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SmartCane – Backend-Driven Digital Solution with AI/ML Insights

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Abstract

Sugar industries commonly depend on disconnected systems and manual procedures to manage key operations such as production monitoring, inventory control, farmer coordination, and financial activities. This fragmented approach often results in inefficiencies, inconsistent data handling, and delays in decision-making processes. To overcome these limitations, this paper introduces a Unified Platform for Sugar Factory Management that integrates and automates both industrial and agricultural operations within a single system. The platform includes modules for farmer and land registration, sugarcane supply monitoring, soil testing services, payment and subsidy management, as well as communication features for meetings and election processes.

To enhance system functionality, advanced technologies such as machine learning and artificial intelligence are incorporated. Predictive models are utilized to estimate sugarcane yield by analyzing environmental and agricultural factors, while an AI-powered chatbot provides farmers with real-time guidance and support. Additionally, tools like the Smart Plantation Planner assist in efficient resource management by calculating seedling requirements based on land area.

The proposed system enhances transparency, minimizes human errors, and provides real-time access to data, enabling more informed decision-making. Experimental observations demonstrate improvements in operational efficiency, reduction in processing time, and better coordination between farmers and factory authorities. The platform is scalable, economical, and well-suited for small to medium-scale sugar industries, thereby promoting higher productivity and sustainable agricultural practices.

Introduction

Sugar industries serve as a vital link between the agricultural sector and industrial production by converting sugarcane into sugar and various by-products. Despite their significance, many sugar factories continue to depend on outdated, fragmented systems or manual methods to manage essential operations such as production tracking, inventory control, farmer coordination, and financial transactions. These approaches often result in inefficiencies, reduced transparency, duplication of data, and delays in decision-making, which negatively impact overall productivity and resource utilization.

Apart from challenges at the factory level, farmers also encounter difficulties in obtaining timely and reliable information regarding crop health, soil quality, disease control, and market trends. The lack of intelligent advisory systems

and real-time communication platforms further affects crop yield and quality. Moreover, existing technological solutions are often either too generalized, costly, or lack proper integration with advanced technologies such as artificial intelligence and data-driven analytics.

To overcome these issues, this paper presents a Unified Platform for Sugar Factory Management that combines industrial operations and agricultural activities into a single digital framework. The system leverages machine learning techniques to predict production by analyzing factors such as weather conditions, soil characteristics, and historical yield data. In addition, a disease detection module based on machine learning algorithms is incorporated to identify crop diseases at an early stage, thereby minimizing losses and improving productivity.

Furthermore, the platform integrates a Retrieval-Augmented Generation (RAG)-based AI advisory system, which delivers accurate and context-aware responses to farmers by combining real-time data retrieval with generative AI capabilities. To ensure scalability and efficient interaction between different modules, a Modular Communication Platform (MCP) is employed, facilitating seamless data exchange and real-time updates across the system.

Overall, the proposed platform is designed to enhance operational efficiency, improve transparency, and support data-driven decision-making. By combining machine learning, artificial intelligence, RAG, and MCP-based architecture, the system offers a scalable, cost-effective, and intelligent approach for modernizing sugar factory management while promoting sustainable agricultural practices

Proposed System

List Of Modules

1. Authentication and Authorization
2. Plot Registration and Record management 3)Fertilizer Allocation
3. Soil Health Analysis & Testing Request Portal
4. Digital Electoral Nomination & Eligibility Verification System
5. E-Governance Notice & Communication Board
6. Smart Agriculture Virtual Assistant (Agri AI Bot)
7. Future production prediction
8. Plat leaf Disease detection

1. Authentication and Authorization

The proposed system implements a secure authentication and authorization mechanism using **Spring Security**, **JSON Web Token (JWT)**, and **OTP-based verification via Twilio API**. This ensures secure access control and identity verification for all users including farmers and administrators.

I.**Authentication (JWT-Based)**

Authentication is handled using Spring Security with stateless session management. After successful login, a **JWT token** is generated and returned to the client.

Workflow:

User login → Credential validation → JWT generation → Token sent to client → Token used in API requests → JWT filter validates token.

The JWT contains user details and role information and is signed using **HS256 algorithm** to ensure integrity and prevent tampering.

