Poster: Empower Smart Agriculture with RFID Reference Infrastructure

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***Abstract*—The burgeoning field of smart agriculture is increasingly leveraging unmanned aerial vehicles (UAVs) for data collection. However, inadequate visual features and plant occlusion can hamper visual-based simultaneous localization and mapping (SLAM) of UAVs. As a potential solution, RFID can work as an efficient reference infrastructure, enabling a connection between aerial imagery and real-world contexts. Despite this promise, hurdles remain in attaining high-accuracy, high-throughput, and long-range RFID localization, as well as practical deployment of RFID tags and reader implementation on UAVs. Overcoming these challenges holds significant potential, particularly considering their impact on numerous applications, such as large-scale agricultural management and plant stand reduction detection.**

I. Introduction

Agriculture is a critical cornerstone of human civilization. Emerging trends such as smart agriculture, offer innovative approaches to enhance farming practices through advanced technologies. Unmanned Aerial Vehicles (UAVs), colloquially referred to as drones, have gained widespread acceptance in agriculture, offering robust solutions for agricultural applications such as crop monitoring, yield estimation, and disease detection. To align features in aerial images with corresponding real-world locations, UAVs routinely utilize Simultaneous Localization and Mapping (SLAM) methodologies, generating accurate maps based on UAV motion and image streams.

Current UAV SLAM strategies typically leverage inherent sensor data (*e.g.,* GPS, Lidar, IMUs) and external visual features and structures. Nevertheless, these techniques often fail in various agricultural scenarios due to the scarcity of distinctive visual features in expansive fields. Additionally, the deployment of external visual landmarks (*e.g.,* colorful flags or barcodes) may fail due to possible occlusions by plant leaves or mulch. Radio Frequency Identification (RFID) technology, which employs radio frequency markers or tags for object or individual identification and tracking, holds promising potential as a novel landmark solution in agricultural fields. RFID-based reference infrastructure for SLAM comes with several advantages: Primarily, RFID tags operate on a non-line-of-sight principle, thus eliminating concerns over occlusion issues. Secondly, RFID tags offer the capacity for information storage. These tags can house data, typically ranging from 512 bits to 8k bits, relating to plant features and environmental conditions, making them uniquely equipped for this application. Thirdly, RFID tags are cheap (*e.g.,* 5 cents each) and battery-free for large-scale deployment, comparing to other RF-based solutions like BLE or Wi-Fi. Lastly, the cost-effectiveness (*e.g.,* as low as 5 cents each) and the battery-free nature of RFID tags make them an attractive solution for large-scale deployment, which offers a marked advantage over other RF-based solutions like BLE or Wi-Fi.

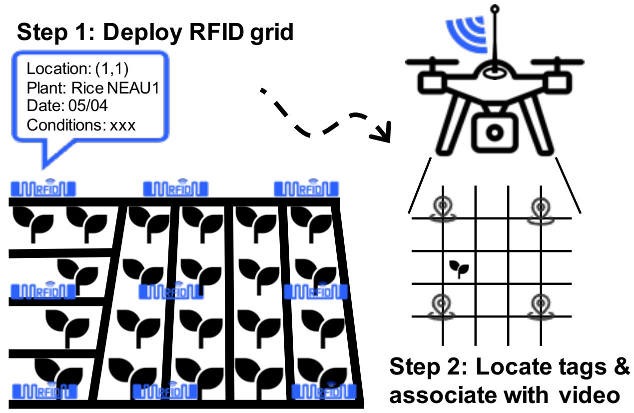

Figure 1: Deployment of RFID-Based UAV Reference Infrastructure: the procedure begins with the deployment of RFID tags grid containing plant and location information. These tags are subsequently scanned and located by an airborne reader, with the resultant data integrated with video content.

II. Design and Challenge

Deploying an RFID-based reference infrastructure involves two key steps as depicted in Fig. 1: 1) Grid deployment: This step involves the pre-emptive placement of RFID tags in a grid-like formation across the field of interest. Essential information (e.g., ID, coordinates, proximate plant details) is encoded onto these tags. This setup bears similarities to the GPS constellation, where grid density must be sufficient to guarantee that UAVs can access an adequate number of tags to infer location with precision at any given point and time. 2) UAV scanning: In this stage, a UAV outfitted with an RFID reader traverses the field with the RFID grid, querying tags and collecting their response packets. The UAV then uses this packet data to estimate the location of the tags, and subsequently, its own location and orientation. Additionally, these packets can relay local information about proximate plants, such as their varieties, planting dates, and conditions.

