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Weather station with a comprehensive program that promotes preventive culture against hail among local farmers

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Abstract– ***The project presents APUY (quechua for 'guardian'), a weather station designed for the Andean community of Molleray, in Cusco, Peru, where hailstorms cause significant annual agricultural losses. The research addresses the problem of insufficient accurate meteorological information and the lack of a prevention culture through a comprehensive early warning system. Inspired by the shape of a corn leaf, APUY integrates a three-color traffic light system (green, amber, and red) indicating the level of hail risk, along with SMS notifications that provide real-time access to information. The system uses the BME280 sensor to measure temperature, humidity, pressure, and altitude, and is powered by solar energy, ensuring its operation in remote rural areas. Moreover, its adaptable design allows for installation on poles or trees, respecting the agricultural environment. APUY not only seeks to reduce economic losses caused by natural disasters but also to promote a cultural shift within the community, strengthening their connection to the land and fostering preventive agricultural practices. The data collected by the station is compared with that of SENAMHI to enhance the accuracy of local forecasts. This project highlights how industrial design can provide sustainable, technological, and culturally relevant solutions.***

Keywords-- Industrial design, Weather station, Agricultural prevention, Hail prevention, Local farmers.

I. Introduction

In the Cusco region of Peru, intense hailstorms represent a recurring threat to high Andean farming communities, where severe weather events have caused the destruction of up to 65 hectares of crops in a single day [1]. This problem, documented in multiple regional reports, reflects the vulnerability of farming families due to the lack of effective warning systems and the limited culture of prevention [2], [3]. Recent assessments by the local Agricultural Agency have estimated economic losses of nearly half a million nuevos soles in the districts of Paucartambo and Colquepata as a result of intense rainfall and hailstorms [12], further highlighting the urgent need for localized meteorological monitoring infrastructure. Traditional strategies, such as the use of anti-hail rockets, have been ineffective and harmful to the environment, which underlines the need for innovative technologies that offer sustainable solutions adapted to rural reality [4].

The APUY project has the general objective of promoting a culture of prevention against hail in the community of Molleray by implementing a meteorological station equipped with sensors and an early warning system through SMS notifications [5]. Inspired by the corn leaf, the design of the device not only responds to the technical aspects of weather monitoring, but also considers local traditions and beliefs to strengthen the bond between the community and its agricultural environment.

The specific objectives of the project are: (1) to reduce agricultural losses resulting from hailstorms, (2) to increase the level of knowledge on preventive measures, (3) to improve farmers' perception of the effectiveness of APUY and (4) to provide lighting on rural roads, improving night-time safety. The integration of prediction technologies, solar energy and IoT platforms will allow for more accurate data and support the community in decision-making to protect their livelihoods [6].

II. Theoretical Framework

Early warning systems and IoT technologies are transforming how communities face extreme weather events. Through constant monitoring and real-time data collection, these technologies enable instant alerts via mobile devices, digital platforms, and physical media. Sensors distributed in strategic locations collect critical meteorological information, which is transmitted through IoT networks for analysis, allowing the issuance of preventive warnings to local populations [10]. This approach, implemented in various rural areas, has proven effective in reducing agricultural damage and preparing communities for natural disasters [4].

Risk management involves identifying threats and vulnerabilities and preparing mitigation and response measures for adverse events. A crucial aspect of this is fostering a preventive culture within the population, where communities learn to recognize potential risks and take appropriate preventive actions [11]. This is complemented by public policies and educational programs that raise awareness of the importance of being prepared for weather phenomena. Without effective management and a preventive culture, economic and social damages caused by natural disasters, such as severe hailstorms, can be devastating [1].

