2023 IEEE Global Conference on Artificial Intelligence and Internet of Things (GCAIoT) | 979-8-3503-8202-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/GCAIoT61060.2023.10385094

Enhancing Agricultural Support for Small Scale Farmers in Kenya: An IoT-based Mini Weather Station as a Machine Learning Data Collector

1st Solomon Itotia
@iLabAfrica
Strathmore University
Nairobi, Kenya
sitotia@strathmore.edu

2nd Betsy Muriithi
@iLabAfrica
Strathmore University
Nairobi, Kenya
bmuriithi@strathmore.edu

3th Stephen Gitahi
@iLabAfrica
Strathmore University
Nairobi, Kenya
sgitahi@strathmore.edu

4th Phylis Korir
@iLabAfrica
Strathmore University
Nairobi, Kenya
phylis.korir@strathmore.edu

5th Morris Murigi
@ilabAfrica
Strathmore University
Nairobi, Kenya
morris.murigi@strathmore.edu

6th Ronny Kimutai
@ilabAfrica
Strathmore University
Nairobi, Kenya
ronny.kimutai@strathmore.edu

7th John Olukuru
@iLabAfrica
Strathmore University
Nairobi, Kenya
jolukuru@strathmore.edu

8rd Joseph Sevilla
@iLabAfrica
Strathmore University
Nairobi, Kenya
joe@strathmore.edu

***Abstract*—This paper presents a mini weather station device as a data collector for a machine learning model, aiming to support the Kenyan agricultural sector through small-scale farmers. Most farmers in Kenya practice small-scale farming and often face challenges in accessing timely and accurate weather information, which deters them from making informed decisions on what kind of crops to grow and the type of resources to allocate to their farms. We propose designing and deploying an affordable IoT mini weather station that collects real-time weather data to address this issue. The device has sensors that collect meteorological parameters such as humidity, temperature, light intensity, and atmospheric pressure. The collected data is transmitted to a cloud server and can be used as input for AI-powered machine learning models for forecasting and advisory systems to personalize recommendations to farmers, such as optimal planting time, irrigation schedules, and pest management strategies based on the prevailing weather.**

***Index Terms*—IoT, AI, weather and climate information, Smart Agriculture**

I. Introduction

Climate and weather information is crucial for making informed decisions across various sectors, such as agriculture, disaster management, energy, the transport industry, and public health [1]. There has been a slow increase in food productivity over the years due to low access to extension and advisory services due to poor input and output data [2]. Similarly, the radical change of climate change has affected farmers due to fluctuations in temperature, precision, or biophysical pathways, which extend changes to soil and water, hence changing growth seasons [3]. In agriculture, timely and accurate weather data is indispensable for farmers to optimize planting and harvesting schedules, manage irrigation, and implement appropriate pest control strategies. This requires innovative solutions leveraging data-driven approaches and emerging technologies to address these issues. Internet of Things (IoT) technology has the potential to revolutionize various industries, such as agriculture by collecting weather and environmental-related information in almost real-time using sensors. The collected data can then be subjected to Machine learning (ML) algorithms for further processing to obtain meaningful patterns and trends for better decision-making [4]. This paper presents the design and development of mini-weather stations to solve the challenges faced by small-scale farmers in Kenya. The device is fitted with various sensors to collect essential environmental data such as humidity, temperature, UV light level, barometric pressure, and altitude. The collected data is used to develop agro-advisories for farmers. Merging these two technologies aims to empower farmers with valuable insights to enhance their capacity to adapt to randomly changing weather conditions, optimize farming practices, and improve overall productivity.

ATPS (IDRC, SIDA), Mozilla

II. Literature Review

This literature review examines the evolution of IoT-integrated weather stations and their impact on weather forecasting. These devices offer real-time, localized data, addressing the limitations of traditional weather monitoring methods. We explore their applications in precision agriculture, environmental monitoring, and disaster management, as well as challenges and prospects, highlighting the potential of IoT in enhancing weather prediction and understanding.

