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Optimization of Intelligent Irrigation Systems for Smart Farming Using Multi-Spectral Unmanned Aerial Vehicle and Digital Twins Modeling †

Muhammad Awais [1], Wei Li [1,*], Haoming Li [1], Muhammad Jehanzeb Masud Cheema [2,3], Saddam Hussain [3,4,5] and Chenchen Liu [1]

1 Research Center of Fluid Machinery Engineering & Technology, Jiangsu University, Zhenjiang 212013, China
2 Department of Land and Water Conservation Engineering, PMAS Arid Agricultural University, Rawalpindi 46000, Pakistan
3 National Center of Industrial Biotechnology (NCIB), PMAS Arid Agricultural University, Rawalpindi 46000, Pakistan
4 Department of Irrigation and Drainage, University of Agriculture Faisalabad, Faisalabad 38000, Pakistan
5 Department of Agricultural and Biological Engineering, University of California (UC Davis), Davis, CA 95616, USA
* Correspondence: lwjiangda@ujs.edu.cn; Tel.: +86-186-5285-0503
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Abstract: This research presents the new techniques and practical experiences of using unmanned aerial vehicles (UAVs) precision agriculture mapping. UAV-based remote sensing systems should be cost-effective, fast-producing, have high geometric accuracy, and be simple to operate by local staff. This work aims to: (1) precisely use high-resolution UAV thermal multi-spectral sensors and machine learning approaches to reliably assess crop water status on a field scale; (2) capture on-field images for quantitative study from the multi-spectral sensors; (3) establish workflows for digital agriculture applications; (4) interpret the intelligent irrigation decision model using UAV indices, maps, and multi-source heterogeneous data integration. This research gives us new methods to set an intelligent method for precision agriculture, which greatly improves the level of agricultural intelligence.

Keywords: UAV application; soil monitoring; infrared image processing; principal component analysis; digital twin

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1. Introduction

The growing global population necessitates an increase in food production, which consumes around 85% of the freshwater resources available [1]. The biggest hurdle preventing China and other emerging countries from achieving long-term sustainable development is a lack of water, and water crises will become the biggest concern for the next 10 years [2]. At present, digital twin technology, one of the top ten key technologies for the future, has been applied to the field of smart agricultural irrigation [3,4]. Soil with inadequate drainage capacity and a hard layer is not suitable for rice–wheat production [5]. The overarching aim of this study is to: (1) precisely use high-resolution UAV thermal multi-spectral sensors and machine learning approaches to reliably assess crop water status on a field scale; (2) capture on-field images for quantitative study from the multi-spectral sensors; (3) establish workflows for digital agriculture applications; (4) interpret the intelligent irrigation decision model using UAV indices, maps, and multi-source heterogeneous data integration. This experiment was performed in a tea field located in Jurong, China. The outcomes of this research will have a great benefit for both farmers and the industry.

2. Materials and Methods

2.1. Description of the Test Area

This experiment was performed on cultivated land located in the Maoshan Tea Garden experimental zone in Jurong City (32°1′00″ N, 119°4′00″ E), Jiangsu Province, China (Figure 1). The texture of the field soil is silty loam. Most of the instruments were deployed in the center of the study field on a flux tower to ensure that the prevailing wind direction had the most significant footprint. The tea plants (Camellia Sinensis) were six years old, with row and plant spacing of 1.5 and m, respectively.