Moreover, weather prediction and climate monitoring are essential for anticipating natural events, especially in high-risk contexts like Andean highland communities. Institutions such as Peru's National Service of Meteorology and Hydrology (SENAMHI) use advanced atmospheric models and satellite data to predict hailstorms and other severe meteorological events [5]. However, in rural areas, limited access to weather stations and deficiencies in information transmission present critical challenges. The implementation of mobile technologies and IoT networks has facilitated the dissemination of alerts, allowing farmers to prepare and reduce economic losses [6]. Fig. 1, 2 and 3.

Fig. 1. State of the art 1: Weather station from Universidad Continental, installed at high altitude.

Fig. 2. State of the art 2: Semanhi weather station 3D-printed in PLA, installed in Cusco.

Fig. 3. Study of the Environment
San Sebastian - Molleray

III. Methodology

A. User

The target population of the APUY project is made up of Andean farming communities, specifically in the town of Molleray, Cusco region, Peru. This group is mainly made up of peasant families whose economy depends largely on subsistence agriculture and local marketing. Most farmers own small plots of land where they grow corn, potatoes and other basic products, constantly facing the risk of losses due to sudden hailstorms [1]. These communities, characterized by low access to advanced technologies and meteorological information services, still retain traditional farming practices and ineffective prevention methods, such as the use of anti-hail rockets [3]. The lack of accurate and timely information, coupled with a limited prevention culture, aggravates their vulnerability to extreme weather events, generating uncertainty and significant economic losses [2].

B. *Context*

The context in which the APUY project is developed is the Andean region of Cusco, specifically in the community of Molleray, where agriculture is the main economic activity and source of livelihood for the local population. This rural environment is characterized by mountainous terrain and an unpredictable climate, with frequent hailstorms that seriously affect the crops of corn, potatoes and other essential products [1]. The lack of access to efficient meteorological stations and limited technological infrastructure aggravate the situation, since many rural communities do not receive timely information about adverse weather events [2]. At the national level, risk management policies still have deficiencies in the coverage and accuracy of meteorological forecasts, which increases the vulnerability of these communities to natural disasters [3].

C. *Design proposal*

APUY's proposal presents a conceptual design, inspired by agricultural elements representative of the Andean region. The shape of the device is inspired by the corn leaf, a key symbol in local agriculture and an element of great cultural value. This inspiration not only responds to the aesthetics, but also to the aerodynamic functionality of the design, allowing the device to minimize wind resistance and optimize solar energy collection. Its elongated and curvilinear structure facilitates the protection of internal components against adverse weather conditions, while the materials used guarantee its durability and weather resistance.

From a technical point of view, APUY integrates a BME280 sensor for temperature, humidity, and atmospheric pressure measurement, mounted in a compact arrangement to maximize the use of internal space and facilitate maintenance. Power is supplied by solar panels strategically located on the top of the device, optimizing the collection of sunlight. An ESP32 microcontroller processes meteorological data and transmits it via WiFi connectivity to an IoT platform for remote monitoring. In case of detection of adverse conditions, the system issues visual alerts using a traffic light-like color code (green, amber, and red), which communicates the level of hail risk. This code is complemented by SMS notifications in the predominant languages of the region (Quechua and Spanish) to ensure its understanding and effectiveness.

In addition to its primary function of weather monitoring, the device includes an integrated luminaire that operates at night, improving visibility on rural roads and offering an additional benefit to the community. The adaptable mounting design allows for installation on poles or trees using an adjustable grip system, facilitating its implementation in different agricultural terrains. This modular and flexible design not only ensures its operational effectiveness, but also allows for future upgrades and improvements based on local needs. Fig. 4, 5 and 6.

