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SmartHydro: Developing and Deploying AI and IoT-enabled hydroponic grow tents with subsistence farmers in South Africa

Yusuf Ismail
The Independent Institute of Education's Varsity College
Durban, South Africa
ST10083671@vcconnect.edu.za

Sarina Till
The Independent Institute of Education's Varsity College
Durban, South Africa
ctill@varsitycollege.co.za

ABSTRACT

South Africa is experiencing extreme weather conditions, often resulting in failed crops. The country has many subsistence farmers who rely on small-scale farming for food security and livelihoods. This paper presents [project name omitted to ensure anonymity], an Artificial Intelligence (AI), and Internet of Things (IoT) hydroponic grow tent implementing the Nutrient Film Technique (NFT) approach for leafy green plant production. The system uses a Random Forest Classifier (RFC) and various sensors for the real-time, accurate management of nutrient levels, pH, light, temperature, and humidity to provide an optimal environment for crop growth, in most cases, regardless of the weather patterns outside of the tent. The system further includes a mobile application that allows farmers to interject and manage all the elements in the tent. This paper reports on the design, development, and first deployment of [project name omitted to ensure anonymity] with rural subsistence farmers in South Africa. We found that South African farmers are keen to explore new agricultural technologies and were able to co-farm using [project name omitted to ensure anonymity] to grow crops that are no longer successfully cultivated due to the erratic weather conditions in South Africa.

CCS CONCEPTS

• **Applied computing → Agriculture**; • **Computing methodologies → Planning for deterministic actions**; **Artificial intelligence**.

KEYWORDS

Hydroponic Agriculture, Nutrient Film Technique (NFT), Random Forest Classifier, Android Application Integration, Environmental Control Automation, Machine Learning in Agriculture, Real-Time Data Monitoring, Sustainable Farming Practices

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1 INTRODUCTION AND BACKGROUND

South Africa and many other LMIC countries are experiencing the effects of climate change[5]. Unfortunately, the resulting erratic weather conditions have proven detrimental to subsistence farmers who grow small crops to feed their families and generate a small income [4]. Hydroponic farming is becoming more popular in the agricultural sector because it provides an alternative approach to conventional soil-based plant cultivation as plants are grown in a water-based, nutrient-rich solution[2, 6]. This farming method is less costly for water consumption and pest control [1], negating the need for large soil plots to cultivate crops. Hydroponics can also produce higher yields if a controlled environment is provided regarding temperature, humidity, nutrients, pH (water acidity), and light [6]. The Nutrient Film Technique (NFT) hydroponic growing method, which involves running nutrient-rich water over the roots of plants, has further proven to be simple and effective in growing hydroponic crops[cite]. Combining the NFT hydroponics growth method with a hydroponics grow tent can mitigate the effects of many erratic weather patterns resulting in crop failures.

However, hydroponic growing can be daunting as it relies on skill and knowledge regarding balancing the nutrient solution (EC) abd providing the correct levels of water acidity (PH) and light, as well as correctly maintaining the humidity and temperature in the grow tent[6]. This paper presents [name of project omitted to ensure anonymity], an NFT-based Internet of Things (IoT) and Artificial Intelligence (AI)-enabled hydroponic grow tent system that adopts automation through a machine-learning and IoT approach. This was achieved through training a Random Forest Classifier (RFC) model using synthetic datasets. This model was then deployed as an Ultra TinyML model running on an 8 bit Arduino Mega microcontroller. The system receives real-time sensor data from the many sensors in the tent. This data is then fed to the ML model, which, in turn, classifies the state of each control element (temperature, humidity, light, Ph, and EC) in the tent[3]. The classification outcome is then used to trigger fans, peristaltic pumps, water flow, and other elements in the grow tent to ensure that the growth environment is optimal. The system enables a farmer to interject and control any tent component via a local WiFi network if the AI model does not perform as intended.

We deployed the system with seven subsistence farmers in two different provinces in South Africa. "However, the extensive implementation of high-tech solutions such as hydroponic farming systems in rural environments is associated with various challenges.

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Given that subsistence farmers live in more significant severe and unpredictable weather conditions, several issues might prevent the successful processes of transformation thinking approaches. Among the most urgent are equipment malfunctions, pest invasions, and difficulties in establishing and maintaining systems in distant rural areas. They are exacerbated by a lack of constant access to electricity and the internet, which are vital for using IoT and AI. In addition, rural dwellers might not have the necessary technical skills and awareness or an opportunity to learn them. In that, cultivation thinking has to understand and manage existing issues to ensure the effectiveness and sustainability of hydroponic farming solutions to reduce the threats of global warming."

