Progress in IS

Jorge Marx Gómez
Anael Elikana Sam
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Smart and Secure Embedded and Mobile Systems

Selected Papers from the First International Conference on Embedded and Mobile Systems (ICTA-EMOS), 24-25th November 2022, Arusha, Tanzania

Springer

Progress in IS

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A Machine Learning Internet of Agro Things (IoAT)—Adaptive Smart Cloud Farming System for Small-Scale Farmers in Tanzania

Alcardo Alex Barakabitze and James Robert

1 Introduction

Crop cultivation is the main agricultural activity of Tanzanian small-scale farmers (SSFs), which consist on average of more than five household members with a mean land holding capacity of around 1.2 hectares. An average small family farm in Tanzania generates a gross income of about USD 5032/year [1]. On-farm activities contribute 56% of this income while the growing and selling of crops contribute to 47%. Although on-farm income is still the most important source of livelihood, poverty remains high and 39% of the smallholders in Tanzania live below the national poverty line. Despite ongoing agricultural growth in the country, there are poor farm management techniques that do not proactively solve current agricultural problems, for example by forecasting risks such as those affecting crop performance due to mismanagement of resources. Environmental factors such as soil fertility, moisture, and weather conditions adversely affect crop production and need urgent attention whenever detected [2]. Unfortunately, farmers who attempt to improve the condition use local techniques to identify and forecast pests and disease outbreaks and perform irrigation schedules that depend on abstract weather and soil conditions information [3].

Sensor technology using the Internet of Things (IoTs) in agriculture offers good support and allows farmers to simply map their areas. Researchers in the agriculture field use the latest technology, such as multispectral cameras, satellite photography, remote sensing, and drones, with the help of the IoTs and cloud computing, to

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rely heavily on sensor technologies for monitoring and manage on-farm and crop performance. The introduction of sensor technologies that improve crop and soil quality, food safety, sustainability, and profitability has resulted in an increase in the production level of agriculture [4]. Farmers may be relieved from the duties of owning servers by implementing IoT networks across Tanzania that are utilized by remote servers or cloud computing technologies [4]. Open-source Long Term Evolution (LTE) modem that utilizes the technology to send the data from a distant location and solar-powered allows us to send text and multimedia data in Tanzania. Therefore, this chapter proposes a Machine Learning (ML) IoT-based smart farming system with cloud computing for farmers in Tanzania by implementing remote sensors like soil moisture sensors, imaging sensors, and weather sensors. Cloud computing will be used to store and interpret data that is received from individual sensors and use the ML algorithm to forecast crop performance, predict pests and disease outbreaks, detect crop stress, and recommend irrigation schedules for farmers. The expected impacts and outcomes of this innovation include (a) increased crop productivity and (b) training and imparting modern farming techniques to smallholder farming groups (e.g., women farming groups) in Tanzania.

1.1 Research Challenges and Motivation

Smallholder farmers employ about 70% of the world's population and produce 70% of the world's food. Tanzania's agriculture sector accounts for 26.7% of GDP and employs more than 80% of the population, with women accounting for 60% of the farm workforce. Most small and medium-sized farmers in Tanzania, on the other hand, cannot afford to embrace such advanced equipment for sustainable agriculture, which goes against the UN Sustainable Development Goals (SDG) tenet of "leaving no one behind." Although the use of digital technologies can help address some of the issues, success in this area has been limited and has not been scaled up sufficiently [1]. The agriculture sector in Tanzania is confronted with the following issues [5]: pests and diseases which are the critical burning issues for SSFs in Tanzania. Small and marginal farmers own less than two hectares, resulting in insufficient farm revenue and poverty. Soil degradation and water stress are the outcome of unsustainable farming methods. Lack of data at the farm, farmer, and sector levels, resulting in greater service costs; Food waste is increasing due to a lack of food processing, logistics, and warehousing infrastructure near farm gates. Financial and digital inclusion challenges; Gaps in market linkages, difficulties in price discovery for farmers, and market price volatility; due to financial constraints and farm mechanization which is inadequate [5–7]. This chapter addresses these gaps by implementing a ML-IoT-based management system for increasing agricultural productivity. The developed AI/ML-IoT-based solution will be able to monitor and manage in real-time crop performance and provide decision support tools for Small-scale farmers (SSFs) in Tanzania.

