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Design and Architecture of BenguetFresh: An IoT-Enabled Data-Driven System for Sustainable Agriculture

Abstract: - Agriculture plays a vital role in the Philippines, contributing significantly to its economy and providing livelihoods to a substantial portion of the population. Benguet province, known as the "Salad Bowl of the Philippines" for its favorable climate and fertile soil, exemplifies thriving agriculture-based livelihoods. However, challenges persist in the sector, with the low compliance rate of Philippine Good Agricultural Practices (PhilGAP) certification highlighting the need for innovative solutions to enhance sustainable practices, market access, and overall agricultural quality for Benguet farmers.

This study presents the design and architecture of BenguetFresh a system designed to integrate data-driven monitoring and management practices with sustainable agriculture, while adhering to PhilGAP standards. Through stakeholder engagement, interviews, and systematic review, specific requirements and challenges of farmers in Benguet were identified and addressed.

BenguetFresh employs cutting-edge technology, Arduino-based smart agriculture monitoring systems, enabling real-time data collection on environmental factors. Data analytics tools process this data to provide valuable insights, facilitating informed decision-making and resource optimization.

The scalable architecture ensures efficient data flow and real-time processing, while user-friendly interfaces empower farmers with real-time and historical data visualization and data-driven recommendations. Furthermore, the integration of e-commerce functionality fosters direct connections between farmers and consumers, expanding market reach and improving economic outcomes.

BenguetFresh's design and architecture serve as a blueprint for implementing data-driven, sustainable agriculture. The potential benefits extend to both farmers and consumers, ensuring high-quality, responsibly produced agricultural products. Embracing cutting-edge technology and industry standards, BenguetFresh paves the way for efficient, sustainable, and prosperous agriculture.

Keywords: Agriculture, Data Analytics, Internet of Things, PhilGAP, Sustainable Agriculture, System Architecture.

I. INTRODUCTION

Climate change has become a pressing global issue, with adverse effects on various sectors, including agriculture[1],[2]. In the Philippines, agriculture plays a vital role in supporting the economy and providing livelihoods for a significant portion of the population. Benguet province, known as the "Salad Bowl of the Philippines," stands as a prominent example of thriving agriculture-based livelihoods, benefiting from its favorable climate and fertile soil. However, despite these advantages, the sector faces numerous challenges that hinder its full potential.

One of the primary challenges faced by Benguet farmers is the increasing unpredictability of weather patterns due to climate change. Irregular rainfall, extreme temperatures, and the occurrence of natural disasters such as typhoons and landslides have a detrimental impact on crop yields, leading to substantial losses for farmers[3]. Additionally, intensive agricultural practices, deforestation, and improper land management contribute to land degradation and soil erosion, compromising soil fertility and adversely affecting agricultural productivity.

Water scarcity during dry seasons presents another critical obstacle for farmers in Benguet, hindering agricultural activities and limiting crop production due to limited access to irrigation water. The lack of stable markets for agricultural produce and price fluctuations pose financial challenges for farmers, impacting their income and financial stability.

Furthermore, outbreaks of pests and diseases can cause devastating losses for farmers who may lack the resources to effectively combat these issues. High input costs, particularly for seeds, fertilizers, and pesticides, coupled with low profit margins, add to the economic burdens faced by farmers, particularly small-scale ones.

Moreover, limited access to credit and financial services restricts farmers' ability to invest in their farms and expand their operations. The slow adoption of modern agricultural technologies and practices also hampers productivity and efficiency for some farmers, hindering their potential for growth and development.

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To address these pressing challenges and promote sustainable agriculture, the Philippine Department of Agriculture introduced the Philippine Good Agricultural Practices (PhilGAP) certification. PhilGAP provides comprehensive guidelines and standards, encouraging environmentally friendly and socially responsible practices in agriculture, with the aim of elevating farming standards and ensuring the long-term viability of the sector[5],[6].

While PhilGAP offers potential solutions to many of the identified problems, there remains a significant issue with low compliance among Benguet farmers. Despite its benefits, only a small percentage of farmers in the province possess valid PhilGAP certification. Based on the March 14, 2023 data from the DA-CAR Planning, Monitoring, and Evaluation Division (PMED), Benguet province including Baguio City recorded 71,609 registered farmers while out of the registered farmers 313 are with valid GAP certificate, which mean the province has only 0.46 % compliance on GAP certification. Therefore, there is a growing need for innovative and comprehensive approaches that integrate data-driven monitoring and management systems to enhance agricultural productivity and sustainability in the face of evolving challenges.