A. IoT-Based Weather Monitoring Systems

Masinde et al [5] introduced the SenseWeather IoT weather monitoring system as a solution to the challenges faced by

Kenyan agricultural farmers. The system, built upon agricultural boards from Libelium, aimed to fill the gap caused by inadequate data collection and the high maintenance costs associated with professional weather stations. It employed an SMS gateway to promptly alert smallholder farmers about extreme weather conditions, enhancing their preparedness. However, the SenseWeather system had limitations. While it effectively addressed the need for localized weather data and provided critical alerts, it fell short in offering day-to-day farming advisory support. Moreover, the absence of remote access capabilities rendered it less self-sustainable in the context of modern agricultural practices.

Math and Dharwadkar [6] proposed an IoT-based real-time local weather station for precision agriculture (PA) in India. The system was developed by integrating low-cost open-source hardware and software components. The hardware includes sensors for measuring weather parameters such as temperature, humidity, rainfall, wind speed and solar radiation, Arduino for weather station setup and Thing Speak for data analysis and obtaining insights through visualization. The collected data is then processed and results consisting of real-time weather data, historical trends. However the data collected is yet to be tailored to farmers.

Similarly, Kapoor and Barbhuiya [7] proposed a cloud-connected IoT weather monitoring system, leveraging Raspberry Pi 3 Zero W and Raspberry Pi 3 boards. Their setup ensured real-time remote access and efficient data collection. The system monitored key weather parameters like temperature, humidity, wind speed, pressure, and rainfall using precise digital sensors. Data transmission between the boards occurred via WiFi, reducing power consumption and costs. The information collected was stored in the Dynamo-DB cloud database, facilitating data processing. Additionally, they employed a cloud-based machine learning model to offer weather predictions and insights. Users could access real-time data through a web application powered by Django. However, the web portal primarily provided raw data, necessitating further processing for practical farming applications.

Monitoring stations for weather conditions is pivotal in enhancing resource utilization efficiency, such as water and fertilizers, within the context of smart agriculture. In their study, Marwa et al [8] introduced a device that automatically and continuously monitors environmental factors like humidity, temperature, and rainfall on large agricultural farms to enhance smart agricultural practices. Over a year, the system collected environmental data and underwent real-world testing on agricultural farms in Tunisia. The system comprised a central hub called the gateway, field-installed nodes, and cloud-based storage. The sensors integrated into the field nodes captured on-site data relayed to the gateway using ZigBee communication modules directly or through multiple hops. Despite its cost-effectiveness and resource conservation benefits, the system lacked comprehensive decision-making support.

Gupta et al [9] presented a sustainable and eco-friendly mini-weather station that can monitor localized weather conditions of an area. They developed the system using the ESP32 platform and collected six weather parameters: rain, temperature, humidity, UV index, light level, and atmospheric pressure. The collected data is then sent to a Firebase database in real-time and availed through mobile and web applications. The ESP32 controller is programmed using Arduino IDE. The authors address the gaps in weather monitoring, such as ensuring constant power and remote accessibility. Despite its user-friendly interface and improved data collection, Gupta et al.'s [9] system fell short in providing actionable insights directly to farmers, suggesting a potential avenue for enhancement.

B. Bridging the Gap with Machine Learning

The marriage of IoT and machine learning holds tremendous promise for enhancing agricultural support. While existing IoT-based weather monitoring systems focus on data collection, the synergy between IoT and machine learning can provide actionable insights to farmers. Our study addresses this gap by integrating machine learning models into a mini weather station for small-scale farmers in Kenya

Bella et al [10] presented the development of a sustainable smart weather station to track weather conditions such as temperature, humidity and wind speed and other weather parameters. The data collected was then sent to an IOTA network via Wi-Fi modules which allows real-time monitoring. The device developed is affordable and sustainable, making it accessible to small-scale farmers although the solution lacks accurate and timely weather information for farmers, especially in developing countries. Moreover, the authors developed a weather forecasting module that generated short-term and long-term weather forecasts with alerts set for extreme weather events. The authors proposed future enhancements to include cross-domain data analysis and personalized weather information.

