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Benefits and challenges of using unmanned aerial systems in the monitoring of electrical distribution systems

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ABSTRACT

This paper presents a study coming from an academic and industry partnership with the goals of exploring potential uses for UAS in distribution system operation and maintenance, establishing baseline costs and capabilities via equipment field tests, and simulating the cost benefits of increased maintenance. Existing UAS technology is shown to be capable of providing situational awareness for disaster response as well as increasing the number of maintenance inspections and speeding them up.

1. Introduction

The 2017 hurricane season was the 9th most energetic on record and included three major landfalls on the US mainland (Erdman, 2017). The ability of low-cost UAS to traverse areas that sustained severe infrastructure damage, or that had been flooded, aided time sensitive recovery efforts. These efforts included search and rescue following Harvey in Houston (Murphy, 2017), damage assessment to prioritize the distribution of recovery assets (Ziskin, 2017), and helping utilities navigate uncertain terrain to accelerate the repair process (Sydell, 2017). Jacksonville Electric was able to complete inspections of their system within 24 h of Hurricane Irma, and Florida Power and Light (FPL) used UAS to inspect areas unreachable by vehicle to accelerate recovery efforts and facilitate repair crews safety (FAA, 2017). In Puerto Rico, AT&T deployed drones as proxy cellular towers to restore internet service far in advance of traditional recovery methods (Reuters, 2017). The growing technical capabilities of UAS, together with the willingness of the FAA to quickly provide regulatory exemptions for emergency work, suggests that they will become more integral to disaster response and recovery in future events.

This paper assesses the monetary benefits and institutional challenges of introducing UAS for disaster response and scheduled electric infrastructure inspections. There are several existing examples of UAS use in normal utility operations by several companies in Europe (Aeryon Labs Incorporated, 2011; Aibotix International, 2014; Alpiq, 2014; CyberHawk, 2017) and one FAA-authorized pilot project by San Diego Gas & Electric (McNeal, 2014). While UAS adoption has begun, the value proposition for incorporation is less clear. Many of the UAS integration efforts focus on the over 200,000 miles of high-voltage transmission lines in the United States. Yet, distribution lines cover over 6,000,000 miles, and similar benefits of improved system reliability and worker safety would also be expected. This study sought to understand what specific activities would benefit from UAS and the value associated with those capabilities.

The project consisted of three phases. The first phase used employee interviews at three municipal utilities in North Carolina to identify possible UAS roles and desired UAS capabilities/performance. Interview subjects included a variety of stakeholder roles including linemen, engineers, and managers. The second phase involved purchase and flight tests of two UAS systems – a DJI Phantom 3 and a DJI Inspire. These flights explored the learning curve for flying commercial-off-the-shelf products around utility poles to support maintenance-related activities, take color and thermal pictures and video, and identify what could be learned from the pictures and video. Flights were conducted around electrical equipment on NC State's campus and at a Huntersville/Cornelius facility. The final phase used simulations to quantify the value proposition of using UAS to conduct grid inspections.

2. Interviews conducted to identify possible use cases

The first portion of the study consisted of interviews with municipal utilities in North Carolina to understand how UAS might be used in distribution system maintenance. These interviews were arranged with the assistance of partners at ElectriCities, Inc. of North Carolina. Four municipalities were interviewed as part of this research: Fayetteville Public Works Commission (PWC) servicing approximately 80,000 customers (Fayetteville's Hometown Utility, 2018), Washington Electric Utilities serving 12,000 customers and servicing 388 miles of power

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distribution lines (Washington, 2010), Tarboro Electric Utility servicing 5828 measuring meters and 120 miles of power distribution lines (Town of Tarboro, 2016), and finally the Huntersville/Cornelius branch of Electricities Inc. servicing 4000 customers.

Interviews involved at least 6 members from the participating municipality, ranging from lineman to managers. The most excitement about UAS possibilities and questions about capabilities came from the interview with Fayetteville PWC. Two general categories of use were identified: emergency management and preventative maintenance. Descriptions of use for each category, along with quotes from interviews, are discussed in the following sections.

2.1. Emergency management

Enhanced emergency response was described as very desirable. Use of UAS in recovery efforts following Irma, Harvey, and Maria support the interviewee responses. North Carolina is subject to hurricanes, ice storms, and severe thunderstorms that can cause distribution system damage. Additionally, there are non-storm related outages caused by wildlife or accidental damage that are less severe but occur more frequently.

