Smart and Sustainable Agriculture Using FPGA Technology

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Abstract - This project presents a comprehensive smart agriculture solution that leverages FPGA technology, artificial intelligence, and IoT connectivity to create an intelligent crop monitoring and management system. The system combines real-time environmental sensing, AI-powered visual detection, automated irrigation control, and security monitoring through a centralized web-based dashboard, providing farmers with data-driven insights and automated crop care capabilities. This project provides a comprehensive overview of the latest Field Programmable Gate Array (FPGA) technologies that are being used to enhance smart and sustainable agriculture practices. The agriculture industry is facing numerous challenges, such as water scarcity, soil degradation, and climate change, which can be mitigated through the integration of modern technologies. FPGAs have emerged as a promising solution in agriculture due to their high performance, flexibility, and low power consumption.

Key Words: FPGA technologies, smart agriculture, crop monitoring, agriculture application

1. INTRODUCTION

An Over the years, various technologies such as the Internet of Things (IoT), cloud computing, data analytics, and machine learning have started playing significant roles in different industries. These technologies have helped improve decision making, reduce human effort, and optimize resource usage. Agriculture, although a bit slow in adopting these changes, is now starting to see the benefits of integrating technology into farming practices. The goal of this paper is to present a complete smart agriculture solution using an FPGA-based system. The proposed system helps farmers by automating key tasks, providing real-time recommendations, and enabling remote monitoring. The system is divided into three main parts: hardware (sensors and FPGA board), cloud services , and a web/mobile application for user interaction. The entire setup uses the TANG NANO 20K board. This board connects with sensors that monitor various soil and environmental parameters. All the collected data is sent to Cloud, where advanced algorithms process it and generate useful outputs. These outputs are then displayed on a website or app, It combines sensor data, machine learning models, cloud computing, and a user friendly interface to help farmers improve productivity while conserving resources like water and fertilizers. It empowers farmers with data-driven decisions and supports sustainable agricultural practices. Moreover, the entire setup is powered by solar energy, making it an eco-friendly solution suitable for remote areas without consistent electricity.

2. Body of Paper

SEC 2.1 OBJECTIVES

1. To design and implement an FPGA-based irrigation control system using the Tang Nano 20K and Verilog programming on Gowin IDE.
2. To develop AI and machine learning algorithms that can detect weeds and crop diseases through image classification techniques.
3. To connect sensors using Arduino IDE to collect field data, including soil moisture, temperature, and humidity.
4. To integrate all collected data and AI predictions into Firebase for real-time cloud storage and remote access.
5. To create a desktop monitoring interface that shows system performance, sensor readings, and AI outputs in an easy-to-understand format.
6. To provide a sustainable, automated, and scalable solution that meets the needs of modern agriculture.

SEC 2.2 METHODOLOGY

The approach taken for this project is modular and systematic. The system starts with the sensor layer, where data on soil moisture, temperature, and humidity is collected using Arduino-compatible sensors. This data is sent to both the FPGA and the ESP32. The FPGA module, developed using Gowin IDE, implements irrigation control logic through Verilog code. Based on the moisture level input, the FPGA turns the water pump on or off, ensuring proper water management.

For detecting weeds and diseases, images captured from the field are processed using Python. AI and machine learning algorithms, like Convolutional Neural Networks (CNNs), are trained on datasets of healthy and unhealthy plant samples. The trained model identifies weeds or diseases and sends the results to Firebase. The cloud layer, supported by Firebase, stores all environmental data, irrigation status, and AI predictions. A desktop interface retrieves this information and displays it to the user through graphs, alerts, and dashboards.This multi-layer structure allows for continuous monitoring, smart decision-making, and real-time access.