In this context, this research presents the design and architecture of BenguetFresh, a blueprint for a pioneering system aimed at aligning with PhilGAP standards. The system integrates data-driven monitoring and management practices with sustainable agriculture, offering insights for optimizing crop yield and resource utilization while adhering to PhilGAP guidelines. By harnessing cutting-edge technologies such as the Internet of Things (IoT) and data analytics, BenguetFresh empowers farmers with real-time information, enabling informed decision-making and promoting resource efficiency[7],[8].

II. METHODOLOGY

The system design process for BenguetFresh began with a thorough requirements gathering and analysis phase, crucial for gaining a deep understanding of the unique needs and challenges faced by the agricultural community in Benguet. The goal is to gain a deep understanding of the unique needs and challenges faced by the agricultural community in Benguet, and to identify the key functionalities and features that BenguetFresh must deliver to align with PhilGAP standards and support sustainable agriculture.

Stakeholder engagement played a pivotal role, involving key stakeholders such as farmers, agricultural experts, local authorities, and agricultural cooperatives in collaborative discussions. This inclusive approach facilitated the exchange of valuable insights and perspectives, providing essential inputs for the system design.

In-depth interviews were conducted with farmers and agricultural experts to elicit detailed information about their farming practices, pain points, and aspirations. These interviews served as a rich source of qualitative data, offering valuable insights into specific requirements and expectations of the agricultural community.

To foster open dialogue among stakeholders, focus group discussions were organized. These sessions encouraged the exploration of common concerns, emerging themes, and innovative ideas related to agricultural practices and system requirements, further enriching the research process.

Understanding the prevailing agricultural practices in Benguet was crucial in contextualizing the system design. Therefore, an examination of existing methods and technologies was undertaken, providing valuable insights into the strengths and limitations of traditional approaches.

Additionally, document analysis played a pivotal role in the methodology. Extensive reviews of the forms used in GAP certifications and the Code of Good Agricultural Practices for Fruits and Vegetable Farming were carried out. This analysis provided important guidance on the standard practices and protocols followed in the agricultural sector, ensuring that BenguetFresh's design would align with PhilGAP standards.

By integrating these diverse methodologies, the research process ensures that BenguetFresh's system design is tailored to address the specific needs and requirements of the agricultural community in Benguet while adhering to the PHILGAP standards. The requirements analysis serves as a foundation for the subsequent stages of system design, guiding the selection of appropriate technologies, architectural patterns, and high-level design to create a system that effectively addresses the challenges faced by farmers and promotes sustainable agriculture in Benguet province.

III. RESULTS AND DISCUSSION

As a result of the requirements gathering and analysis employed in the system design process, BenguetFresh has successfully established clear system design goals that prioritize scalability, reliability, maintainability, and alignment with PhilGAP standards. These goals serve as the guiding principles for selecting appropriate technologies, architectural patterns, and system architecture to create an effective platform that tackles the challenges faced by farmers while promoting sustainable agriculture.

A. Maintaining the Integrity of the Specifications

The system design goals as shown in Fig. 2 for BenguetFresh have been carefully formulated to address the unique needs and aspirations of the agricultural community in Benguet province.
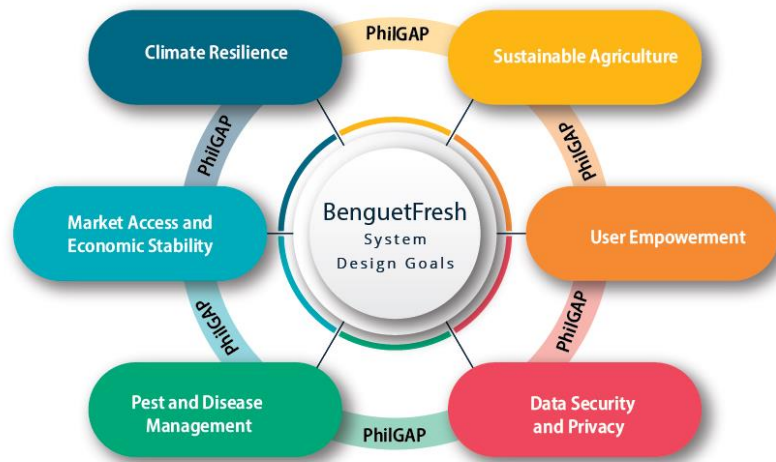

Figure 1. System Design Goals

Recognizing the increasing unpredictability of weather patterns due to climate change, BenguetFresh will be designed to provide real-time weather data and predictive analytics, empowering farmers to adapt their agricultural practices to cope with irregular rainfall, extreme temperatures, and natural disasters. By promoting climate-resilient agricultural practices, BenguetFresh aims to minimize crop losses and enhance the resilience of farmers against changing environmental conditions.