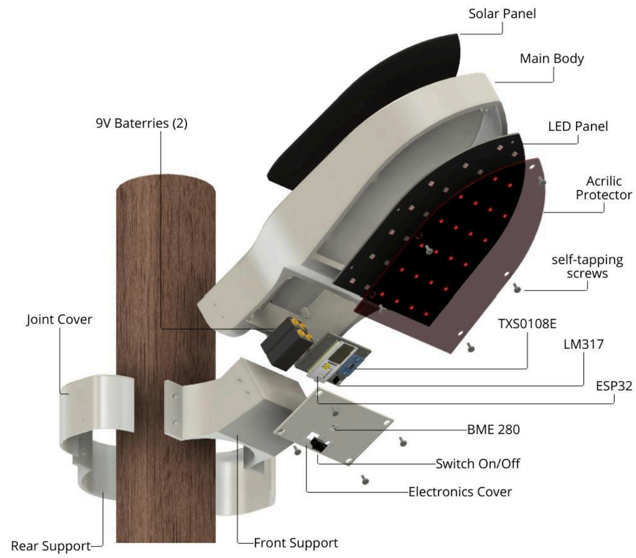

Fig. 4. Exploded view of APUY components.

Fig. 5. Conceptual design of Apuy developed in Autodesk Fusion.

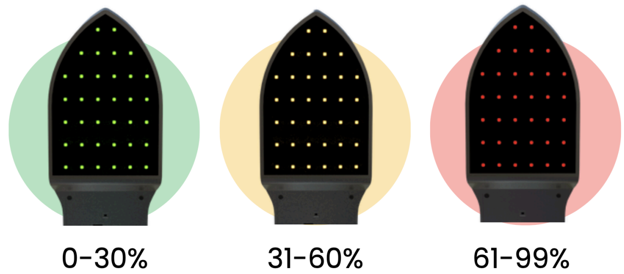

Fig. 6. Color codification system (green, amber, and red), similar to a traffic light operation.

D. Validation

The APUY project carried out technical validations to ensure its performance in early hail detection and its integration into the rural environment. These validations included calibration tests of the main sensor BME280, under simulated conditions of rapid and fluctuating weather changes. The ESP32 microcontroller processed the data in real time, allowing the assessment of measurement accuracy and system reliability when issuing visual and SMS alerts. The results of these tests were instrumental in optimizing the device's prediction algorithm, adjusting detection thresholds to reduce false positives and ensure accurate alerts.

Preliminary insights were gathered from exploratory interviews with farmers and community members of Molleray. These inputs allowed for adaptation of aspects of the device's design, such as the use of SMS messages in Quechua and Spanish, and the traffic light-type color-coded alert system. In the future, it is proposed to conduct pilot field tests with end users to validate the full functionality of the system in real-life situations, evaluate its impact on agricultural decision-making, and gather additional feedback for further improvements. Fig. 7, 8 and 9.

Fig. 7. Physical prototype of Apuy.

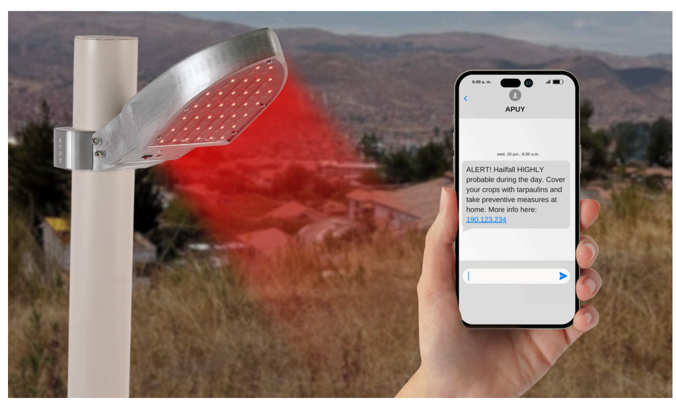

Fig. 8. Interface development with alert notifications.

Fig. 9. Interface development: Hailfall probability.

