A Review of Unmanned Aerial Vehicle Technology in Power Line Inspection

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The electric power industry is one of the heaviest adopters of Unmanned Aerial Vehicles (UAV) technology, utilizing their versatility to enhance power line maintenance programs. For reliable power grids, routine maintenance operations and rapid repair operations are required across substantial geographical distances. Both maintenance and repair decisions are driven by assessment operations, such as inspections of mechanical structures with visible-band sensors, inspections for the presence of high voltage coronas and hot spots with multispectral sensors, and surveying of equipment and adjacent features (particularly vegetation) with photogrammetric and Light Detection and Ranging (LiDAR) sensors. Assessment was historically accomplished with manned helicopter flights or foot patrols. Recently, this critical economic segment harnessed advances in Unmanned Aerial Systems (UAS) technology to accomplish assessment tasks with faster results, lower cost, and higher levels of safety than historical methods. Adoption of UAVs in high-voltage electric power transmission activities is well underway. Adoption of UAVs for low voltage distribution activities is still emerging, with the important exception of post-storm damage assessment following major hurricanes (Harvey and Maria in 2017 and Michael in 2018). This report reviews the broad UAS adoption in high-voltage electric power transmission operations and early attempts at adoption in distribution operations. The ability to fly beyond visual line of sight (BVLOS) may increase the advantages of UAV inspection over former options, and in the United States, regulators have approved two pilot projects to demonstrate BVLOS methods and their benefits in operating and maintaining the power grid.

I. Introduction

In the past, electric transmission line inspections were conducted by helicopter or ground crews, but are known to be time consuming, expensive, and dangerous. In recent years, more power companies have adopted the use of UAVs to supplement these inspections. UAV suitability for infrastructure inspections has been enabled by both improvements in aerial platforms (e.g., autopilot capability and air-ground communications and control) and the miniaturization of sensors. The primary push for the use of UAV technology is the safety aspect of keeping the crew on the ground and away from high voltage structures. The secondary considerations - cost and time-to-results - are now known to be equivalent or better as compared to historical methods.

II. Inspection Methods and Technologies

Routine maintenance is essential to maintain a reliable energy grid. To prevent unforeseen outages regular inspections must be conducted. Many groups are working to improve the process of manual inspection, while others are focused on the long-term goal of a fully automated infrastructure self-diagnosing system. While multispectral

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inspections are used to detect potential issues or ongoing faults, visual spectrum inspections are the most commonly used method for infrastructure inspection.

A. Visual Inspection

Visual cameras attached to UAVs are commonly used for transmission line inspection. Aside from major disaster assessment for downed structures, they can be used to detect smaller issues that could lead to future outages; such as loose cotter pins, broken insulators, corrosion, and structural damage to the poles supporting the lines.

B. Thermal (Infrared) Inspection

Thermal inspections are also conducted on transmission lines. These inspections help detect worn splices and faults within the system if one of the three phase conductors is significantly hotter than the other two, indicating a higher load on that phase.

C. LiDAR Inspection

LiDAR is routinely used to map assets for pole deformation, line sagging, and 'dangerous point detection'. Dangerous point detection is the industry term for the monitoring of vegetation growth and unwanted structures in or near the power line corridor. Should any of the dangerous points breach the air gaps corresponding to a voltage breakdown distance, arcing could occur, leading to outages and fires. In addition to LiDAR, photogrammetry is used to monitor vegetation growth and structures in the right-of-way.

D. Visual Computation

Power grid integrity could be greatly facilitated by the development of special-purpose visual algorithms. This is a broad and potentially fruitful area of investigation which includes 'visual assistants' for post processing of inspection data, automated mechanical fault identification, and 'navigational assistants' to guide the UAV and keep the camera on track for a more efficient inspection.

E. Automation of Asset Detection

While some groups focus on manual inspections, guided by the safety pilot, others collect data in pass-by inspections. This type of inspection is carried out with preprogrammed waypoint guided flights to collect (typically huge) sets of data which are then postprocessed. Postprocessing generally takes many man-hours to accomplish. Visual computation research currently underway detects important assets, such as power lines and insulators, and potential faults to streamline the post processing process. Algorithmic approaches generally filter out portions of the data that is of no interest to the inspector and retain (in some cases with contextual 'tags') data that may be of critical importance for subsequent verification and analysis by experienced staff.