To ensure the long-term viability of agriculture in Benguet, BenguetFresh will adhere to PhilGAP standards and offer data-driven recommendations on eco-friendly farming methods, encompassing soil conservation, proper land management, and integrated pest management, thus seeking to enhance soil fertility, reduce land degradation, and foster sustainable agriculture for generations to come.

Moreover, the integration of e-commerce functionalities into BenguetFresh will enable direct connections between farmers and consumers, minimizing reliance on intermediaries and creating stable markets for agricultural produce, enabling farmers to showcase their products to a broader customer base. Consequently, BenguetFresh aims to improve economic outcomes and enhance financial stability for the agricultural community in Benguet.

Additionally, by leveraging data analytics and sensor monitoring, BenguetFresh will provide early detection and prevention of pests and diseases, empowering farmers with timely alerts to take prompt actions, mitigating the impact of outbreaks, and minimizing crop losses. Furthermore, the platform will strive to reduce dependency on expensive pesticides, promoting sustainable pest and disease management practices.

BenguetFresh adopts a user-centric approach through its intuitive and interactive dashboard, providing real-time and historical data visualizations to farmers, along with a tracking mechanism for monitoring compliance with PHILGAP standards. This comprehensive system empowers farmers to make informed decisions, embrace data-driven practices, and ensure adherence to sustainable farming methods, ultimately leading to enhanced agricultural outcomes.

Given the sensitive nature of agricultural data, BenguetFresh will prioritize robust data security and privacy measures, including encryption of data during transmission and storage, user authentication, and access control mechanisms, thus safeguarding information and ensuring the confidentiality and integrity of agricultural data while complying with data protection regulations.

B. System Architecture

BenguetFresh utilizes the Layered architecture pattern, which is a proven and effective system design approach that organizes complex applications into distinct horizontal layers, each responsible for specific functionalities[9]-[11]. Its modularity, separation of concerns, and scalability make it an ideal choice for BenguetFresh. The adoption of the Layered architecture in BenguetFresh is a strategic decision that aligns perfectly with the system design goals and the unique challenges faced by farmers in Benguet province[12].
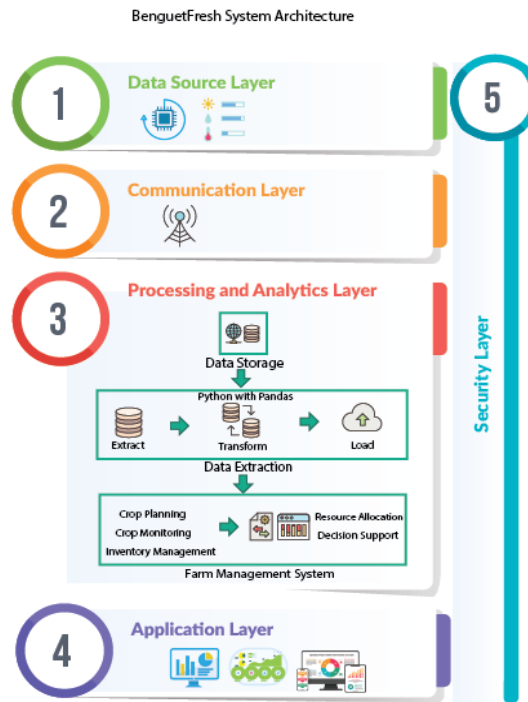
Figure 2. System Architecture

Fig. 3, the system architecture of BenguetFresh, this architecture, each layer fulfills specific functionalities, contributing directly to the achievement of BenguetFresh's design goals. The Data Source Layer plays a pivotal role in gathering real-time weather data and sensor information, crucial for climate resilience and pest and disease management. By leveraging IoT sensors deployed in agricultural fields, farmers gain access to timely environmental data, empowering them to make informed decisions and respond proactively to potential pest outbreaks. This data is then transmitted to the Communication Layer through wireless communication modules, ensuring immediate processing and direct storage in the data storage located in the Data Processing and Analytics Layer.

The Data Processing and Analytics Layer serves as the core of BenguetFresh where the Extract, Transform, Load (ETL) process takes place, processing the collected data and generating meaningful insights and predictive analytics. By utilizing advanced data analytics tools and machine learning algorithms, this layer provides valuable weather predictions, crop growth forecasts, and data-driven recommendations on eco-friendly farming methods, supporting climate resilience and sustainable agricultural practices.

