PROPOSING IOT AND CLOUD-BASED ARCHITECTURE FOR SMART IRRIGATION – A CASE FOR TANZANIA

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ABSTRACT - Agriculture has been the main backbone of Tanzania's economy. Every year, it contributes between 25 and 30% of the GDP and employs over 60% of the country's total workforce. However, despite the abundance of water resources, farming in Tanzania has been seasonally restricted to rainy seasons only. Several irrigation methods such as flooding, water cane, drip irrigation, etc. have been employed by farmers, with the support of the government to ensure all-year-round farming, while these methods might be temporarily successful for subsistence farming, they are expensive, and have several drawbacks which result in inefficient outputs in commercial agriculture as well as other environmental degradation issues. The most paramount of these challenges is over-irrigation or under-irrigation.

As Information Technology continues to disrupt several socio-economic activities, this report discussed the adoption of emerging technologies; Climate-Smart Agriculture to resolve the over-irrigation and under-irrigation challenges. It proposed the adoption of IoT Sensors, IoT Actuators, and Cloud technologies after studying irrigation systems of Korea and Rwanda with information sourced from secondary data.

Due to the political, economic, social, technology, and environmental variations in these countries, the report recommended a best-fit IoT & Cloud-based irrigation systems architecture for Tanzania. A cost-benefit of the proposed solutions revealed that adopting an IoT & Cloud-based irrigation system in Tanzania will eradicate the challenge of over and under-irrigation, increase yield by a minimum of 30%, and reduces the cost of irrigation systems management by 52.3%.

Keywords: Climate-Smart Agriculture; Agriculture; IoT; Cloud Computing; Smart Irrigation; Architecture.

1. INTRODUCTION

The global population has been growing at a rate of over 1% adding approximately 81 million people every year since 1951. In Africa, the growth rate has been consistently over 2% since 1960 and the region has been the worst hit by rising global hunger and food security challenges with 20% (worldometer, 2021) of the population facing chronic hunger. Tanzania is 94th of 113 in Global Food Security Index and one-quarter of its 55.9 million people face chronic hunger (Global Hunger Index, 2021). A global situation that informed the 2015 UN Agenda to end global hunger by 2030.

Although statistics show that the world is producing enough to feed its growing population, Agriculture in Tanzania, even though employs more than 60% of her population, has experienced a stagnant growth of 4.4% over the past years. In seasons when there is adequate rainfall, Tanzania produces enough food to feed its growing population and export to neighboring countries. However, during drought seasons, the country experiences serious food shortages largely due to seasonal dependencies, dwindling food production, lack of storage facilities, and often have to depend on food importation and receiving food aid (Amani, 2006).

Considering the abundance of water resources around the country, the Tanzanian Government, through the National Irrigation Commission had employed several irrigation schemes; sprinklers, flooding irrigation, plastic cane watering, treadle pumps, etc. to address challenges of seasonal dependent agriculture.

These irrigation schemes and techniques are not without their own challenges, most pressing of which is over, and under-irrigation stemming from the absence of modern irrigation systems due to high management cost and the initial cost of adoption (World Bank, 2019). Therefore, this study proposed a low-cost smart irrigation system easily adoptable by amongst subsistence Tanzanian farmers towards reduction of water loss, and improving agricultural productivity in the country with minimal management cost incurred.

2. LITERATURE REVIEW

The main challenges of conventional irrigation techniques are under and over-irrigation with the efficiency of water application in the field, *Field application efficiency (ea)*, at 60%, 75%, and, 90% for Surface, Sprinkler, and Drip irrigation methods respectively (C Brouwer et al., n.d.). While the drip irrigation systems have higher water-use efficiency, in East Africa, conventional irrigation systems are characterized with water use efficiency below 50% (Kimaro, 2019), the initial cost of adoption of modern systems are unaffordable to small-scale farmers with capital cost ranging from $1500 to $2500 per acre, and are knowledge-intensive (García et al., 2020).

As technology advanced, new low-cost drip irrigation (LCDI) systems with better field application efficiency than conventional drip systems have emerged. Practical deployments of LCDI in Nepal, India, USA proved that LCDI is more advantageous than conventional drip irrigation means in terms of long-term productivity and management cost savings(Von Westarp et al., 2004).
Further advances in sensors and the evolution of IoT and cloud computing technologies are heralding smarter LCDIs by adopting sensors in monitoring environmental parameters resulting in the reduction of water wastage by up to 95% (Pernapati, 2018), offering cheaper management costs by providing remote management of deployed LCDI systems, and precision agriculture.

2.1. Macro-Economic Factors affecting Irrigation Agriculture in Tanzania

Tanzania has abundant water resources, it is home to the greatest lakes in Africa; Lake Victoria, Lake Tanganyika, and Lake Nyasa. With relatively high, but seasonal rainfall. As an alternative solution for the seasonal rainfall and semi-desert vegetation, farmers turn to irrigation farming with water sourced from the Lakes, and as of 2017, 461,326 acres of land is irrigated.

