SIGNAL CHARACTERIZATION OF ICT COMPONENTS FOR MALFUNCTION DETECTION FOR OPEN-FIELD IRRIGATION SYSTEMS

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ABSTRACT

Agricultural practices in open fields increasingly rely on automated irrigation technologies and ICT components, whose operational status impacts their reliability and efficiency. This study aimed to develop a malfunction detection pattern for sensors and actuators through signal characterization in an open-field irrigation setup. The experiment included environmental sensors and actuators, interfaced with a programmed microcontroller, operating in cycles (On/Off) or alternatively. Signals were continuously recorded under normal and induced faulty conditions using a real-time data acquisition module. Time-domain (RMS, variance, peak) and frequency-domain (dominant frequency, spectral entropy) features characterized component status, with instability and amplitude changes indicating faults. A two-stage hybrid machine learning framework managed complex, dynamic signal patterns, enabling robust detection beyond traditional methods. A feature-optimized k-Nearest Neighbors (kNN) algorithm was applied for rapid classification, followed by a lightweight, wireless sensor network compatible ensemble model for result verification. Statistical thresholding filtered transient noise, reducing false positives. An adaptive learning strategy was also integrated to update model parameters using newly labeled operational data incrementally. High detection performance is expected, with a mean average precision potentially reaching 96% across all the components, and detailed findings will be documented in a future scientific publication. This method uses robust signal characterization and adaptive machine learning to provide a scalable, real-time, and low-cost solution for detecting malfunctions that enhance open-field irrigation system reliability and automation under diverse conditions.

Keywords: Smart agriculture, ICT components, open-field irrigation, signal characterization, hybrid machine learning

INTRODUCTION

ICT-enabled irrigation management demonstrates significant potential to enhance water productivity in open-field agricultural farming, provided that irrigation components operate reliably (Benameur et al., 2024). However, sensor and actuator malfunctions frequently result in excessive water loss and increased crop water stress. Traditional malfunction detection methods based on static thresholds or manual inspection often fail under varying weather

conditions and gradual component degradation. Signal characterization, using spectral patterns and static variations, combined with machine learning techniques, enables real-time fault detection and irrigation efficiency. This study aims to develop a malfunction detection pattern for sensors and actuators through signal characterization in an open-field irrigation setup.

MATERIALS AND METHODS

Temperature, relative humidity, soil moisture, solar radiation, rainfall, wind speed, pump, and solenoid valve sensors provided signal data. Missing values and noise were checked, then reduced with a low-pass filter (LPF), and outliers were removed with a median filter. Time-domain features comprised root mean square (RMS), variance, and peak amplitude, while frequency-domain characteristics included dominant frequency and spectral entropy. To monitor multifunction, amplitude, and spectrum variation features were chosen. A k-Nearest Neighbors (kNN) classifier was trained and tested on the collected dataset to characterize data patterns in normal and abnormal conditions.

RESULTS AND DISCUSSION

The application of a low-pass filter and a median filter improved the performance of the multifunction detection model. Without preprocessing, the model achieved an overall classification accuracy of 89%, with a mean average precision (mAP) of 88%, a precision of 87%, a recall of 88%, and an F1-score of 0.88. After preprocessing, the model performance increased substantially, achieving an accuracy of 96%, mAP of 96%, precision of 95%, recall of 96%, and an F1-score of 0.96.

CONCLUSIONS

A two-stage machine learning framework for irrigation malfunction detection was developed, combining signal characterization with an adaptive learning routine to provide high accuracy and low false alarms, making it suitable for deployment on low-power devices in the field.

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