III. Results

The results of the APUY project research show that the proposal meets the objectives of climate monitoring and functionality in the rural environment. The early warning system proved to be effective in issuing visual alerts and through SMS messages, allowing a timely response to hail risk conditions. Technical tests indicated that the pressure, temperature and humidity sensors achieved adequate performance in weather prediction, optimizing their integration with the microcontroller and solar panels to ensure the continuous operation of the device. The product showed good preliminary acceptance by potential users, who highlighted the intuitive design based on a three-color traffic light and the accessibility of messages in Quechua and Spanish. The additional night lighting function improved the perception of the device as a comprehensive solution for rural needs. It was concluded that field implementation will allow future optimizations based on direct feedback from users and improvements in predictive algorithms for greater accuracy in forecasts.

IV. Discussion

The findings of the Apuy project highlight the urgency of accessible and culturally relevant meteorological solutions for Andean communities exposed to extreme weather events. The implementation of an early warning system based on BME280 sensors, visual signals and SMS notifications allows farmers to access meteorological information in real time, promoting a culture of prevention and response. These results coincide with studies that highlight how the lack of historical records and meteorological infrastructure limits the effectiveness of Early Warning Systems (EWS) in managing hydrometeorological threats such as heavy rains, floods and debris flows [7]. Furthermore, research has shown that combining citizen observations with automated systems improves data accuracy and service reliability, highlighting the potential of Apuy to integrate local information with SENAMHI data to optimize its forecasts [8], [9].

From a practical approach, this study demonstrates that the design of low-cost and easy-to-implement technologies can strengthen food security and agricultural resilience in vulnerable communities. However, key challenges are identified, such as the need to validate the accuracy of meteorological data and measure the impact of the system on community behavior over time. Future research should focus on evaluating the effectiveness of the system in different seasons of the year and its adaptability to other regions with similar conditions. In this way, Apuy not only represents a breakthrough at the intersection between technology, design and sustainability, but also sets a precedent for the development of climate adaptation strategies in highly vulnerable territories.

V. Conclusions

The early warning system implemented at APUY could significantly contribute to reducing agricultural vulnerability in rural communities exposed to hailstorms, allowing farmers to make timely decisions to protect their crops. In the future, this technological approach is expected to generate a positive impact on climate risk management, optimizing its effectiveness through improvements in sensors and predictive algorithms.

The initiative is projected to foster the development of a sustainable preventive culture, driving changes in agricultural practices through the integration of accessible and culturally relevant technologies. The combination of visual alerts and notifications in Quechua and Spanish would remain key to facilitating its long-term adoption in communities with limited technological access.

The modular design of the device could allow for future upgrades, such as the incorporation of new sensors and customized functionalities according to local needs. The use of solar energy and resistant materials will remain a pillar of the system, ensuring its operational sustainability in challenging rural environments.

Additional benefits, such as night lighting, are anticipated to continue improving community perception of the technology's usefulness. This component could be expanded to other applications, promoting the development of integrated basic infrastructures for rural communities.

Finally, the field validation process will provide crucial data to measure the impact of the system on agricultural resilience, allowing for progressive adjustments and replicability in other regions.

VI. Applicability

This project has clear applicability in Andean rural communities, such as Molleray, where hailstorms represent a recurring threat to food security and economic development. The implementation of APUY seeks to effectively reduce agricultural losses through an accessible and sustainable early warning system. First, the technical feasibility of the project lies in its modular and autonomous design, powered by solar energy, which guarantees its continuous operation even in remote regions without access to electricity. Likewise, the use of notifications in Quechua and Spanish, together with an intuitive visual code, facilitates its adoption and understanding by local communities.

Beyond its agricultural benefits, the system also holds significant potential for livestock protection. Through community interviews, it was identified that APUY could serve as a warning system for nocturnal frost events, which often occur without prior notice and pose a serious risk to livestock. By alerting farmers in advance, they can take preventive measures to safeguard their animals, ultimately preserving their livelihood and the local economy.

The impact of the project is evident in three key areas: the improvement of agricultural resilience by providing accurate and timely meteorological data, the strengthening of a preventive culture through community awareness and the integration of traditional practices, and long-term sustainability, thanks to the low maintenance cost and the possibility of future technological adaptations.

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