults of power networks include field surveys and airborne surveys, which have been used for decades [18]. After an emergency occurs, e.g., storms, hurricanes, and earthquakes, teams of inspectors visually inspect the power lines with the help of binoculars and sometimes with InfraRed (IR) and corona detection cameras [19]. Visual inspection is popular method because it can cover a variety of faults on both power lines components (Fig. 1(b)) and the power lines themselves (Fig. 1(a)) in one inspection [20]. However, this methodology is quite slow, expensive, potentially dangerous, and with detection rates limited by the visual observation skills of the inspectors. Recent studies tried to propose and perform automatic visual inspection using helicopters, flying robots, and/or climbing robots; however, they only used simple algorithms for image processing and classifications. In this paper, we aim to propose a design of automatic autonomous vision-based inspection of power lines using UAVs. Currently, the existing power line inspection methods include foot patrol, helicopter-assisted, automated helicopter-assisted, climbing robots, and UAV inspection. One of the popular inspection methods is vision-based inspection, which includes mapping and inspection of power line components too [20]. The main advantage of the vision-based inspection approach is that this method reduces or sometimes completely eliminates the human intervention in both data collection and analysis.

Among the recent vision-based studies, we can point out to computer vision-based power line inspection [22]. Remote sensing and data analysis approaches have also affected the technologies involved in automatic power line inspections [18]. The various remote sensing approaches for power line inspection include Synthetic Aperture Radar (SAR) images, optical satellite and aerial images, thermal images, airborne laser scanner data, mobile mapping data, and UAV data [18]. Among the popular and conventional power line inspection methods we can point out to foot patrol inspection [19], helicopter-assisted inspection [20], automated helicopter-assisted inspection, climbing robots inspection [24], and UAV inspection. In UAV inspection, an equipped UAV with multiple sensors and cameras is navigated along the power lines to detect the faults and also to collect data for offline inspection and analysis.

Appropriate data sources for power line inspection include thermal images and UAV data. Thermal images are taken by infrared cameras based on infrared radiation to extend our vision by the visible light emitted by warm object [25]. The popular data types collected by UAVs in power line inspections are optical images and laser scanning data [18].

The three major components required for an automatic and autonomous vision-based power line inspection method are: an inspection method (e.g., UAV inspection, helicopter-assisted inspection), an appropriate data source (e.g., thermal images, SAR images), and more importantly a suitable method for data analysis. Based on the recent studies, UVA inspection method is more promising compared to the other methods due to lower cost, ability to fly close to power lines, and flexibility to access hard-to-reach locations with high speed [20]. Further, recent advances in UAV components, sensors and battery technologies have allowed UAV inspection method to be more promising than the other methods. Deep learning approaches such as convolutional neural network (CNN)-based object detection and classification [26] have proven to be very promising for detecting and inspecting poles, crossarms, and dead end body components.

III. Components of the proposed design

In the section, we explain the required components that could be used for the proposed concept designs.

A. Hardware Requirements

The hardware required for our proposed concept designs include an appropriate Unmanned Aerial Vehicle (UAV), suitable high resolution cameras, a server or a base station, an electronic board with a suitable and low-cost Programmable Logic Controller (PLC), such as an Allen-Bradley Micro810, and several other suitable sensors.

The different types of cameras include 3D cameras, optical, thermal, and ultraviolet cameras [27] to better detect more complicated faults of power lines such as cracked insulators, rotten poles, and corona discharges. In particular, thermal cameras and thermal sensors, e.g., long wave infrared (LWIR), are used to capture the heat emitted from the electrical assets or the heat loss due to the damage or faulty parts. To resolve the line of sight issue, in the UAV navigation, a 360-degree camera can be used in the designs to make sure the UAV has sufficient line of sight [20].