Authorization (Role-Based Access Control)

Authorization is implemented using **Role-Based Access Control (RBAC)**. Access to system modules is restricted based on user roles such as FARMER, ADMIN, and OFFICER. Spring Security annotations like @PreAuthorize are used to enforce endpoint-level security.

OTP Verification (Twilio Integration)

For secure user verification, **Twilio SMS API** is used to send OTP to the user's registered mobile number.

Workflow:

Generate OTP → Send via Twilio SMS → User enters OTP

→ System validates OTP and expiry → User is verified.

This provides **Two-Factor Authentication (2FA)** for enhanced security

2. Plot Registration and Record management and Fertilizer Allocation

In this system, the Slipboy is responsible for registering farmer details along with their respective land plot information. The module captures essential data such as farmer identity, contact details, plot location, area, and crop type, which are stored in the centralized database.

The system follows a **role-based access mechanism** to ensure secure and controlled data visibility. The Slipboy can view only the records they have entered, the Admin has full access to all farmer and plot records, and each Farmer can view only their own registered plot details.

This module ensures **accurate data collection, structured storage, and secure role-based data access**, enabling efficient management of agricultural records within the system.

The Fertilizer Allocation module manages the distribution of fertilizers to farmers based on

crop type, soil conditions, and land area. The system utilizes registered farmer and plot data to determine eligibility and required quantity of fertilizers.
Allocation requests are processed by authorized users and recorded in the centralized database. The system ensures transparency by providing role-based access, where Admin can monitor all allocations, Slipboy can manage assigned distributions, and Farmers can view their allocated fertilizer details.
This module ensures **efficient resource utilization, fair distribution, and proper tracking of fertilizer supply**, improving agricultural productivity and reducing manual errors.

3. Digital Electoral Nomination & Eligibility Verification System

This module automates the nomination and eligibility verification process for farmers. The system evaluates applications based on predefined criteria such as age eligibility, continuous sugarcane supply records for the last three years, and completion of required documentation.
Initially, the submitted application is validated by the system, where non-eligible applications are automatically rejected. Eligible applications are forwarded to the Admin for final verification and approval.
Upon approval by the Admin, the nomination status is updated and reflected in the respective farmer's profile. This ensures a transparent, rule-based, and efficient eligibility verification process with minimal manual intervention.

4. E-Governance Notice & Communication Board

The E-Governance Notice & Communication Board module provides a centralized platform for publishing and managing official announcements, meeting notices, and administrative communications. It enables authorized users to upload, update, and broadcast important information to farmers and stakeholders in a structured manner.
The system ensures role-based access control, where only Admin or authorized personnel can publish notices, while farmers and slipboys can view relevant updates. All notices are stored in the database with timestamps for tracking and retrieval.
This module enhances transparency, timely communication, and efficient dissemination of information, reducing dependency on manual notice distribution methods

5. Soil Health Analysis & Testing Request Portal

The Soil Health Analysis & Testing Request Portal allows farmers to submit soil testing requests for their registered plots. The system captures relevant details such as land information, crop type, and sample requirements, which are stored in the centralized database.
The request follows a multi-level workflow where the submitted application is first forwarded to the respective village Slipboy for initial verification. After validation, it is passed to the laboratory personnel, who assigns the request to a lab technician for soil analysis.
Once the testing is completed, the results are updated in the system and made available to the respective farmer, Slipboy, and Admin based on role-based access control.
This module ensures a structured approval workflow, accurate soil health analysis, and efficient communication between field staff and laboratories, enabling better agricultural decision-making.

6. Smart Agriculture Virtual Assistant (Agri AI Bot)

The Smart Agriculture Virtual Assistant is implemented using a **Retrieval-Augmented Generation** (RAG) architecture to provide intelligent and context-aware responses to farmers' queries. The system integrates a Spring Boot backend with a Vector Database to enable efficient semantic search over agricultural knowledge sources.
In the RAG pipeline, user queries are first converted into embeddings and matched with relevant context stored in the vector database. The retrieved information is then combined with a generative AI model to produce accurate and domain-specific responses related to crop management, soil health, fertilizer usage, and disease control.
The system ensures real-time, personalized, and knowledge-driven assistance, improving decision-making capabilities for farmers while reducing dependency on manual advisory systems

7. Future production prediction

This system uses a supervised machine learning approach to predict future agricultural production based on historical data. The dataset is collected from past seasonal records containing features such as cultivated area, season year, and village-wise information. The data is preprocessed by handling missing values and converting categorical variables into numerical form using encoding techniques. A

Multiple Linear Regression model using Ordinary Least Squares (OLS) is applied to learn the relationship between input features and crop yield. The model is trained on historical data and evaluated using performance metrics such as R^2 score, MAE, and RMSE. After training, the model is used to predict future production based on new input conditions. The trained model parameters are then exported and integrated into a backend system for real-time prediction, enabling efficient agricultural planning and decision- making.