Systems	Throughput	Range	Accuracy
xSpan (commerial RFID system)	**200 tags/s**	12 m	Low
Tagoram [3]	5 tags/s	2 m	Median
RFind [4]	0.16 tags/s	6 m	**High**
TiSee [5]	NA [1]	5 m	**High**
PushID [6]	NA	**64 m**	Not Support
POLAR [1]	NA	3 m	**High**
RF-Chord [7]	**180 tags/s**	6 m	**High**

Table I: Performance of SOTA RFID systems: none of them meets all the requirements of throughput, range, and accuracy.

Despite the promising potential of RFID-based reference infrastructure, the practical implementation of real-world systems and high-efficiency RFID localization systems continue to pose significant challenges. In the following discussion, we list SOTA RFID localization/reading systems in Tab. I and delve into these challenges with their performance limitation.

Deployment Challenge. The integration of RFID readers onto UAVs, and the grid-based deployment of RFID tags in the field, come with their own set of substantial challenges. Firstly, conventional RFID localization systems are generally sizeable and heavy, making their integration onto UAVs a complex task. Further miniaturizing these systems can result in a significant decrease in their effective performance [1]. Secondly, deploying tags in a grid-like formation across a field, and associating them with relevant plant information, is a process that is not only time-intensive but also susceptible to errors. This necessitates the development of an automated method for tag deployment. Lastly, the signal quality of RFID tags can experience significant degradation when placed near liquid environments [2]. This can impede the successful implementation of RFID grids in certain agricultural scenarios, such as paddy fields designated for rice cultivation.

Localization Challenge. RFID localization forms a crucial part of the RFID-based reference infrastructure for UAVs. However, achieving high-accuracy, high-throughput, and long-range localization concurrently presents a significant technical challenge. Numerous existing localization systems can provide centimeter-level median accuracy, yet their evaluations often overlook long-tail and in-the-wild errors. Moreover, these systems tend to have limited localization throughput–defined as the number of tags a reader can locate per second–which can potentially constrain the flight speed of UAVs. The mainstream RFID localization systems [3], [4], [5], [1] typically require the receipt of multiple packets (*e.g.,* 10) from different locations to form a synthetic aperture radar for single tag localization. This implies a trade-off between accuracy and throughput: reading one tag more times means higher accuracy but lower throughput and vice versa. Working range is another concern. High-precision RFID localization systems typically operate within only a few meters while the flight height of agricultural UAVs often exceeds 10m. Longer distances result in a lower Signal-to-Noise Ratio (SNR), which simultaneously compromises accuracy and read throughput.

III. Opportunities

Leveraging RFID-based reference infrastructure can propel new smart agriculture applications. One example is large-scale breeding experiment management. Agriculture scientists conduct experiments with crops of different genotypes under various conditions (e.g., soil, irrigation, and fertilization). RFID-based reference infrastructure enables UAVs to associate observations of different phenotypes (e.g., height, lodging, leaf area) with specific locations and experimental conditions stored in RFID tags. Another example is plant stand reduction detection, which involves monitoring decreased plant numbers due to factors like low germination rates, pest infestation, or adverse weather. With an RFID-based reference infrastructure, UAVs can detect such reductions and map them to specific locations and pre-stored plant information, providing a comprehensive data set useful for informed replanting decisions.

In essence, an RFID-based UAVs' reference infrastructure can integrate three distinct types of information: 1) computer vision-based data from aerial videos; 2) related information of local plants from RFID readings; 3) mapping of aerial images with real-world locations, facilitated by RFID localization. This fusion of cyber-real-world information has the potential to significantly enhance farming management practices and catalyze the development of promising agricultural applications.

IV. Summary

Historically, RFID localization has been mainly associated with *indoor* localization systems, focusing on accuracy. This focus often results in the overlooking of equally essential facets, namely throughput and working range, particularly in the context of *real-world* applications. In this work, we explores the opportunities and challenges involved in utilizing RFID as an outdoor reference infrastructure for UAVs. We believe that this discourse will incite renewed research interest in the domain of RFID localization *in the wild*, and also promote the evolution of wireless-enabled smart agriculture.

References

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[1] NA refers to 'Not Reported'. However, we can conjecture that the throughput might be close to that of Tagoram because they employ a similar SAR technique. This inference could also be applied to POLAR.