There are certain factors while choosing the sensors namely, resolution, range, environmental condition, and controllability

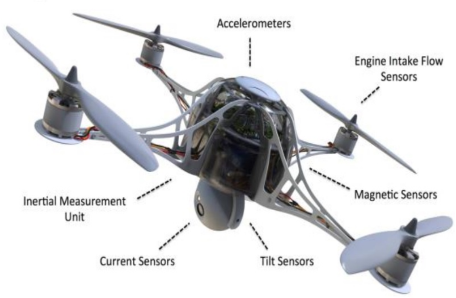

Fig. 2. Different sensors on a UAV [7].

[28]. The sensors will fetch useful information and the AI would compare and detect the faults or defects. The most common sensors necessary for the UAV flight are (Fig. 2) [7]: accelerometers for positioning the drone, inertial (combined with GPS) for maintaining direction and flight paths, tilt (combined with gyros and accelerometers) for providing input to the flight-control system to maintain altitude, current sensors for monitoring and optimizing power drain, safe charging of internal batteries, and detecting fault conditions with motors or other areas of the system, magnetic sensors (or electronic compasses) for providing critical directional information to navigation systems, and flow sensors for effectively monitoring air flow into small gas engines used to power UAV.

B. UAVs

The various applications of UAVs include surveying infrastructures, bridges, power lines and equipment, etc. An appropriate UAV for our design would have the following features:

- Light weight, regarding sensors attached to it
- Built in sensors like GPS, camera, proximity sensors would reduce installation costs
- Long range, as it would reduce the risk of losing the signal and control over the drone
- Ability to transmit radio frequency from which the videos/images can be downloaded
- Long flight time, i.e., better battery life or a hybrid power supply for UAV
- Stability to natural forces, e.g., wind and rain, etc.

The DJI Inspire 2 is an appropriate option for our proposed designs due to the features such as top speed of 94 km/h, flight time of 30 minutes, range of 7 km, and multifunctional RC with dual frequency video download link (DL) of 5.8 GHz and 2.4 GHz. The technical specifications, the advantages and disadvantages of DJI Inspire 2 are listed in Table I. Based on these features, we have chosen the DJI Inspire 2 for our proposed concept designs. Its top speed of 94 kmph makes the inspection process faster and more efficient. Its multifunctional wireless RC which provides dual frequency video DL can be useful for capturing and saving different aspects of the surveillance in detail. The lightbridge of DJI Inspire 2 delivers quality 1080p/720p videos, and first person view (FPV) to the pilot and camera operators. The dual controller mode allows the pilot to control the UAV while the camera operator concentrates on composing the shots.

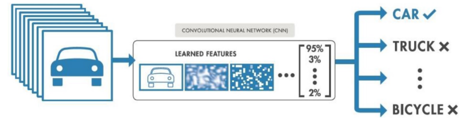

Fig. 3. Deep learning workflow [6].

C. Deep Learning and Artificial Intelligence

Artificial Intelligence (AI) is widely used in many automated systems. AI has many applications, ranging from Aviation to Medical applications. The requirements of this project demand a neural network that recognizes images and patterns. One of the most popular forms of AI recognition is convolutional neural networks (CNN). CNN is a method that focuses on pixels located next to each other. CNN is one of the most popular algorithms for deep learning, in which a model learns to perform classification tasks directly from images, videos, texts, or sounds. CNNs are particularly useful for finding patterns in images to recognize objects, faces, and scenes. They learn directly from image data, using patterns to classify images and to eliminate the need for manual feature extraction. CNNs are widely used for object recognition and computer vision applications, e.g., self-driving vehicles and face-recognition.

Using CNNs in deep learning is very efficient and practical due to the following reasons [6]:

- Automatic feature extraction is feasible by CNNs (Fig. 3).
- The recognition results of CNNs are accurate.
- The trained CNNs can be retrained for new recognition tasks, enabling the system to build on pre-existing networks

Image recognition and pattern detection can be optimized using CNNs. The advances in GPUs and parallel computing enable CNNs to be easily used for automated image recognition and classification [3].

IV. Design Options

A. Concept Design 1

This design option (Fig. 4) comprises a UAV with the cameras and sensors mounted on it which will gather data and send it to the base station where a person is monitoring it and then data will be sent automatically to the cloud servers with a secure Virtual private network (VPN) connection. In this design system, we use VPN cloud for securing the clients data.