To achieve the goal of sustainable agriculture aligned with PhilGAP standards, BenguetFresh incorporates a Farm Management System within its Data Processing and Analytics Layer. This integrated system provides personalized and data-driven recommendations on soil conservation, land management, and pest control strategies, tailored to the specific needs of each farmer, while actively promoting and tracking compliance with responsible farming practices. By playing a pivotal role in enhancing soil fertility, reducing land degradation, and supporting long-term agricultural sustainability in Benguet province, BenguetFresh's integration with PhilGAP emphasizes environmentally sustainable practices. The system's decision-making algorithms consider ecological factors, such as optimized irrigation schedules, efficient resource utilization, and reduced chemical inputs, thereby contributing to the preservation of the region's ecological balance. Furthermore, BenguetFresh enables farmers to track their progress towards PhilGAP certification and receive feedback on their practices, facilitating the certification process and encouraging more farmers to adopt responsible and sustainable farming methods. Detailed reports generated by BenguetFresh on farm practices and their alignment with PhilGAP standards can be used for auditing and compliance purposes, helping farmers meet regulatory requirements and participate in agricultural programs and incentives.

The Application Layer completes the architecture by providing farmers with a user-friendly dashboard. This dashboard offers real-time and historical data visualizations, empowering farmers with insights on crop health, growth progress, and resource availability. Market access and economic stability are addressed through this layer, facilitating direct connections between farmers and consumers. By showcasing agricultural produce to a broader customer base, this layer reduces dependency on intermediaries, leading to improved economic outcomes and enhanced financial stability for farmers.

In addition to its multi-layered approach for data flow and processing, the BenguetFresh architecture incorporates a robust Security Layer to ensure data protection and user access control. Security is of paramount importance to safeguard sensitive agricultural data and maintain the integrity of the system.

To secure data transmission and storage, the architecture employs advanced encryption protocols. Data sent from the Data Source Layer to the Communication Layer is encrypted to prevent unauthorized access during wireless transmission. Similarly, data stored in the database is encrypted to safeguard it from potential breaches. These encryption measures ensure that only authorized users can access and interpret the data, providing a strong layer of defense against potential cyber threats.

Access control mechanisms are also integrated into the system. User authentication and authorization protocols restrict access to the system and its functionalities, ensuring that only authenticated users with appropriate privileges can interact with the data and dashboard. This prevents unauthorized individuals from tampering with critical agricultural information and settings.

The Layered architecture's inherent benefits, such as a systematic and maintainable design, enable BenguetFresh to efficiently address the challenges faced by farmers. Moreover, the scalability of this architecture ensures that the system can accommodate future enhancements and technological advancements.

C. Technical Specifications

1) Hardware and software components

BenguetFresh is a sophisticated agricultural management system that embraces a comprehensive range of hardware and software components, alongside web technologies, to create an innovative solution aligned with Philippine Good Agricultural Practices (PhilGAP) standards[12]-[14].
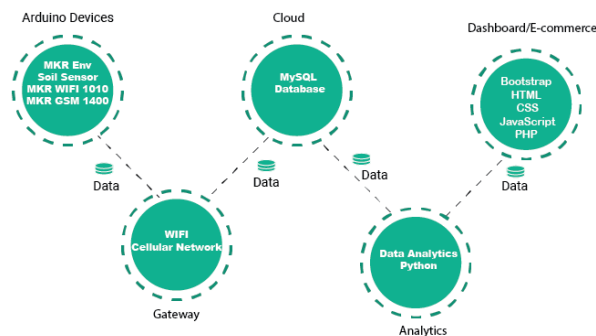

Figure 3. Hardware and software components

On the hardware side, the system integrates humidity sensors like DHT22 and light intensity sensors such as light-dependent resistors (LDRs) or photodiodes to continuously monitor critical environmental factors affecting crop growth. The central hub for data collection and processing is the Arduino MKR Env board, purpose-built to host the humidity and light sensors, enabling accurate and direct data collection. Wireless communication modules, namely Arduino MKR WIFI 1010 and Arduino MKR GSM 1400, facilitate real-time data transmission via Wi-Fi or cellular networks, ensuring seamless connectivity and data flow.