F. Corona Inspection

Corona discharge is created by the ionization of the air surrounding a conductor at high voltage. A corona will occur when the strength of the electric field around a conductor is high enough to form an electron avalanche region, but not high enough to cause arcing to nearby objects. While mostly harmless, coronas are potential indicators of problems in high voltage conductors or insulating structures.

Typically, high voltage corona inspections are done by a UV camera, either mounted to a helicopter or carried by ground crew. UV cameras have a long range and high accuracy for detecting coronas, but they are heavy, expensive, and fragile. These factors make them impractical for UAV corona inspections. One research group turned their attention to a compact UV Geiger-counter-like bulb primarily used for fire detection, but reactive to the same UV emitted by high voltage coronas. Through numerous research flights the validity of this sensor in UAV based corona inspections was proven. Then they researched augmenting the sensor with a parabolic dish to increase detection range.

III. Innovations in Navigation

There is an increased push to employ fully autonomous UAV inspections of power lines. To enable this, technologists in industry, academia, and government labs are developing navigational methods that enhance GPS positioning used for autonomous waypoint missions, and leverage LiDAR survey maps of power line corridors, and visual recognition of geotagged structures to supplement GPS waypoints.

IV. Long Range Inspection Operations and Technologies

As new technology emerges, long range UAV flights are becoming more common. Increased safety and reductions in both cost and inspection time are impelling development of BVLOS operations in power line inspection. If successful, this innovation will reduce the number of times a crew needs to rig up and down to complete inspection of a stretch of towers. Regulations introduced by the FAA in 2012 restrict the distance a pilot can fly a UAV to visual line of sight (VLOS) (H.R. 658 §§ 332-334). Several electric utilities and inspection companies have taken innovative approaches to push the boundaries of the VLOS restriction. To date, few have made a safety case with a level of rigor that allows a waiver of the VLOS requirement.

A. EVLOS

The Part 107 update to UAV aviation regulations, released in 2016 (FAA Advisory Circular 107-2), allows for the extension of flight distances for UAVs with the use of a) daisy-chaining visual observers, b) a chase vehicle containing the safety pilot, or c) midflight pilot control handoff. Each method has its advantages and disadvantages. The daisy-chained observers method is simple but requires a large crew already positioned along the entire flight corridor before the mission can begin. The multi-pilot method requires a larger crew and a complicated hand-off procedure to ensure loss of control does not occur. The ground chase vehicle method uses a smaller crew and a less complex concept of operations (CONOPS) but is vulnerable to ground traffic interference.

B. BVLOS

The greatest plausible improvement in safety and efficiency is realized if inspection is conducted by flying UAV based power line inspections BVLOS over long distances. Some teams of technologist have taken the approach of working in countries that have fewer regulations on UAV flight in their early phase of development. Other teams have taken advantage of restricted airspace, which is assumed to be void of non-participants, for safety reasons. Then there are those teams that worked within regulations and used technology to close the safety gaps.

C. DAA

Unlike manned aircraft, the pilot does not travel along with the UAV, and thus a means of detect and avoid (DAA) is needed on the drone. Multiple approaches have been taken to develop DAA systems; such as first person view (FPV) systems to give the remote pilot situational awareness, equipping the UAV with Automatic Dependent Surveillance–Broadcast (ADS–B) to detect other aircraft and alert them of the UAVs presence, or visual spectrum cameras using software to instruct the autopilot to avoid collision risks. Some take the approach of validating DAA systems within restricted airspace before flying in general airspace to minimize risks.

D. Communication systems

For safe operations of the UAV during BVLOS operations, the command and control link must be reliable, robust, and redundant. For more reliable data links during BVLOS inspection, some companies have turned to cellular radios to maintain a safety link. If communications fail, a predictable action should be executed by the autopilot and multiple layers of range containment need to be in place.

V. Conclusion

By utilizing leading edge technology, electric power companies are minimizing power line maintenance costs while boosting power grid reliability and worker safety. UAVs allow for closer inspections at angles not possible by helicopter or ground crews. UAVs are a valuable tool that keep linemen on the ground and out of harm’s way during power line inspections.