2 METHODS: DEVELOPING [NAME OF PROJECT OMITTED FOR ANONYMITY]

2.1 Development and implementation of the RFC machine learning model

In this project, we developed and deployed an RFC Machine learning (ML) model to automate the hydroponic grow tent by classifying whether the tent's growing conditions are optimal. The ML model receives real-time input regarding environmental such as temperature, humidity, nutrients, and light in real-time. Obtaining relevant, publicly accessible datasets that included enough records for thorough model training proved difficult. We thus resorted to generating synthetic data using the random module from the Numpy library[1] as the data needed to train the ML was quite simple. We generated datasets that covered a complete range of optimal and sub-optimal values for each environmental parameter. Each record in the data set was labeled low optimal or high. Our synthetic data set consisted of a minimum of five thousand records on each parameter and was used to train four distinct models (EC, pH, temperature and humidity) from the Scikit learn Random Forest classifier library[2]. We evaluated the model based on an accuracy score and the result of a confusion matrix. Both results showed that the models successfully classified the tent's state with an F1 score higher than 70. After training, the created model was ported to an Arduino AT-Mega 2560[3], where it was built as an Ultra Tiny ML project using the microalgal python package that compiles python models in C++ code for deployment onto Arduino platforms.

2.1.1 Automation Features. The grow-tent is controlled and monitored by an AI-driven microcontroller attached to two kinds of relays: one 12 volts and the other 230 volts. The 12-volt relay enables the AI controls for peristaltic pumps [4] used to adjust the EC level (basically, how much nutrient is in the water). The AI receives input regarding the nutrient levels in the tent via an EC sensor [5] and triggers the peristaltic pump to either pump nutrient (if the EC is low) solution or freshwater (if the EC is high) into the water reservoir. The AI similarly manages pH levels with a pH sensor[6] The hydroponic grow light, extractor fan, and airflow fans are connected to the 230-volt relay. The AI receives input from a DHT22 [7] temperature and humidity sensor for switching on and off fans and a DHT11 [8] light sensor for control of the grow light. This configuration results in the environment inside the tent being constantly monitored in real-time, enabling plants to grow under optimal conditions.

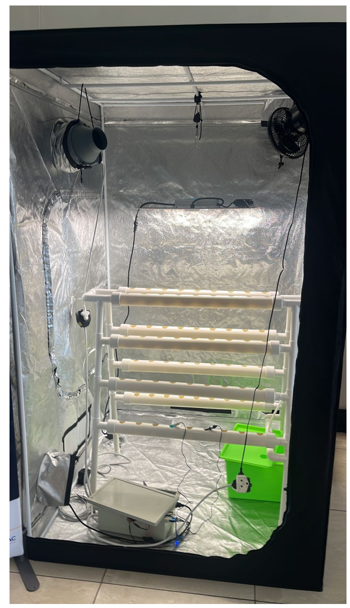

Figure 1: A fully constructed AI and IoT enabled grow tent.

2.2 IoT: Integration with Android App

One essential part of our project was developing and deploying an Android-based mobile application to assist with the manual overriding of different parts of the hydroponic tent. The Android application consumes data from a Restful Application Interface (REST-Api) on the microcontroller. The API has endpoints that enable the manual control of each element within the tent. The mobile application issues a GET request to retrieve the relevant sensor data. This sensor data is then visualized in the User Interface (UI), designed by working closely with the farmers to ensure the applications suit their needs. This was achieved by constantly getting feedback from the farmers, ensuring that the final application was working well and useful for the farmers. The application allows any farmer to interject should the AI not correctly classify and control the tent environment. This is achieved using POST requests sent to the API to fire up pumps to pump nutrients or turn on lights and other elements in the tent if necessary. This automation feature through the use of a mobile application resulted in :

[1]https://numpy.org/
[2]https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.RandomForestClassifier.html
[3]https://store.arduino.cc/products/arduino-mega-2560-rev3
[4]https://www.takealot.com/sobo-submersible-water-pump-15w-880-l-h-max-height-1-2m/PL
[5]https://www.dfrobot.com/product-102
[6]https://www.dfrobot.com/product-1025.html
[7]https://www.dfrobot.com/product-1102.html
[8]https://www.dfrobot.com/product-1004.html

2.2.1 *Real-time Monitoring and Control.*

: Users can access the system metrics in real-time from the above. This means that they will be able to make on-the-fly adjustments to the hydroponic environment, thus improving the system's adaptability to changing conditions.

2.2.2 *Data-Driven Decision Making.*

: Integrating machine learning with the random forest classifier and providing historical data supports data-driven decisions based on historical and real-time data.

2.2.3 *User Friendly Interface.*

: Iterating with farmers to create a mobile application resulted in many versions of the application based on the feedback and remarks from farmers. The development of this application is still in progress as we learn more throughout the project. The current Android application has a user-friendly and straightforward interface designed to reduce the entry barrier for hydroponic farming and thus bring the opportunity to a greater audience. Consequently, adopting this co-design method for the application's development has resulted in more precision and efficiency when growing plants within the hydroponics system. We attribute this to not involving the farmers directly at every stage of the application's development but instead considering their expertise as farmers, which served to ensure that the application is innovative and practical.

3 SYSTEM DEPLOYMENT AND FARMER TRAINING

Deploying advanced agricultural technology in rural settings poses a set of uniquely challenging tasks that require both substantial planning and due consideration. In the case of implementation of our AI and IoT-enabled hydroponic grow tents, a step-by-step deployment procedure was devised that covered the technical and training aspects.