1.2 Research Objectives and Contributions

The main objective of this chapter is to develop a ML-based adaptive smart farming management system with an open IoT solution over cloud computing to increase agricultural productivity of SSFs in Tanzania. The main contributions of this chapter are twofold:

- We propose and develop an efficient ML-driven IoT-based cloud computing farm management and monitoring system to monitor in real-time crop performance and provide decision support tools for SSFs.
- We provide the implementation of the proposed using real-time devices that send and receive data for the farmers' recommendations.
- We develop measures and recommendations that that will support decision-making in terms of policy and intervention strategies in the context of spreading crop diseases among plants in the farms belonging to these regions.

2 Related Work

Rapid developments in the IoT, cloud computing, robotics, and AI are accelerating the transition to smart farming and the promotion of big data and precision agriculture to improve agri-food sustainability [2]. Previous works investigated the application of ML and IoT technologies for improving agriculture [2, 8]. Aworka et al [8] propose three prediction models: crop random forest, crop gradient boosting machine, and crop support vector machine where data on crop productivity, the use of pesticides, and the climate are combined to create a decision-making system based on cutting-edge machine learning algorithms. Authors suggested a decision system that can forecast crop yields at the country level in 14 East African countries despite the limited availability of agricultural data in Africa. Ayaz et al [2] provide the potential of IoT and wireless sensors in agriculture, as well as issues that are anticipated when integrating this technology with conventional farming methods. The authors present state-of-the-art IoT-based architectures and platforms used in agriculture. However, the authors do not provide any implementations and prototypes of IoT/ML for agriculture. Lufyagila et al [9] propose the IoT technology for low-resource smallholder farmers to monitor environmental conditions in chicken houses. Compared to the conventional approach, the system saves time (84%) and labor costs (66.7%) since the farmer can remotely monitor and regulate the conditions with security and dependability. Additionally, the chapter suggests an algorithm for the system's online and offline functionality (i.e., synchronizing with the cloud server when Internet access is available). However, these works are limited in the implementation aspects of integrating ML and the IoT devices in monitoring and managing crops performance. There is also no real-time implementation in these works stated above, making serious concerns for their adoption by smallholder farmers in Tanzania. There has been a limited study in the area of providing a real-time implementation and a prototype of AI/ML-IoT-based solution to monitor and manage crop performance and provide decision support tools for Small-scale farmers (SSFs) in Tanzania.

3 Research Methodology

3.1 Study Area

This study was carried out in Morogoro at SUA farming sites. The study area was selected based on climate-related conditions and easy monitoring of study implementation. We utilized a group of weather, soil, and environmental sensor nodes positioned at different locations in the farms/plots to communicate with the gateway over local telecommunication systems to measure the growth and performance of root activity of crops in the farms.

3.2 A Proposed Architecture for ML-Driven Agriculture IoT-Based Farming Monitoring and Management System in Tanzania

The proposed IoT-based ML farming management system using cloud computing, virtualization, and big data analytics employs weather, soil, and environment sensors to monitor crops growth and predict diseases and pests, detect crop stress, and predict yield based on the following components: the gateway, cloud infrastructure, pests and disease prediction, crop stress prediction, and smartphone application.

3.2.1 A Network Gateway

A network gateway acts as an interface between the field sensors (soil moisture sensors, weather stations, humidity sensors, and crop health sensors) and the central server or cloud-based platform, allowing data to be transmitted, processed, and acted upon. It enables the collection, transmission, and analysis of data related to agricultural activities in order to optimize crop production and facilitate efficient farm management. Advanced algorithms and ML techniques can be applied to derive meaningful insights from the collected data. This analysis can help identify patterns, predict crop growth, detect diseases, and optimize resource usage. Based on the analyzed data, the gateway system can generate alerts, notifications, and recommendations for farmers and agronomists. For example, it can send alerts about soil moisture levels dropping below a certain threshold, indicating a need for irrigation. These alerts can be delivered through mobile apps, SMS, or email (Fig. 1).