C. Research Gap and Contribution

The literature has outlined the evolution and current landscape of IoT-integrated weather stations designed to enhance weather prediction and environmental understanding. Researchers have employed various methods, platforms, and sensor arrays to develop weather monitoring systems that are affordable, adaptable, and capable of collecting real-time localized data. These stations have applications in precision agriculture, environmental monitoring, and disaster management, presenting a significant improvement over traditional weather monitoring systems by offering remote accessibility, cost-effectiveness, and insights derived from localized data collection. The reviewed studies showcase the creation of different systems, utilizing platforms such as ESP32 and Raspberry Pi, to collect an array of weather parameters. Open-source technologies allow for the systems keep the system low-cost and affordable for small-scale farmers. These systems often employ cloud databases and web applications to facilitate real-time data accessibility and management. These technologies have been applied in various contexts, from en-

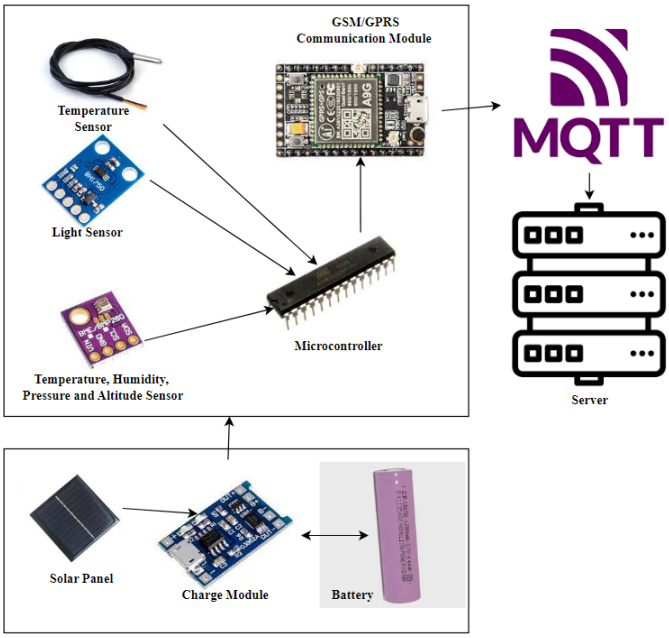

Fig. 1. System component configuration.

hancing agricultural productivity in Kenya to supporting smart agriculture, indicating their global relevance and applicability.

While the studies have undeniably made significant strides in employing IoT technology for weather prediction and monitoring, there seems to be a noticeable gap in leveraging the synergy of IoT and Machine Learning (ML) in providing nuanced climate advisory services specifically catered to smallholder farmers. Most of the studies focus on data collection and real-time monitoring, but there is a potential to expand these systems by incorporating ML algorithms that can analyze the large datasets collected to provide actionable insights and predictive analytics to farmers. Thus this research paper attempts to leverage both IoT and ML for localised weather and climate information services for smallholder farmers.

III. Materials and Methods

This section shows a detailed approach to building a low-cost mini weather station. These components are interconnected, as shown in Fig. 1. Sensors are connected to a microcontroller unit (MCU) through analogue or digital general-purpose input/output (GPIO). A Global System for Mobile Communication (GSM)/ General Packet Radio Services (GPRS) module is also connected to the microcontroller through Universal Asynchronous Receiver/Transmitter (UART) pins to enable data transmission remotely. The system was equipped with a battery and a solar panel for a consistent power supply. The most optimal deployment sites were selected carefully, ensuring they were well elevated from the ground, minimally obstructed, and exposed to enough light. The area was secure and accessible for maintenance.

A. Barometric Pressure Sensor (BMP280) - Atmospheric Pressure, Attitude, Temperature and Humidity

BMP280 sensor is a high-precision sensor module that supports both SPI and I2C interface. This sensor is recalibrated, hence capable of measuring parameters as soon as they are powered. This sensor requires a minimum of 1.71 V, a maximum of 3.3V, and a current consumption of 2.7µA. The precision of this sensor is 0.12hPa or a change in height of 1 meter.