Cloud server or virtual server is an online or virtual server rather than a physical server which is used for online data storage. It is created, hosted and delivered via the internet and can be accessed remotely. The basic purpose of cloud servers is to store the data online and to access the data from any device. Cloud servers are cost-effective. We can increase or decrease

TABLE I
DJI INSPIRE 2 – ADVANTAGES AND DISADVANTAGES

Technical Specifications	Advantages	Disadvantages
Weight: 3440 g (7.58 lbs)	Long flight range	High price tag
Battery: 6000 mAh 2S LiPo	Decent flight time	Focusing could be improved
Charging time: 90 min (1.5 hrs)	Excellent camera quality	Camera comes separate
Control Range: 7 km (4.3 miles)	5.2 K crisp, clean image quality	
Max flight time: 27 min	Nice ergonomics	
Max speed: 94 kmph (58 mph)	Impressive flying stability	
	Safety features	
	Nice wide viewing angle	
	Reasonable low-light ability	

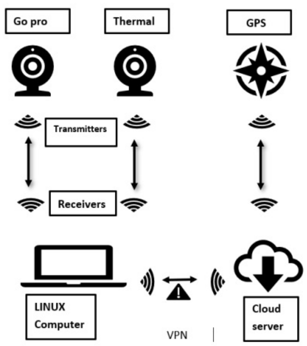

Fig. 4. Concept Design 1.

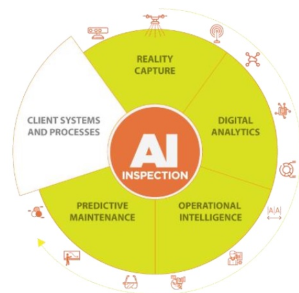

Fig. 5. Artificial Intelligence (AI) inspection [8].

the required capacity in a cost-effective way compared to the traditional method of storing the data in physical servers which are spacious and more expensive. Further, cloud servers offer more redundancies. VPN is a method that creates a secure and encrypted connection over the internet. VPN creates a point-to-point connection between the user and the server. VPN performance can be affected by internet speed, internet protocols used by service provider and encryption methods used by different providers. The advantages and disadvantages of this design option are as follows:

1) Advantages:

- Reliability: VPN cloud servers are more reliable and effective than tradition physical servers.
- Manageability: These cloud servers are easy and convenient to manage the data as well as increasing or decreasing the required storage capacity.
- Cost saving: It is more cost effective as compared to other physical servers.
- Accessibility: It is easy to access and manage the data from anywhere with internet.
- Backup: Cloud storage provides you a service to back up your data in which your data is stored in remote location and you can access it in case of loss of data.

2) Disadvantages:

- Data security: There are still issues regarding VPN securities via internet.
- Limited access: The user may not get all the services and features in cloud storage as compared to physical servers because of different policies of service providers.
- Fast internet connection: For using cloud storage, the user needs fast and reliable internet connection for transferring and managing the data.

B. Concept Design 2

This design is similar to concept design 1, except it uses the CNN algorithm (Fig. 5 and Fig. 6). To construct a simple deep learning machine, the following components can be used

- Motherboard ASUS Mini ITX DDR4 LGA 1151 B1501 PRO GAMING/WIFI/AURA
- RAM 8GB of Corsair Vengeance
- CPU Intel I5-6600
- Hard Drive – 1TB SATA drive
- Graphics card/GPU – GeForce GTX 1060
- Heat sink – Cooler Master Hyper 212 EVO

After setting up the computer, the user can boot the system with Ubuntu or Linux. After booting up the system, the user can install CUDA and CudNN. The software can be downloaded from the NVIDIA website [31]. The above design describes the following:

- A communication system between the tablet, used as an RC to operate the drone, and the deep learning algorithm.
- The library of images used by the algorithm requires large data storage, i.e., a cloud server that has a built-in channel with the AI.
- CNN algorithm constantly compares the images seen by the drone with the library trying to validate the comparison profiles. If there is a mis-match, the AI automatically triggers a notification stating a difference or a fault detected on the power line.