3.1 Deployment Process

The deployment process of our technology started with identifying the sites that matched the selection criteria that included accessibility, pre-existing infrastructure, and community willingness to participate. Upon choosing site which fitted the criteria, the installation process was commenced, it included constructing the tent, establishing the necessary hardware, connecting the power and internet. Particular emphasis was placed on developing a resilient connection grounded on the local realities, such as heavy wind and rainfall.

3.2 Farmer Training, Engagement and Feedback

The training of farmers was also carried out in stages. In the beginning, an introductory session was conducted, which familiarized the farmers with the basic concepts of hydroponic farming and the technologies used in the pilot project. It was essential to develop trust and confidence, as this was a new system for the farmers. Then, practical training was delivered on the farm, where the farmers were trained on how to maintain the operations of the actual hydroponics system, including monitoring from the mobile application and maintenance of the system. The training also covered troubleshooting for the everyday operations such as managing pH and other nutrient solutions. These ensured that farmers were able to run the systems on their own. During the deployment phase, regular field visits were conducted, and a helpline was available to the farmers. If any issue occurred, the farmers could call for an immediate team to come to repair any issues. To measure the effectiveness of the training and refine our deployment strategies, feedback was actively sought from the farmers through focus groups and individual interviews. This feedback was invaluable for understanding the farmers' perspectives on the technology, the challenges they faced, and their satisfaction with the training provided. Adjustments were made based on this feedback to improve both the technology and the training programs, demonstrating our commitment to a participatory approach in technology deployment.

4 SYSTEM PERFORMANCE AND ADAPTABILITY

The performance and adaptability of our AI and IoT-enabled hydroponic grow tents must be evaluated in order to determine the viability and effect on subsistence farming. In this section, we will examine the performance metric and the system's adaptability to changes in the environment and the user operations.

4.1 System Performance and Real-Time Data Utilization

A critically important assessment of the performance of our hydroponic system is also made through key metrics such as crop yield, the reliability of the system, and the satisfaction of users. For example, crop yield can be measured by comparing growth rates and physical health in terms of crops grown in our hydroponic tents and the normal crops harvested using soil farming. This measure is important not only as an indicator of hydroponic efficiency but also as a primary measure of the system's ability to improve agricultural productivity. Another measurement involves the use of the reliability of the system. This can be quantified in terms of the number of downtime events brought about by component failures especially the sensors and issues with connectivity. The length of time it takes to restore functioning and whether or not the system performs this restoration without excessive manual input is also a measure of how optimal and reliable it performs. The other critically important feature of our hydroponic system is real-time data use to dynamically change the growing environment. This is achieved through the use of fuzzy logic integrated with machine learning algorithms to adjust values for various parameters such as nutrient amount, pH, and humidity based on real-time data analysis by changing the environment. Not only does this feature ensure a much-improved yield rate, but it also ensures optimal utilization of resources as it significantly reduced water and nutrient waste. The ability to adjust the system through data input and analysis are due to the high levels of user satisfaction since it enables the users to rely on a working, optimal, and efficient farm system.

4.2 Farmer Adaptability, Training Impact, and Feedback-Driven System Adjustments

Furthermore, the well-preparedness and adaptability of the farmers were another aspect of the project's success. The regular training programs and the systems' application being user friendly enabled the farmers to man the process within a short time. Also, as indicated by the increased span between a technical assistance team, it is evident that the knowledge was effectively transferred and the farmers were very instrumental in the implementation process. The second approach was based on improving the system based on the received feedback report from the farmers. It involved minor alteration of the hardware to suit the remote areas' situation and fine-tuning the control spectrum to enhance its overall performance. It indicates that the process of adopting and implementing the hydroponic system in marginalized areas can be fine-tuned to suit the farmers better. The dual approach ensures the system and the farmers are educated at the same pace, leading to sustainability.

5 CONCLUSION

In conclusion, the deployment of AI and IoT-enabled hydroponic grow tents has delivered several benefits to subsistence farming in South Africa. The integration of these innovations resulted in increased plant growth rates and reduced labor costs and promoted highly efficient and sustainable agriculture. The system's adaptability enabled by data and machine learning entails precise adjustments of the environmental conditions, making it possible for the plant to grow as needed despite the external weather conditions. The deployment of these technologies has been especially beneficial for the mature female farmers who are overburdened by the labor-intensive traditional farming methods. The tents allow such farmers to remain fruitful for longer into old age and, as such, support their livelihoods and the community's food security. Additionally, the engagement with the farmers that played a key role in developing and deploying the technology has ensured that the system is user-friendly and responsive to the needs and limitations of the community. The successful outcomes seen in this project indicate that the technology could be used to scale up the solutions across the region due to substantial positive outcomes. Expanding the adoption of AI and IoT in farming could provide broader benefits on the socio-economic level to both the target and the neighboring communities, such benefits could include increased agricultural yields, high food security, and empowering farmers with technology. As we continue to develop more improvements to the solution in the future, it will be important to ensure that the technology is not only a technological solution but a social one, all farmers must feel like they are part of the technology development to avoid endangering their livelihoods and cultures. These new innovative solutions will help the subsistence farmers in South Africa to find their way out of some of the most challenging situations of modern times due to climate change and resources constraints in food security.

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