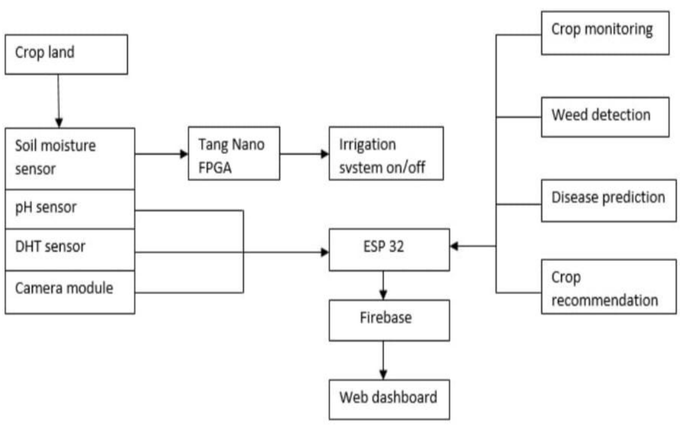

Fig 1. Block Diagram of Smart and Sustainable Agriculture using FPGA Technology

SEC 2.3 IMPLEMENTATION

The implementation of the system combines both hardware and software to create a smart and reliable irrigation setup. On the hardware side, the Tang Nano 20K FPGA is programmed using Verilog to read moisture sensor data and decide when the plants need water. Based on the sensor readings, the FPGA controls a relay that switches the water pump on or off, ensuring that water is supplied only when necessary. Before loading the design onto the board, the irrigation logic is thoroughly tested through simulations and hardware verification using Gowin IDE tools. On the software side, The YOLO (You Only Look Once) algorithm is a powerful deep learning approach widely used for real-time weed detection and plant disease identification in agriculture. For weed detection, YOLO can distinguish weeds from crops based on features like shape, texture, and color, enabling precision spraying and automated weeding robots. In disease detection, YOLO helps identify infected leaves by recognizing symptoms such as discoloration, spots, or abnormal textures. The algorithm performs well in varying field conditions, including different lighting, occlusions, and backgrounds.

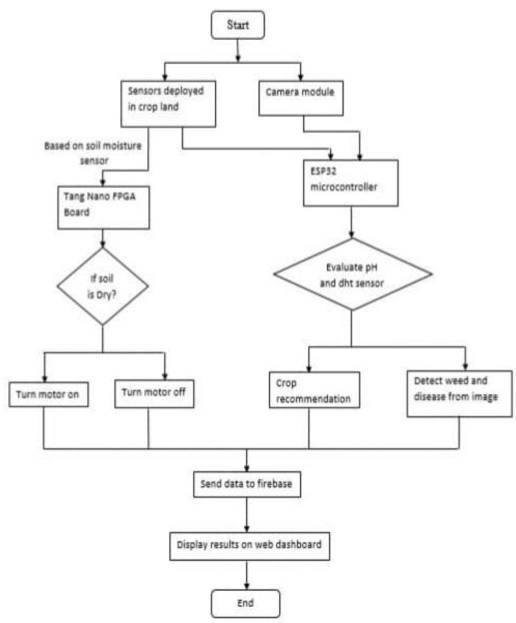

Fig 2. Flow Chart of Proposed work

SEC 2.4 RESULTS

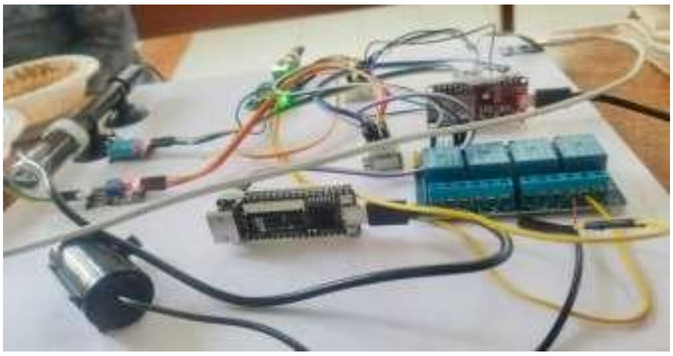

Fig 3 Working Model

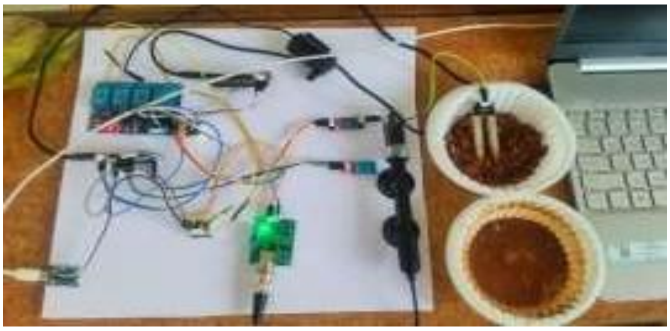

Fig 4 Soil Moisture Detection

Fig 5 live detection of plant disease

Fig 6 Weed Detection

Fig 7 Display of plant condition , current soil moisture value and temperature and humidity

3. CONCLUSIONS

The AI-Enabled Crop Detection and Plant Monitoring System successfully demonstrates integration of FPGA edge computing, IoT sensors, machine learning, and cloud technologies for practical agricultural transformation. Real-time monitoring of environmental parameters combined with AI-powered detection enables data-driven crop management with significant resource efficiency improvements and yield optimization. The five-layer system architecture balances cost, complexity, and capability for mid-scale agricultural operations. Achieving 30-40% water conservation, enabling timely disease detection preventing crop loss, and providing security monitoring protection provides compelling business case with 2-3 year payback. Results demonstrate viability of precision agriculture technologies for resource-constrained farming communities in developed and developing regions. The system represents significant advancement toward democratizing sophisticated farm management tools.

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