B. Digital Thermometer Sesnor - DS18B20

DS18B20 provides temperature measurement and communicates over a 1-wire bus that requires only one communication data line for communication with the central microprocessor. This sensor utilizes parasite power, eliminating the need for an externally connected power supply. This sensor needs a minimum of 3V, a maximum of 5.5V, and an active current of 1 to 1.5 µA.

C. Ambient Light Sensor - BH1750

This sensor is used to get the amount of light in an environment. It provides 16-bit light measurements in lux SI Units. This sensor has an I2C bus interface and operates with a power supply of 2.4V minimum and a maximum of 3.6V. The current required by this sensor is 190 µA.

D. GPRS and GPS Module

This is a complete qual-band (850/900/1800/1900MHz) GSM/GPRS plus GPS module based on the RDA8955 chip designed by Ai-Thinker. The integration of this chip with a full protocol stack such as GSM/GPRS helps support phone voice calls, Short Message Service (SMS), serial to GPRS, and GPS data transmission functions. The module supports a low power mode of 2mA with a power supply requirement between 3.5V and 4.2V.

E. Microcontroller - ATMEGA328P-PU

The ATmega328P-PU is a versatile 8-bit microcontroller chip manufactured by Microchip Technology, belonging to the AVR family. It features 32KB of Flash memory for program storage, 2KB of SRAM for data manipulation, and 1KB of Electrically Erasable Programmable Read Only Memory (EEPROM) for non-volatile data storage. This microcontroller can operate up to 20 MHz, offers 23 general-purpose I/O pins, supports various peripherals like timers, USART, Serial Peripheral Interface (SPI), and I2C (Inter-Integrated Circuit), and includes a 10-bit ADC for analogue-digital signal conversion. Its plastic dual in-line package (DIP) makes it suitable for hobbyists and prototyping projects, and it is widely used in developing embedded systems, often serving as the core component in popular platforms like the Arduino Uno.

The chip operates within a voltage range of 1.8V to 5.5V, making it compatible with various power sources. It incorporates low-power modes such as idle, power-down, and standby modes, enabling significant reductions in power consumption during periods of inactivity. These low-power features make

TABLE I
MICROCONTROLLER, SENSORS AND COMMUNICATION MODULE CONNECTIONS

Sensor/Module	Microcontroller	Connection type	Voltage
A9G Module	TX, RX pins (2,3) Power (GND, VCC)	UART/Serial	3.3V
DS18B20 Temperature Sensor	Digital Pin (4) Power (GND, VCC)	Data	3.3V
BMP280 Pressure, Temperature Humidity Sensor	SDA, SCL (A4, A5) Power (GND, VCC)	I2C	3.3V
BH1750 Light Sensor	SDA, SCL (A4, A5) Power (GND, VCC)	I2C	3.3V

the ATmega328P-PU ideal for applications where energy efficiency and power optimization are paramount, such as portable devices, sensor nodes, and IoT applications, helping to extend battery life and reduce overall power consumption.

F. Hardware Prototype

The device was implemented by connecting the components on a breadboard. Header files were utilized to write a program uploaded to the microcontroller. The connection between the microcontroller, sensors, and communication module is summarised in Table. I.

G. Printed Circuit Board (PCB) Design

A printed circuit board (PCB) was designed and prepared to host all the components on one board. The schematic and PCB are shown in Fig.2.

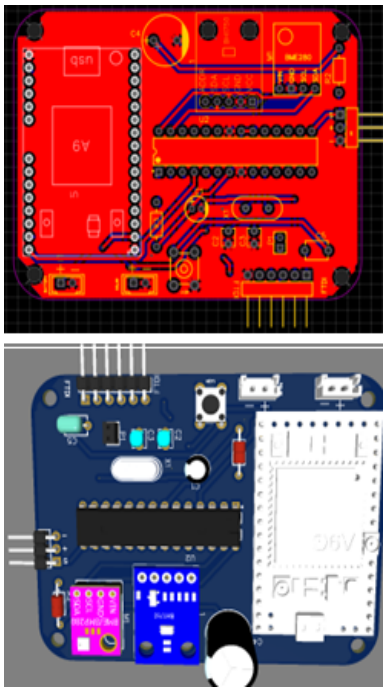

Fig. 2. Printed Circuit Board (PCB) Design.