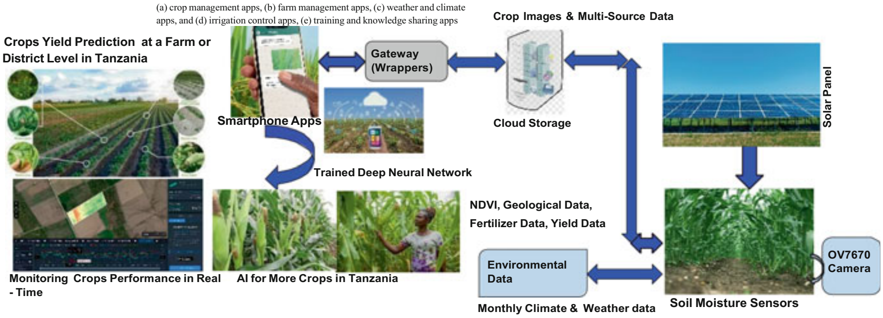

Fig. 1 The ML-driven IoAT-based farming monitoring and management architecture in Tanzania

3.2.2 Environmental Data

The environmental data from different IoT devices (sensors) is collected and filtered using the gateway. We employ an OpenIoT Extended Global Sensors Network (X-GSN) component to perform data ingestion and to facilitate the deployment and programming of sensor networks [10]. We also use wrappers to encapsulate the data received from the data source into the standard X-GSN data model. Note that the wrapper is an interface that allows the gateway to pull/push data from/to the underlying IoT device (sensor). We deploy gateways at various sites or locations in farms/plots consisting of sensors.

3.3 ML-Driven IoAT Prototype Implementation in Real-Time

3.3.1 Cloud Storage Infrastructure

We use ThingSpeak (https://thingspeak.com/) to store and manage the data that are generated by sensors. ThingSpeak allows you to aggregate, visualize, and analyze live data streams in the cloud [11]. ThingSpeak provides instant visualizations of data posted by IoT sensors. To handle a large volume of data streams from different IoT devices both (virtual and physical) implements publish/subscribe queues and stores the sensor data in the resource description framework (RDF) format. Different metadata, functional data for small-scale farmers' accounts, and ontology are stored in the cloud infrastructure. The ontology refers to farmers' plots descriptions, types of crops cultivated (e.g., maize and tomato), and different treatments (e.g., plots/farm irrigated or not irrigated) applied to the plots. Using these ontologies, farmers can perform basic operations (reading, updating, deleting) data from IoT devices (sensor) using a Smartphone Application interface. Then, interactive data analytics and interpretation will be delivered to farmers' smartphones after specifying specific information such as crop species selected, amount of crops soil moisture contents in the farm, types of predicted disease/pests, health and unhealthy crops, and roots activity of crops.

3.3.2 OV7670 Camera

It is used to capture the leaf images throughout the growth period of crops in the farms. We define four collection windows (1-h window, 1-day window, 1-week window, 1-month window, 2-month window) of leaf images based on the root activity measured using the soil moisture sensors. Each of these windows holds data points collected from leaf images which are then used as inputs for developed (a) pests and disease predictions ML algorithm, and (b) crop yield prediction algorithms. For predicting the health of the crop, a camera is also interfaced with the solar panel module. Then, we employ an open-source software namely, OpenIoT (http://www.openiot.eu/) which is deployed in a JBOSS application container. We use it to provide real-time scalable analytics on the sensor data generated from captured crops. The sensor data to be analyzed is delivered to the cloud infrastructure using a local gateway. Weather station: it collects information such as rainfall, humidity, wind speed and direction, and temperature. Soil moisture and temperature sensor: the paper uses the DHT11 Sensor type to measure soil temperature, conductivity, and estimates the amount of water in the soil/farm where crops are cultivated. We use both stationary sensors and portable soil moisture probes in the implementations. We place 40 soil-moisture sensors at multiple locations at depths (e.g., 15 cm–1.5 m) below the soil surface in the farms. The deployed sensors will help us to know the water extraction of crops' roots from the soil throughout the cultivation season.

3.3.3 A/ML-Driven Crop and Farm Monitoring Using IoT

Real-time monitoring of farm operations is performed using the processed data. Farmers can access this information through intuitive dashboards or mobile applications as indicated in Fig. 2. They can monitor various aspects/parameters such as soil moisture, temperature, humidity, light intensity, weather conditions, water levels in reservoirs or tanks, energy consumption, and equipment status. AI algorithms can leverage historical and real-time data to provide predictive analytics. Multiple factors such as weather forecasts, soil conditions, and past trends can be used by the AI/ML algorithms to forecast crop growth, disease outbreaks, or irrigation needs. This allows farmers to plan and make informed decisions in advance. IoT devices and sensors can be integrated with automated control systems to enable remote monitoring and control of farm operations.

AI-driven crop and farm monitoring using IoT technologies offer immense benefits to farmers, including improved resource management, early detection of issues, optimized operations, and enhanced productivity. By leveraging real-time