Controlling UAVs by Sensing the Electric or the Magnetic Field Around Power Lines

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***Abstract*—We provide a procedure for estimating the relative position of a drone with respect to three-phase power lines. This is done by making use of the root mean square (rms) measurements of the electric/magnetic fields emanating from the power lines. Maxwell's equations are used to derive the sensor measurement model showing that the total rms electric/magnetic field is a measure of the relative position of the drone. The squared inverse of the total rms electric/magnetic field serves as a potential function for a Hamiltonian, which in turn is a Lyapunov function. It is shown that the gradient of this potential function always points to the (convex hull of the) power lines. Based on Lyapunov analysis, a control algorithm is developed that forces a drone to follow the gradient of the potential to the power lines. This controller provides the capability to inspect power lines or carry out installation tasks on them. Simulations are presented to illustrate the efficacy of the approach.**

***Index Terms*—Electrodynamics, state estimation, control.**

I. Introduction

ROBOTIC automation has been expanding in scope over the last few decades. Many aspects of our everyday lives has been penetrated by service robots that improve the quality or efficiency by which certain tasks are performed. Efficient power distribution is another such area whose efficiency can be improved with the help of robotic agents, but this potential has yet to be exploited due to some technological gaps.

Power transmission and distribution through power lines are fundamentally limited by the amount of current a given power line can carry. This depends on several factors, but perhaps the most important is the weather environment around the power line. Currently, power companies rate the maximum current using what called a static-line rating (SLR), which is a worst-case capacity for a power line, based on empirical seasonal temperature estimates without regard to instantaneous weather conditions, such as strong winds, which would help transfer heat from the power line into the surrounding air [1]. This observation hints at a simple conceptual solution to increasing the efficiency of power distribution: measure the instantaneous weather conditions around a power line at regular intervals to determine the amount of power allowed to flow through the wires. This concept may be realized by installing dynamic-line rating (DLR) sensors on power lines, which house an array of sensors, such as wind speed, ambient/line temperature, and line angle. They are powered by small solar panels or even through inductive charging once installed on a power line. These measurements are communicated back to power utilities, who then use this information to determine the amount of power which can be sent through the power lines.

Even though the DLR technology has been known to power engineers for a long time [2], [3], it has largely been underutilized until recently because of the cost and difficulty in installing DLR sensors. Helicopter installations are dangerous due to the necessity that they must hover at low altitude next to a live power line [4]. Fortunately, recent advances in drone technology provides an alternative method to autonomously place these sensors. As for any robotic manipulation task, this one requires accurate localization of the drone with respect to the power lines so that the drone can perform the installation task.

Conventional state estimation schemes, involving vision-based systems and time-of-flight sensors have difficulty in performing accurate localization as power lines have a small volumetric footprint. The video in [5] shows a DLR sensor being installed on a live power line at the Idaho National Laboratory by one of the authors (Z.A.). An additional video in [6] shows the first-person view of Z.A. installing a DLR sensor on another power line. It can be observed that the drone must approximately be within a foot from the power line for localization. Further, small noise in image formation can easily cause large localization errors since the cross-section of a power line occupies just a few pixels in a camera's image. Magnetometers will not work next to a power line. Furthermore, a GPS cannot provide the position of the UAV with respect to a power line. Instead of relying on conventional state-estimation modalities, we exploit the measurements of the electric and/or magnetic fields around power lines in order to perform localization. We develop a model of this

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