The software components of BenguetFresh encompass advanced data analytics tools equipped with algorithms for data preprocessing, filtering, and cleaning, ensuring accurate data analysis. Predictive models, powered by machine learning, forecast crop growth, pest outbreaks, and weather patterns, empowering farmers with valuable insights for informed decision-making. The system further includes a decision support system, offering data-driven recommendations to optimize farming practices and enhance crop yield. Integration and communication software, including APIs and middleware, enable efficient data exchange between hardware components, further enhancing data flow and system performance.

To ensure seamless data saving and processing, BenguetFresh leverages PHP and MySQL technologies. This combination enables the smooth storage of sensor data in the MySQL database, providing a reliable and accessible repository for agricultural information. Python drives the Extract, Transform, Load (ETL) process, efficiently extracting data from the MySQL database, preprocessing, and conducting data analytics to generate actionable insights for farmers. The user-friendly Farm Management Interface, built with Bootstrap, HTML, CSS, and JavaScript, presents real-time and historical data visualizations through a responsive dashboard. This intuitive dashboard empowers farmers with data-driven decision-making capabilities, facilitating sustainable and efficient farming practices. These components form the minimum requirements for the system's optimal functioning.

2) Data Model Components

The data model is carefully crafted to capture and organize crucial environmental factors and contextual data, enabling farmers in Benguet province to make data-driven decisions and adopt sustainable agricultural practices[12]-[14]. The primary goals of the data model are climate resilience, sustainable agriculture, market access, and data security.
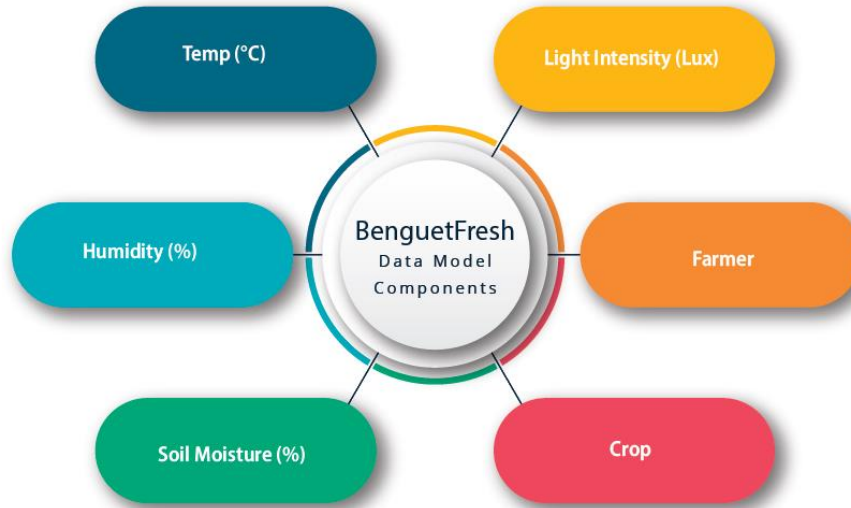

Figure 4. Data Model Components

The Timestamp component in BenguetFresh records the date and time when sensor readings are taken, allowing farmers to monitor environmental trends and identify patterns that affect crop growth over time. The IoT sensors deployed in agricultural fields capture Temperature (°C) readings, a critical factor influencing crop growth and development. Humidity (%) readings indicate the amount of moisture in the air, impacting plant health and susceptibility to diseases. Soil Moisture (%) levels signify the amount of water in the soil, essential for optimized irrigation and plant growth. The Light Intensity (Lux) component measures the intensity of light received by crops, crucial for photosynthesis and determining the amount of sunlight a crop receives. The Farmer attribute identifies the farmer associated with each set of sensor readings, enabling data segmentation and personalized recommendations based on their specific farming practices. Additionally, the Crop attribute specifies the type of crop being cultivated by each farmer, providing crucial information for tailoring recommendations according to the unique environmental requirements of different crops.

IV. CONCLUSION

In conclusion, BenguetFresh's meticulously crafted design and architecture will serve as a blueprint not only for BenguetFresh Farm Monitoring and Management system but also for other agricultural systems. By aligning with PhilGAP standards and leveraging advanced technologies, the system revolutionizes farmers' interactions with real-time data and data-driven recommendations through intuitive interfaces. BenguetFresh becomes a powerful ally in elevating farming standards and fostering a thriving agricultural sector, addressing key challenges faced by farmers. As climate change and uncertainties loom, BenguetFresh stands as an essential tool for resilience, adaptability, and responsible resource management. Its impact extends beyond Benguet province, inspiring similar solutions worldwide to foster a positive impact on agriculture and livelihoods. With BenguetFresh paving the way for sustainable and efficient farming practices, it ensures continued prosperity amidst evolving challenges.

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