8. Plat leaf Disease detection

A custom Convolutional Neural Network (CNN) model is trained using TensorFlow/ Keras on a plant leaf image dataset. After training, the model is saved in **.h5 format**, which stores both the architecture and learned weights.

During the prediction phase, the system works as follows:

- The trained .h5 CNN model is loaded inside a Flask API for inference.
- A user uploads a plant leaf image through the frontend interface.
- The image request is sent to the Spring Boot backend.
- The Spring Boot application acts as a middleware and forwards the image to the Flask API.
- The Flask API processes the image using the CNN model and predicts the type of leaf disease.
- The prediction result (disease name and confidence score) is returned to Spring Boot in JSON format.
- Finally, Spring Boot sends the response back to the frontend, where the result is displayed to the user.

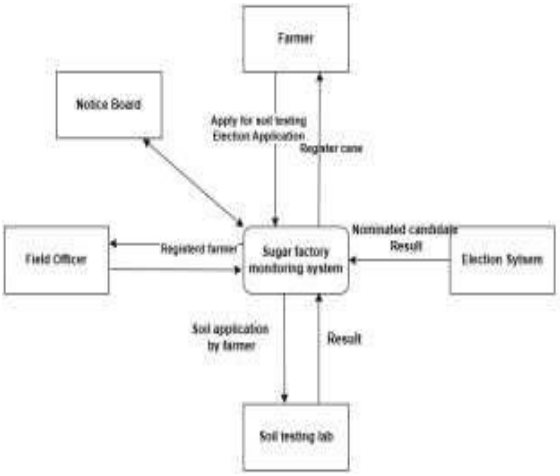
9. Simplified Problem Integration Using MCP (Model Context Protocol)

Using MCP (Model Context Protocol), problem integration is simplified by providing a standardized communication layer between AI models and external tools, APIs, and data sources. Instead of developing separate and complex custom integrations for each service, MCP enables a unified interface through which different systems can interact seamlessly. This reduces system complexity and ensures consistent data exchange across components. In this approach, the model can directly connect to required resources such as databases, applications, or services without additional integration overhead. As a result, the overall system becomes more modular, scalable, and easier to maintain, while significantly reducing development time and integration errors in AI-based applications.

In a farmer-focused system, MCP enables the farmer to retrieve all his relevant agricultural data using a single command line query. Instead of navigating multiple applications or records, the farmer can simply request information once, and the system aggregates and delivers data such as crop details, soil health, production history, and subsidy status in a unified response, making the process faster, simpler, and more user-friendly.

On the administrative side, MCP allows efficient management and analysis of farmer data at a village level. The admin can access consolidated production records, compare crop yields across villages, monitor trends, and generate reports through simple queries. This centralized access helps in better decision-making, resource allocation,

and monitoring of agricultural productivity across different regions.



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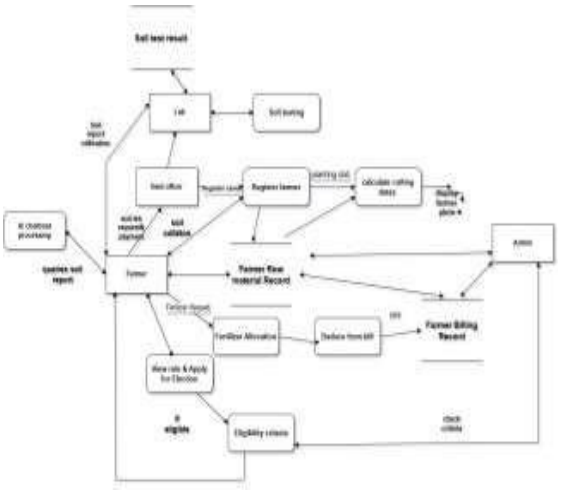
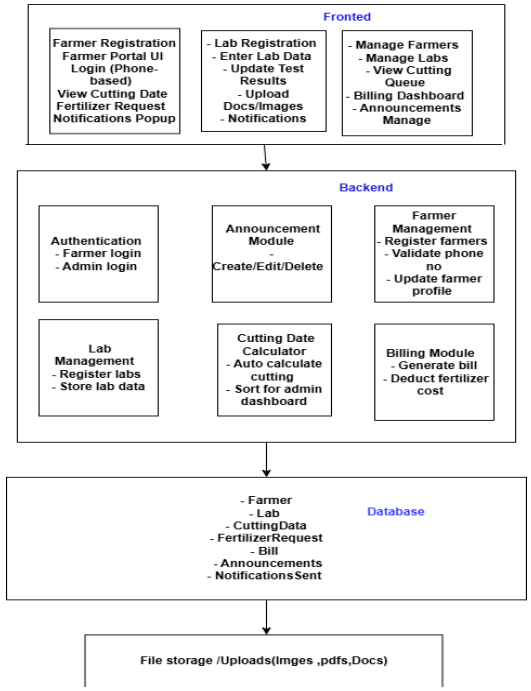