One of the most valuable capabilities provided by UAS after a storm is enhanced situational awareness. This was demonstrated by utility use in Florida (FAA, 2017) and also identified during the interviews. Downed trees, flooded roads, and icy conditions can make it difficult for utility personnel to assess the location and severity of damage. Fayetteville PWC interviewees described the added capability as “huge”. Aerial inspection can be accomplished more quickly and safely to inform the recovery process, which is especially important when damage impacts critical infrastructure like hospitals or shelters. Only one utility (Fayetteville PWC) explicitly expressed the desire for real-time imaging. The other subjects viewed photo and video processing after the drone landed as acceptable, and there was limited interest in having the system deployed in poor weather conditions.

UAS were also seen as possible “first responders” to localized outages. UAS could be used to check sites for damage once an outage is reported. There were two advantages identified with using a UAS as a first responder. First, the presence of the UAS overhead would alert those on the ground that the outage had been detected by the distributor and that a repair team could be expected. Second, photos and videos from the UAS could be used to identify the supplies/equipment needed for the repair thereby increasing efficiency and reducing outage time. This is what was done by Jacksonville Electric and FPL in Florida to speed restoration of service after Hurricane Irma (Florida Power and Light, 2017). Video from FPL operators show that UAS can be used in dense foliage to provide situational awareness about damaged equipment.

2.2. Preventative maintenance

Several opportunities were identified for using UAS in preventative maintenance. Utilities vary in the type and timing of inspections performed on their systems. The interviewees identified the ability for a UAS to help perform more/better inspections, and considered multiple sensor packages as advantageous. At a minimum, access to color images was considered a necessity.

A primary type of surveillance is the inspection of overhead components including transformers, switches, poles, and insulators. The interviewed utilities had various inspection strategies from annual inspections to ad-hoc inspections wherever linemen happen to travel. Estimates for the time to set up a truck with linemen to perform and inspect overhead components ranged from 10 to 45 min per pole. Utility personnel were also excited about the possibility to inspect equipment that is difficult to reach like secondary lines that cross backyards or substations with limited visibility.

Right-of-way management was also identified. Right-of-way inspections typically have a formal timeline and ensure that lines, poles, and equipment are located sufficiently far from vegetation or other encroachments. A 2012 Congressional Research report on Weather-Related Power Outages highlights the importance of tree-trimming schedules and associated inspections as important for the prevention of storm related outages (Campbell, 2012).

Interviewees were most interested in combining UAS mobility with thermal imaging because distribution components often overheat before failing. Replacing components before failure prevents outages and can prevent the need to remediate further damage caused by catastrophic component failure. Most interviewed utilities paid for ground-based annual thermal inspections of major components. Current practice involved inspecting the system at least once a year, and reported costs were between $1800 and $3000, depending on the size of the system. One interviewee stated “you really can’t see everything from the ground level; you either have to be far away or you have to only see the bottom.” Thermal imaging can also be used to identify dead or dying trees bordering the right-of-way (FLIR, n.d.).

A currently unavailable but desired capability is for the UAS to perform autonomous inspections. This is not currently possible due to FAA regulations and UAS duration limits, but remains an attractive future possibility.

3. Flight testing of purchased equipment

The second phase of the project involved purchasing equipment and conducting three different test flights to assess current costs and capabilities. Two different craft were purchased, a DJI Phantom 3 (DJI, n.d.) and a DJI Inspire (DJI, n.d.) with thermal camera attachment. A key selling point of the Inspire 1

The thermal camera purchased was the DJI Zenmuse XT thermal camera (DJI, 2017). Four different lenses can be chosen as the point of purchase (7.5 mm, 9 mm, 13 mm, and 19 mm), and control of the camera allows for temperature spot metering. Photos can also be taken while recording video. Specifications for the two purchased UAS can be found in Table 1.

3.1. Costs

Given the growth of UAS as an industry, the pace of technological advancement for these systems are expected to continue or accelerate. As price and detailed specification information will become quickly dated, this section discusses the types of costs that are likely to be incurred when establishing and maintaining a UAS program.

Current commercial UAS provide most features a utility might desire. Custom software for additional automation or physical modifications involves additional cost, but the price of the example UAS is equivalent to, or less than, the cost of the thermal imaging sensor. As seen in Table 2, the all-in equipment price was on the order of $10,000 including a thermal imaging sensor.

There are several other potential costs that should be considered. There is liability insurance that may have to be purchased to cover the

Table 1
UAS specifications of the systems used in this study.

Specification	DJI Inspire 1	DJI Phantom 3 Pro
Weight with Camera (kg)	3.06	1.28
Max Horizontal Speed (kph)	79	57
GPS Hover Accuracy (m)	Vertical: ± 0.5 Horizontal: ± 2.5	Vertical: ± 0.1 (Vision Positioning) ± 0.5 (GPS Positioning) Horizontal: ± 0.3 (Vision Positioning) ± 1.5 (GPS Positioning)
Max Flight Time (min)	18	23