H. Sensor Data Validation

Data validation involves comparing the data received against conventional weather stations deployed by the Kenya Agricultural and Livestock Research Organization (KARLO) and Weather API hosted on Rapid API [12]. A systematic error analysis Root Mean Square Error (RMSE) and the correlation coefficients of the sensor readings with the weather station were computed.

I. Weather Agro-advisory Mobile Application

The Weather Agro-Advisory application is designed to provide farmers with localized weather forecasts and agricultural advice. It relies on a combination of technologies and components to deliver this functionality seamlessly, including the RASA framework, a Speech-to-Text (STT) and a Natural Language Processing (NLP) translation module. At its core, the system begins by collecting weather data from IoT mini-weather stations. This data serves as the foundation for generating accurate 7-day weather forecasts. Additionally, the application features a chatbot that offers agricultural advice based on the weather conditions, which is particularly valuable for farmers. The RASA framework handles the dialogue flow by managing Structured query language (SQL) queries with our English-based knowledge base developed from the Food and Agriculture Organization (FAO) Crop Calendar [11].

To enable users to interact with the application in Swahili, a Speech-to-Text (STT) module converts spoken Swahili input from users into text, making it accessible to the system. The STT module employs the Mbaaza STT model, which has been fine-tuned specifically for Swahili STT tasks [13]. The text is translated to English via a Natural Language Processing (NLP) translation model [14]. For example, it can translate a Swahili term like ”maharagwe” into its English equivalent, ”beans.” The translated input is then fed into the RASA framework to obtain a relevant response to the user input. Once the system generates a response in English, it undergoes a reverse translation process to ensure that the user receives the answer in Swahili, making the information accessible and understandable to the target audience. The architecture is summarised in Fig.3.

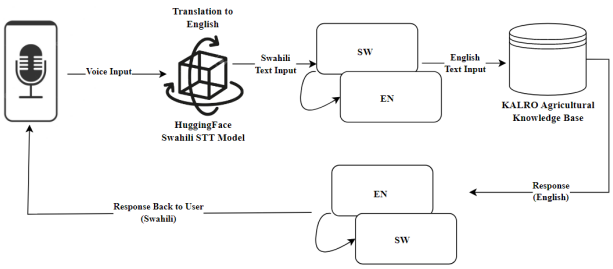

Fig. 3. RASA Open Source Framework

IV. RESULTS AND DISCUSSION

The development stations were deployed in two counties for testing purposes. Two stations were deployed on a farm

Fig. 4. Deployed prototypes of the mini-weather stations.

within Machakos County, and two more stations in Kiambu County. These marked an advanced step to fuse meteorological research and agricultural practices. The devices are actively collecting data. By harnessing this localized information, farmers will get valuable insights into micro-climates while assisting in making informed decisions through crop cultivation and disaster preparedness technology. Fig.4 shows the two deployed mini-weather stations in Machakos county.

A. Web Application

Through visualization, datasets transmitted to a server space using the MQTT protocol were represented on a web application with graphs that made patterns and trends readily apparent. Users can monitor parameter trends and their fluctuation with user-friendly web applications. This application enhances data compression and empowers the end user to note trends and make informed decisions. This application offers customisable features such as real-time data updates and historical data retrieval to ensure users have the most recent and up-to-date information. Fig.5 shows a snapshot of one of the device data on a web application.

Fig. 5. Web application for real-time monitoring of the weather stations and historical data tracking

The validation shows good performance in terms of RMSE and correlation coefficient for temperature data. However, humidity data had a higher error rate when validated against KARLO weather stations compared to the Weather API.