1 DFD LEVEL

The diagram represents a soil testing and agricultural support workflow system where

farmers submit soil samples or requests that are processed by a lab for testing and report generation. Based on the soil test results, recommendations such as fertilizer application and suitable crop guidance are generated and shared with farmers through an administrative system. The system also maintains records like farmer registration, eligibility criteria, billing details, and soil reports, ensuring a complete end-to-end process from soil testing to decision support for improving agricultural productivity.



System Architecture

This system architecture is divided into frontend, backend, database, and file storage layers to manage agricultural operations efficiently. The frontend provides separate interfaces for farmers, labs, and admins, supporting features like registration, data entry, notifications, billing, and management dashboards. The backend handles core logic such as authentication, farmer and lab management, announcement handling, cutting date calculation, and billing generation. The database stores all structured data including farmer details, lab records, billing, notifications, and cutting information, while file storage manages uploaded images, PDFs, and documents. Overall, this layered architecture ensures smooth communication, centralized data management, and efficient operation of the entire agricultural system.

Tools and technology

- **Frontend: React.js is used to build an interactive** and responsive user interface that supports image upload for disease detection, input forms for production prediction, and chat/query interface for RAG-based responses. It provides a unified dashboard for farmers and administrators.
- Backend: Spring Boot is used to develop a scalable RESTful API layer that manages user requests, handles authentication, and coordinates communication between frontend, machine learning models, and AI services.
- Machine Learning Models:
  - Plant Disease Detection: A Convolutional Neural Network (CNN) built using TensorFlow and Keras is used to detect plant leaf diseases from uploaded images.
  - Production Prediction: A Multiple Linear Regression model using Ordinary Least Squares (OLS) is used to predict sugarcane production based on features such as area, season, and village. Model evaluation is done using R^2, MAE, and RMSE.
- AI Service Layer: Flask is used as a lightweight microservice to deploy the trained CNN model and regression model, enabling real-time predictions through REST APIs.
- RAG (Retrieval-Augmented Generation) System: A RAG-based AI module is used to provide intelligent, context-aware answers to farmer queries. It retrieves relevant agricultural data from a vector database and combines it with a language model to generate accurate responses regarding farming practices, crop management, and production insights.
- Database: MySQL is used to store structured data such as farmer profiles, village-wise production records, disease prediction history, and system logs. A vector database (used in RAG) stores embedded agricultural knowledge for semantic search.
- Data Format: JSON is used for seamless communication between Spring Boot, Flask, and the frontend services.
- Development Tools: Python, Java, Visual Studio Code, and IntelliJ IDEA are used for system development, integration, and testing.

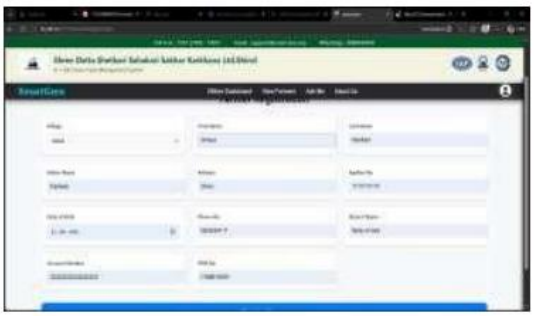
Result

1. Authentication

This page serves as the role selection interface for the SmartCane Management System. Users can choose their respective role Farmer, Field Officer, Admin, or Lab to access functionalities specific to their responsibilities. The clean and user-friendly design ensures easy navigation and a personalized workflow for each type of user.