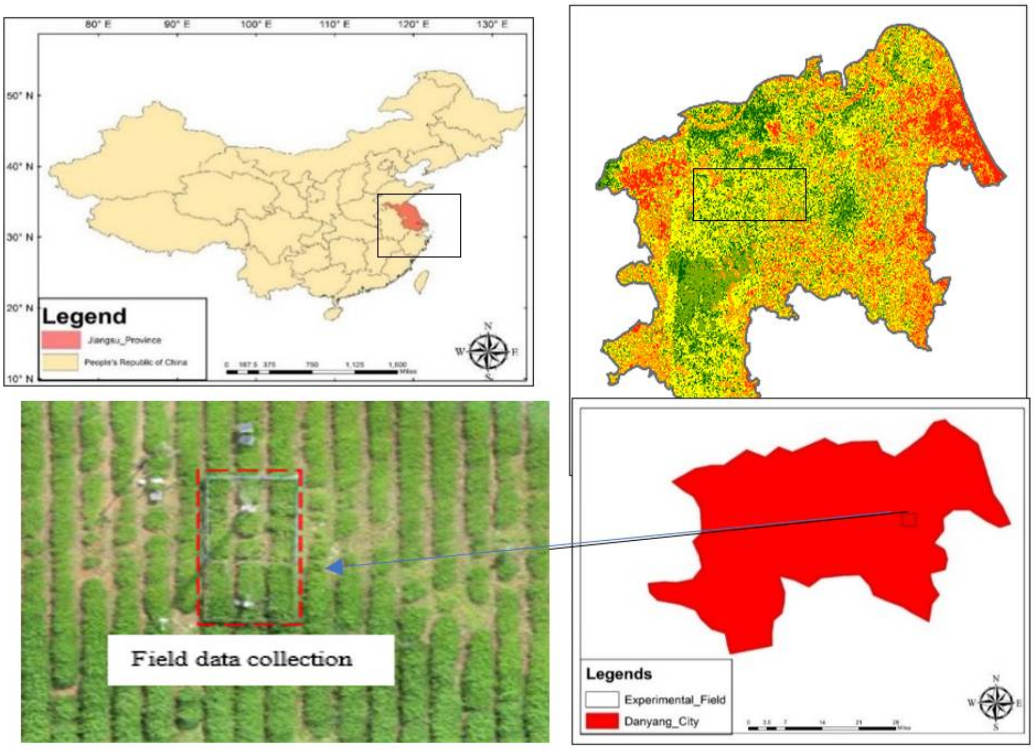

Figure 1. Study map of the experimental site.

2.2. Airborne Image Acquisition

The digital and thermal photos were collected using a quad-rotor UAV equipped with a multi-spectral sensor to capture spectral photos (Figure 2). During crop growth, we performed an airborne campaign to gather photos at various times of the day (9.00, 11.00, and 14.00 h.). Throughout the experimental field, several arbitrary GCPs (ground control points) were measured, and coordinates were calculated with a total precision of 0.1 m. For the orthomosaic map and picture pre-processing, a Pix-4D mapper and DJI Terra were applied. This program was created primarily for photogrammetry and computer visualization techniques to handle UAV images.

(**a**) (**b**)

Figure 2. Types of UAVs and sensors used in this study: (**a**) quad-rotor UAV with RGB sensor, DJI Phantom 4 RTK, (**b**) flying operations.

2.3. Intelligent Decision-Making Irrigation Systems

Figure 3 shows the design framework of the system, which deeply integrates the digital twin, the internet of things, big data, wireless transmission technology, cloud computing, and automatic control technology to build a physical layer, a data acquisition layer, a twin model layer, a functional layer, and an application layer. In addition, it is necessary to build the hardware perception and control system of the digital twin irrigation system from the perspective of the system level. With the help of various types of sensors and electrical control methods, the interconnection and intercommunication of various types of irrigation equipment in farmland can be realized, so as to carry out unified information operation, maintenance, and control.

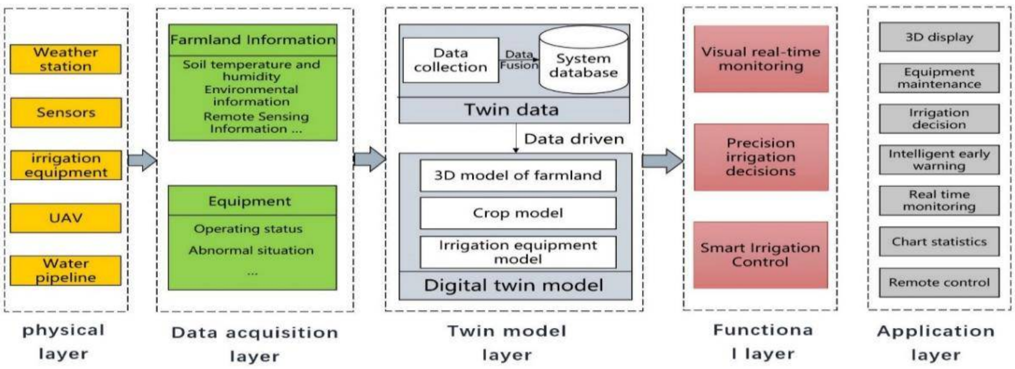

Figure 3. Block diagram for an intelligent irrigation system using a digital twin.