TABLE II
VALIDATION OF DATA COLLECTED IOT SENSOR DATA

Datasets	Temperature		Humidity	
	RMSE	Corr.Coef	RMSE	Cor. Coef
KALRO	1.9	0.70	25.92	0.41
Weather API	2.49	0.40	7.38	0.40

B. Localized Android App

The IoT mini weather station data was used to develop a localized advisory system for small-scale farmers through an Android app. Since most farmers are conversant with the national language, a chatbot was developed using Swahili. This localization ensures that there is less effort in training farmers and that technology is open for adoption by many farmers. The user interface of the application adopts an audio and text format with a seamlessly blended functionality and user-friendly design, catering to both information retrieval and interactive engagement. Upon launching the app, users are greeted by a dynamic homepage which includes a bottom navigation that offers two distinct pages. The first page presents an intuitive weather dashboard, with real-time meteorological data alongside a comprehensive five-day forecast as illustrated in Fig.6

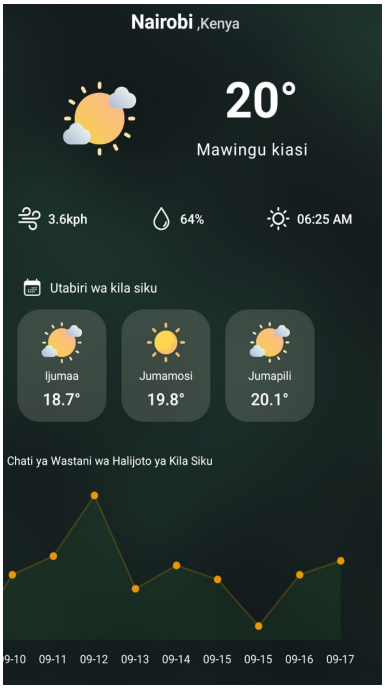

Fig. 6. Daily weather and forecast page of the mobile application

On the second page, the interface transforms into an inviting conversational space featuring a chatbot. The page includes a responsive microphone icon awaiting Swahili voice input. This

enables users to engage in natural, hands-free interactions with the chatbot, fostering an immersive and efficient dialogue. The minimalist yet sophisticated design exudes accessibility, with user-friendly icons and seamless navigation facilitating a fluid experience throughout the application as illustrated in Fig.7

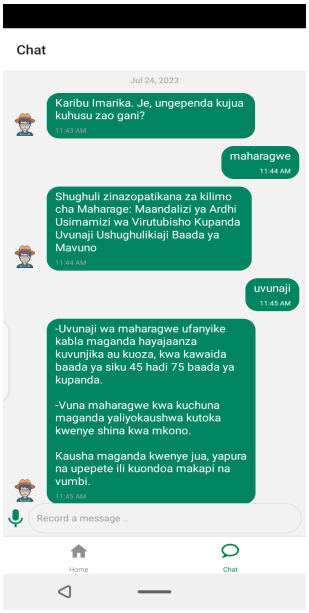

Fig. 7. Daily weather and forecast page of the mobile application

V. Conclusion

Weather changes over time, impacting many regions of human beings, animals, and crops. Monitoring weather variations and acting accordingly is important to improve and save living beings' survival. In this paper, we developed a mini weather station to track weather data and fuse the parameters collected to an ML model for advisory purposes to help farmers grow and harvest food in masses, improving food security. Adopting localized weather-related data can improve accuracy in predicting weather patterns. For farmers, this kind of data will act as a guiding light and guide on when to plant, irrigate, and harvest crops with AI and IoT-assisted systems. This way, they can protect their crops from calamities while ensuring good health and quality of their harvest. In addition, adopting these technologies will aid in insurance assessments and claim processing when weather-related losses occur.

The key findings and contributions of this work underscore the significance of technology in revolutionizing agriculture. The successful integration of AI-driven tools with IoT-based weather stations has shown how data-driven insights can empower smallholder farmers. The deployment of interactive voice response systems in local languages further promotes inclusivity and user-friendly access, addressing barriers posed by limited digital literacy. The lessons garnered from the Strathmore University, Machakos and Muguga sites provide a solid foundation for future deployments in regions of Busia, enabling the refinement and optimization of the system based on real-world experiences. Specifically, 20 mini-weather stations will be deployed in Butula and Nambale Sub-counties in Lwanikha, Kisoko, Bulwani and Bukhalalire Villages.