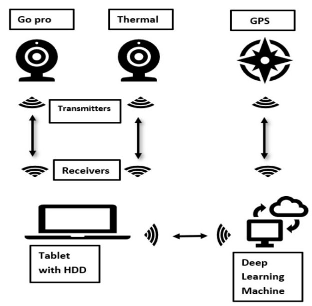

Fig. 6. Concept Design 2.

- Thermal sensor used in this design is Zenmuse XT, which increases the drone flight time due to its lightweight .

The advantages and disadvantages of this design option are as follows:

1) Advantages:

- The user can decide which data should be stored. This has many advantages such as, requirement of low data storage, less consumption of energy, data redundancy.
- Zenmuse XT is lighter than FLIR duo Pro R, which makes the entire system lighter and more efficient.
- The deep learning machine has the capability to learn while in use.
- Due to the elimination of data communication compared to design 1, there will be no risk of data loss.
- Since the deep learning computer is manually assembled, the cost of the design reduces drastically.

2) Disadvantages:

- The sensors can only be used for some specific drones, and inappropriate to be used with any arbitrary drones.
- The data set for the deep learning algorithm needs to be created manually with all the defects on the electrical assets, which is a daunting task.
- The DJI most advanced automatic flight creation and execution is only available for the professional version of the application and for the top-tier aircraft.

C. Concept Design 3

The system in this option has all the functioning of the previous design options except a few limited features. This design is shown in Fig. 7. The DJI inspire 2 is equipped with Flir Duo Pro R sensor. The data captured by drones is stored in the HDD connected to the tablet to keep the performance level without any lagging. To detect the fault automatically, the AI is already programmed into the tablet which operates at the backend of the main program. Hence, there is no need of the server or router to communicate with the field operating team, thus eliminating the additional cost and maintenance of them. The advantages and disadvantages of this design option are as follows:

1) Advantages:

- The recorded data is not stored on to the servers which may be advantageous in terms of cyber security.

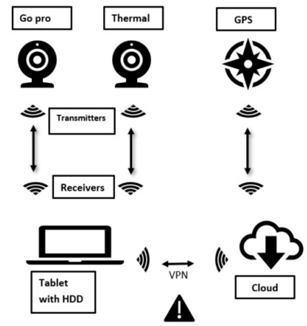

Fig. 7. Concept Design 3.

- Development of application would make the process simpler because AI would be running in background helping to recognize any faults or defects at the same instance.
- The thermal camera has inbuilt on-board suite of GPS, magnetometer, barometer making the flight safer and more efficient.
- The overall cost of the system would be less, mainly due to the thermal sensor cost.

2) Disadvantages:

- Data recovery is very difficult in this option.
- The thermal sensor has limited technical specifications such as frame rate capabilities and digital zoom options are better with DJI Zenmuse XT.
- The weight of thermal sensor is higher which affect the flight time of the drone.
- Inspecting power lines with this design option covers narrow areas as compared to other previous design options because of the thermal camera lens.

V. Discussions

Thus far, we have proposed three concept design options with their components, advantages and disadvantages. All these design options are feasible for implementation. All options include a UAV with a camera and different sensors. For instance, concept design 3 uses FLIR Duo Pro R as a thermal sensor. Whereas, design option 1 and 2 use Zenmuse XT for thermal vision. The communication methods used in the three design options are different. The design option 1 uses cloud-based virtual private network (VPN) for a secure connection between remote control (RC) of the UAV and the server. The most preferable and feasible design option is design 2. The sensors used in this design are lightweight and thus, flight time is longer. Further, the AI interface is coded on to the RC, making it economical, as there will be no database which needs to store big data. The back-end of the neural network is stored in a cloud server. With the help of GSM antenna, the AI can run on the tablet if there is an available cellular network.