3. Results and Discussion

In this paper, a complete field automatic irrigation control system was built through the whole system design and the selection of the system hardware. The irrigation supervisory control system was tested (Figure 4). The pipeline used in this test was the PVC pipeline. The diameter was 20 mm, and the distance between the upstream and downstream probes was 4.05 mm, according to the calculation. The main tests were: the reliability test of the circuit hardware, the stability test of the wireless network communication, the security test of the power supply system, and the overall operation test. The wireless network communication status test is mainly about the communication distance and the networking stability of the communication module. The power supply system test is mainly about the safety and stability of the battery power supply, as shown in Figure 4 below. After the test is completed in the laboratory, the equipment is installed in the tea garden irrigation system for field application.

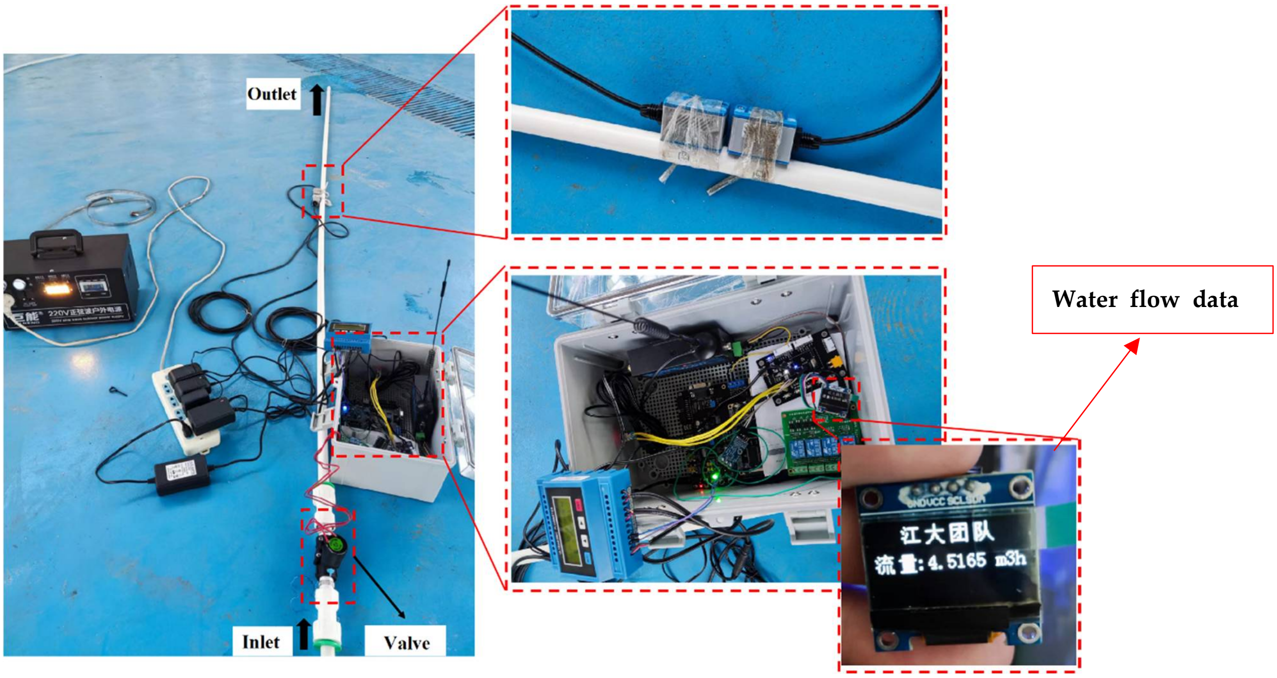

Figure 4. Spot application test.

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Conflicts of Interest: The authors declare no conflict of interest.

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