This page allows farmers to securely log in by entering their registered mobile number and receiving an OTP for verification.

2. Record Management



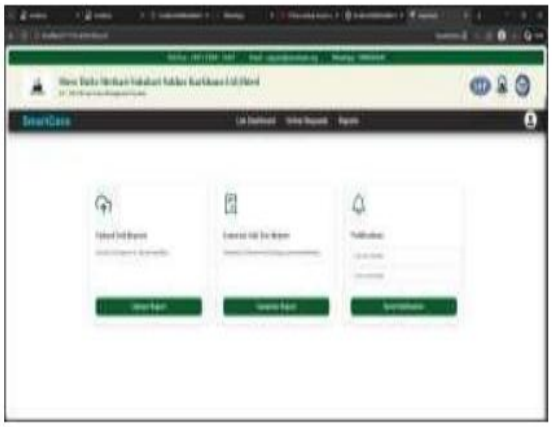
This page is designed to collect detailed information from farmers, including personal details, land area, village data, and identification numbers. It ensures accurate farmer profiling for streamlined management and future processes.

This page displays a complete list of farmers registered under the officer's village, along with their personal, land, and identification details. It helps officers quickly verify farmer information and manage village-level records efficiently.

3. Soil Testing application

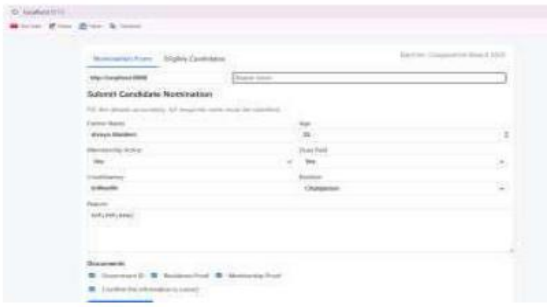
This screenshot shows the SmartCane farmer portal interface, where registered farmers can make payments through a simple form by entering their mobile number and amount.
The right-side panel displays the farmer's profile details, including contact information, land area, and branch, along with quick options to edit profile or log out.

This page displays the Soil Testing Payment gateway, where farmers can securely pay the testing fee using multiple payment options



4. Election System

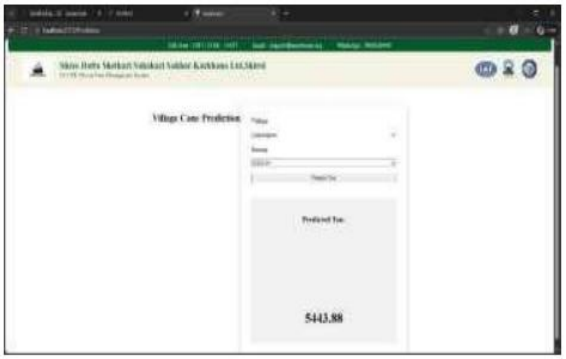
This page allows farmers to submit their nomination for cooperative board elections by providing personal details, eligibility information, and required documents. It ensures a transparent and structured nomination process with validation for all mandatory rules.



5. Notice Board Production Prediction

This screen shows the Admin Announcement Control Panel of the SmartCane system. The admin can create, view, edit, and delete announcements related to farming activities like sugarcane seasons.

6. Production Prediction



Conclusion

The SmartCane system successfully transforms the traditional, paper-based operations of the sugarcane industry into a modern, efficient, and user-friendly digital platform. By integrating farmers, slip boys, soil experts, and administrators into a single system, SmartCane ensures transparency, accuracy, and faster processing of essential services.

The project eliminates manual errors, reduces delays, and improves communication through digital workflows. Farmers can now track soil test results, supply details, payment status, and meeting notices easily, without repeated visits to

the factory. Similarly, slip boys and soil experts benefit from automated data handling, ensuring better productivity and reliability.
Overall, SmartCane provides a centralized, scalable, and secure solution that modernizes sugarcane supply management and enhances the relationship between the factory and farmers. This system not only improves operational efficiency but also empowers farmers by giving them better access to information and services. It sets a strong foundation for future enhancements such as mobile app integration, AI-based crop recommendations, and predictive analytics.

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