VI. Conclusion

This paper presents three drone-oriented concept designs for automatic fault detection of power lines. The proposed systems could be potential candidates for replacing traditional inspection methods of power lines, which are risky and costly. By incorporating a robust neural network, ie., Artificial Intelligence (AI), and using appropriate and efficient sensors, the system can detect various faults and defects on power lines with high precision.

We have proposed three concept design options comprised of different hardware/software components and their feasibility factors. For instance, concept design 3 uses FLIR Duo Pro R as a thermal sensor. Whereas, design option 1 and 2 use Zenmuse XT for thermal vision. The communication methods used in the three design options are different. The design option 1 uses cloud-based virtual private network (VPN) for a secure connection between remote control (RC) of the UAV and the server. All these design options are feasible for implementation. However, the most preferable and feasible design option is design 2. The sensors used in this design are lightweight, which result in longer flight time. Further, the AI interface is coded on to the RC, making it economical, as there will be no database which needs to store big data. The back-end of the neural network is stored in a cloud server. With the help of GSM antenna, the AI can run on the tablet if there is an available cellular network.

The implementations of these three design options is an interesting topic for future work. There are some other improvements to the concept designs which will be left for future work, e.g., increasing the flight time by using UAVs with hybrid power supplies or solar powered batteries, incorporating path conformance autonomy and lidar-based geofences for increasing the safety and autonomy of the UAV, increasing cyber security by applying updated protocols for communications between the RC of the UAV and remote servers.

References

[1] AgriTechTomorrow 2017, "The 3 Main Categories of Drones and Their Advantages & Disadvantages — AgriTechTomorrow," online available https://www.agritechtomorrow.com/article/2017/10/the-3-main-categories-of-drones-and-their-advantages–disadvantages/10316

[2] Elisa Iannunzio 2011, "Drone autonomy for improved power pole inspection," online available https://utilitymagazine.com.au/drone-autonomy-for-improved-power-pole-inspection/

[3] E. Iannuzio 2018, "Drone autonomy for improved power pole inspection — Utility Magazine," online available https://utilitymagazine.com.au/drone-autonomy-for-improved-power-pole-inspection

[4] Zinfra, "Zinfra," online available http://www.zinfra.com.au/

[5] A. Bist M. Chatsko A. Goyal and D. Stine , "Aerial Survey Mapping Drones," online available https://www.cmu.edu/epp/people/faculty/course-reports/Identified%20Technologies%20-%20Aerial%20Surveillance%20Drone.pdf

[6] MathWorks 2018, "Convolutional Neural Network," online available https://au.mathworks.com/solutions/deep-learning/convolutional-neural-network.html?s_tid=srchtitle#whatitis.

[7] Sensors Online, "How Many Sensors are in a Drone, And What do they Do?," online available https://www.sensorsmag.com/components/how-many-sensors-are-a-drone-and-what-do-they-do.

[8] AI Inspection, "Are you ready to manage your assets in digital?," online available https://twitter.com/ai_inspection/status/838389129780084736

[9] T. Furukawa, F. Bourgault, B. Lavis, and H. F. Durrant-Whyte, "Recursive bayesian search-and-tracking using coordinated uavs for lost targets," in Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006., May 2006, pp. 2521 2526.

[10] S. Waharte and N. Trigoni, "Supporting search and rescue operations with uavs," in 2010 International Conference on Emerging Security Technologies, Sept. 2010, pp. 142147.

[11] M. A. Goodrich, L. Lin, and B. S. Morse, "Using camera-equipped mini-uavs to support collaborative wilderness search and rescue teams," in 2012 International Conference on Collaboration Technologies and Systems (CTS), May 2012, pp. 638638.

[12] D. Maturana, S. Arora, and S. Scherer, "Looking forward: A semantic mapping system for scouting with micro-aerial vehicles," in 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Sept 2017, pp. 66916698.

[13] K. C. T. Vivaldini, V. Guizilini, M. D. C. Oliveira, T. H. Martinelli, D. F. Wolf, and F. Ramos, "Route planning for active classification with uavs," in 2016 IEEE International Conference on Robotics and Automation (ICRA), May 2016, pp. 25632568.

