UAV-Assisted Electromagnetic Look-Ahead Sensing to Support Risk-Aware Horizontal Directional Drilling in Urban Environments

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In the United States, electrical system interruptions cost consumers billions of dollars annually, partially due to the damage to the aboveground outdated grid system by severe weather events. While Subsurface installation of power lines has been demonstrated to enhance the resilience of power systems, current power line undergrounding technology presents challenges. The conventional open-trench approach, which involves excavation, installation, and backfilling, could result in surface damage and significant social or traffic disruption in urban areas. In comparison, trenchless methods like horizontal directional drilling (HDD) offer a low-impact alternative. However, they carry a risk of collision with existing subsurface utilities. This trade-off underscores the urgent need for risk-aware sensing strategies to detect and avoid obstacles, ensuring safe infrastructure management in dense urban environments.

Accordingly, we proposed an UAV-assisted logging-while-drilling (LWD) real-time electromagnetic (EM) resistivity sensing modality for horizontal directional drilling. The proposed methodology adopts a tomographic imaging and drilling workflow, as illustrated by the reference configuration in Figure 1(a). In this scheme, the transmitting antenna on the drilling tool radiates electromagnetic field through the subsurface medium, and the resulting responses are recorded by receiving antennas mounted on airborne UAV platforms. The acquired signals are first processed by an onboard embedded computing unit for preliminary conditioning. As the speed of the UAV is much higher than the drilling rate, multiple UAV-LWD measurements can be taken for any drilling station, even using just one UAV, within a relatively brief span. After data acquisition, the measurement is utilized to reconstruct subsurface images in front of the drill bit, which are subsequently used to inform and tune the HDD trajectory to avoid risks.

Compared with conventional LWD sensing technology in the oil and gas sector that mainly provides lateral, the proposed UAV-LWD sensing approach can greatly improve the look-ahead sensitivity to detect and avoid underground infrastructure or obstacles ahead of the drilling trajectory, as illustrated in Figure 1(b). This look-ahead capability is particularly relevant for urban engineering geology, where complex underground conditions pose significant risks to construction safety. By integrating the UAV-LWD sensing approach with trenchless construction, this study contributes to urban subsurface monitoring and risk-aware underground infrastructure development, offering a new pathway toward safer and more resilient urban utility installation under increasing climate and hazard pressures.

Keywords: Electromagnetic induction, Subsurface sensing, Powerline undergrounding, Unmanned aerial vehicle, Horizontal directional drilling

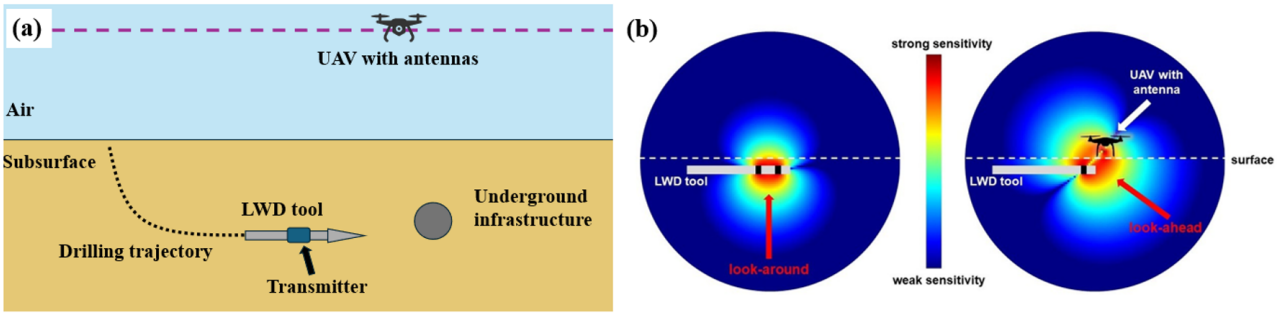

Figure 1. (a) The schematic for proposed tomographic subsurface imaging and drilling procedure in HDD applications. (b) A simulation result compares the sensitivity of traditional EM LWD sensing system and the UAV-LWD system. Traditional resistivity LWD tool (left) itself mainly provides lateral sensitivity ("look-around") while (right) UAV-LWD provides strong "look-ahead" sensitivity.