Acknowledgment

We give special regard to the African Technology Policy Studies Network: ATPS and Mozilla Common Voice whose sponsorship has and continues to enable this work.

References

[1] Nkiaka, E., Taylor, A., Dougill, A. J., Antwi-Agyei, P., Fournier, N., Bosire, E. N., Konte, O., Lawal, K. A., Mutai, B., Mwangi, E., Ticehurst, H., Toure, A., and Warnaars, T. (2019). Identifying user needs for weather and climate services to enhance resilience to climate shocks in sub-Saharan Africa. Environmental Research Letters, 14(12), 123003. https://doi.org/10.1088/1748-9326/ab4dfe

[2] Ferris, S., Robbins, P., Best, R., Seville, D., Buxton, A., Shriver, J., and Wei, E. (2014). Linking smallholder farmers to markets and the implications for extension and advisory services. MEAS Brief, 4(10), 13-14.

[3] Weaver. (2019). Climate Change Impacts on Small Scale Producers. Evans School of Public Policy and Governance. Retrieved August 2, 2023, from https://epar.evans.uw.edu/blog/climate-change-impacts-small-scale-producers

[4] Abu, N., Wan Daud, W. M. B., Ong, C., Kassim, A. M., Izzuddin, T., Sukhaimie, M., Norasikin, M., and Rasid, A. (2022). Internet of Things applications in precision agriculture: A review. Journal of Robotics and Control (JRC), 3, 338–347. https://doi.org/10.18196/jrc.v3i3.14159

[5] Masinde, M., Bagula, A., and Nzioka, M. (2013). SenseWeather: Based weather monitoring system for Kenya. 2013 IST-Africa Conference and Exhibition, 1–13.

[6] Math, R. K. M., and Dharwadkar, N. V. (2018, August). IoT Based low-cost weather station and monitoring system for precision agriculture in India. In 2018 2nd international conference on I-SMAC (IoT in social, mobile, analytics and cloud)(I-SMAC) I-SMAC (IoT in social, mobile, analytics and cloud)(I-SMAC), 2018 2nd international conference on (pp. 81-86). IEEE

[7] Kapoor, P., and Barbhuiya, F. A. (2019). Cloud-based weather station using IoT devices. TENCON 2019 - 2019 IEEE Region 10 Conference (TENCON), 2357–2362. https://doi.org/10.1109/TENCON.2019.8929528

[8] Marwa, C., Othman, S. B., and Sakli, H. (2020). IoT based low-cost weather station and monitoring system for smart agriculture. 2020 20th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), 349–354. https://doi.org/10.1109/STA50679.2020.9329292

[9] Gupta, A., Tripathi, A., Coutinho, R., Rodrigues, R., and Raut, P. (2021). Smart sustainable mini weather station. 2021 IEEE 9th Region 10 Humanitarian Technology Conference (R10-HTC), 01–05. https://doi.org/10.1109/R10-HTC53172.2021.9641672

[10] Bella, H. K. D., Khan, M., Naidu, M. S., Jayanth, D. S., and Khan, Y. (2023). Developing a Sustainable IoT-based Smart Weather Station for Real Time Weather Monitoring and Forecasting. In E3S Web of Conferences (Vol. 430, p. 01092). EDP Sciences

[11] Fao Crop Calendar. Accessed: 6 August 2023. [Online]. Available: https://cropcalendar.apps.fao.org/

[12] Free Weather API - WeatherAPI.com. Accessed: 30 August 2023. [Online]. Available: https://www.weatherapi.com/

[13] Elamin, M., Chanie, Y., Ewuzie, P., Rutunda, S. (2023, April). Multilingual Automatic Speech Recognition for Kinyarwanda, Swahili, and Luganda: Advancing ASR in Select East African Languages. In 4th Workshop on African Natural Language Processing

[14] RapidAPI, "NLP Translation API Documentation (gofitech) — RapidAPI," RapidAPI