[14] M. Popovi, G. Hitz, J. Nieto, I. Sa, R. Siegwart, and E. Galceran, "Online informative path planning for active classification using uavs," in 2017 IEEE International Conference on Robotics and Automation (ICRA), May 2017, pp. 57535758.

[15] M. Coombes, W. H. Chen, and C. Liu, "Boustrophedon coverage path planning for uav aerial surveys in wind," in 2017 International Conference on Unmanned Aircraft Systems (ICUAS), June 2017, pp. 15631571.

[16] D. Meyer, E. Fraijo, E. Lo, D. Rissolo, and F. Kuester, "Optimizing uav systems for rapid survey and reconstruction of large scale cultural heritage sites," in 2015 Digital Heritage, vol. 1, Sept 2015, pp. 151154.

[17] P. Roy and V. Isler, "Active view planning for counting apples in orchards," in 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Sept 2017, pp. 60276032.

[18] L. Matikainen, M. Lehtomki, E. Ahokas, J. Hyypp, M. Karjalainen, A. Jaakkola, A. Kukko, and T. Heinonen, "Remote sensing methods for power line corridor surveys," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 119, pp. 10-31, 2016.

[19] J. Katrasnik, F. Pernus, and B. Likar, "A survey of mobile robots for distribution power line inspection," IEEE Trans Power Delivery, vol. 25, no. 1, pp. 485-493, Jan. 2010.

[20] V. N. Nguyen, R. Jenssen, and D. Roverso, "Automatic autonomous vision-based power line inspection: A review of current status and the potential role of deep learning," International Journal of Electrical Power and Energy Systems, vol. 99, pp. 107 - 120, Jan. 2018.

[21] J. Ahmad, A. S. Malik, L. Xia, and N. Ashikin, "Vegetation encroachment monitoring for transmission lines right-of-ways: A survey," Electric Power Systems Research, vol. 95, pp. 339-352, 2013.

[22] F. Miralls, N. Pouliot and S. Montambault, "State-of-the-art review of computer vision for the management of power transmission lines," Proceedings of the 2014 3rd International Conference on Applied Robotics for the Power Industry, Foz do Iguassu, 2014, pp. 1-6.

[23] L. F. Luque-Vega, B. Castillo-Toledo, A. Loukianov and L. E. Gonzalez-Jimenez, "Power line inspection via an unmanned aerial system based on the quadrotor helicopter," MELECON 2014 - 2014 17th IEEE Mediterranean Electrotechnical Conference, Beirut, 2014, pp. 393-397.

[24] G. Zhou, J. Yuan, I. Yen and F. Bastani, "Robust real-time UAV based power line detection and tracking," 2016 IEEE International Conference on Image Processing (ICIP), Phoenix, AZ, 2016, pp. 744-748.

[25] J. M. LIoyd, Thermal Imaging Systems, Springer Science & Business Media: 2013.

[26] K. He, X. Zhang, S. Ren and J. Sun, "Deep Residual Learning for Image Recognition," 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, 2016, pp. 770-778

[27] R. Gade and T. B. Moeslund, "Thermal cameras and applications: a survey," Machine Vision and Applications, vol. 25, no. 1, pp. 245-262, 2014.

[28] S. Quintero, "Tips on sensor selection," online available https://www.controleng.com/single-article/tips-on-sensor-selection.

[29] C. Winkler, "How Many Sensors are in a Drone, And What do they Do?," online available https://www.sensorsmag.com/components/how-many-sensors-are-a-drone-and-what-dothey-do.

[30] P. Hawk, "LIDAR Sensors," online available https://www.precisionhawk.com/sensors/advancedsensors-and-data-collection/lidar

[31] L. Biewald 2017, "Build a super fast deep learning machine for under $1,000," online available https://www.oreilly.com/learning/build-a-super-fast-deep-learning-machine-for-under-1000