The 2010 National Irrigation Policy (NIP) and National Irrigation Strategy (NIS) of 2015 of Tanzania hope to ensure sustainable irrigation for enhanced food production towards food security and poverty eradication. One of its specific objectives is to ensure irrigation development is technically feasible, economically viable, socially desirable, and environmentally friendly. The Ministry of Water and Irrigation expects that through the policy, schemes, and public-private partnership, the creation of the National Irrigation Commission (NIRC), and the constitution of the National Irrigation Fund (NIF), the area of irrigated land in Tanzania would have increased to 1 million irrigated acres of land by 2020.

Tanzania's digital transformation is facilitated by Mobile technology. 82% of the population subscribes to a mobile service as per June 2020 report and mobile internet penetration has reached 49% of the total population. Presently, 3G coverage stands at 68%, 4G stands at 28%, while fibre 10,500KMs (August & Kowero, 2012).

2.2. IoT in Irrigation Agriculture?

The Internet of Things (IoT), Is a group of different forms of sensors interconnected together to allow their management, as well as the access to the data being generated by them. It employs to collect and send data over the internet. In agriculture, it has found uses in monitoring environmental parameters such as humidity, soil moisture, wind speed, precipitation, soil pH, temperature and others, providing farmers with the opportunity to observe, measure, and respond to inter and intra-field variability in crops.

In irrigation farming, the most relevant environmental parameters are soil moisture, the water level in reservoirs, temperature, and humidity. A low-priced, two-forked YL-69/38 sensor that provides soil moisture readings based on the conductivity between two electrodes placed in the soil is mostly used for measuring soil moisture. FC-28, S-XNQ-04, 200SS, SEN0114, all are all based on a similar principle with the YL-69/38. With different working principles, SM300 and VH400 are capable of measuring soil moisture and temperature. However, with YL-69/38 (García et al., 2020).

DHT11 and DHT12 are the most used humidity and temperature sensors while LM35 sensors (-40 to +125ºC) and THERM200 sensors (-40 to +85ºC) with an accuracy of +or-0.5 °C are commonly used to measure soil temperature. Irrigation systems that source water from rivers use solid-state relays to check water availability while the water level in reservoirs is measured by Ultrasonic based HC-SR04 sensors. Commonly deployed cloud services are AWS-IoT, Blink Cloud or Remote XY for remote operation of deployed IoTs such as actuators in the pumps, valves, and sprinklers of the irrigation. 3G communication technology is recommended in developing countries because of its wide deployment (García et al., 2020).

2.3. IoT-Based irrigation Agriculture Architecture.

System architectures are abstract system specifications consisting primarily of functional components described in terms of their behaviors and interfaces and component-component interconnections. Integration of different heterogeneous technologies; IoT, Data Analytics, Cloud Computing, and Fog Computing requires system architectures. The choice of architecture depends on the available technology, environment setting, budget, as well as expertise.

A PIC16F877A microcontroller was combined with a YL-69 soil moisture sensor and DS18B20 temperature sensor that all communicates via an RTC DS1307 sensor module was combined by (Gavali et al., 2018) and monitored via an android mobile application to monitor soil moisture and temperature, and control the water pump valves.

Price and power requirements were considered by (Gupta et al., 2017) in adopting Arduino UNO attached with soil pH and YL-69 moisture sensors and controlled by a python based analytics engine and messaging module to design an irrigation system that notifies farmers by message and automatically starts and stops the pump motors based on these readings.

In a rather knowledge-intensive architecture that requires LAN or WiFi to operate, (Kuruva & Sravani, 2016) deployed sensors (YL-69 soil moisture sensor, water level sensor, and DHT11 temperature and humidity sensor) connected through Arduino UNO for remote plant watering and monitoring system. Sensor data collected through the Arduino UNO is forwarded to a Raspberry Pi running Johnny-Fibre library and an AWS-IoT SDK and analyzed data is visualized from a Dynamo database presented to users from a Web application that also allows them to control the water pump.

(Zamora-Izquierdo et al., 2019) adopted a smart-farming architecture based on low-cost hardware and supported by three-tier open-source software platforms. At the local tier, Cyber-physical Systems also known as IoT are deployed to gather data and for actuators. The edge tier of the architecture is in charge of monitoring and managing the irrigation system, while the third tier, the cloud platform, adopts a FIWARE deployment to analyse past and current records. This architecture however requires an access network through microwave radio links, fibre optic, or DSL for interconnections.

3.0 METHODS

We reviewed works of literature on the subject matter and sourced information from secondary data; government white papers, acts, policies, publications, reports and compared the macro-economic conditions in Tanzania with that of two other countries. The Republic of Korea, a country that has implemented over 800,000 acres of smart irrigation in rice farms which in turn contributes to over 80% of the total rice production in the peninsula (*Statistics Korea*, n.d.), and Rwanda, an East African country who through the Smart Rwanda Strategy have implemented various smart irrigation systems (Bamurigire et al., n.d.). Figure 1 and 2 below presents smart architectures deployed in Korea and Rwanda respectively.

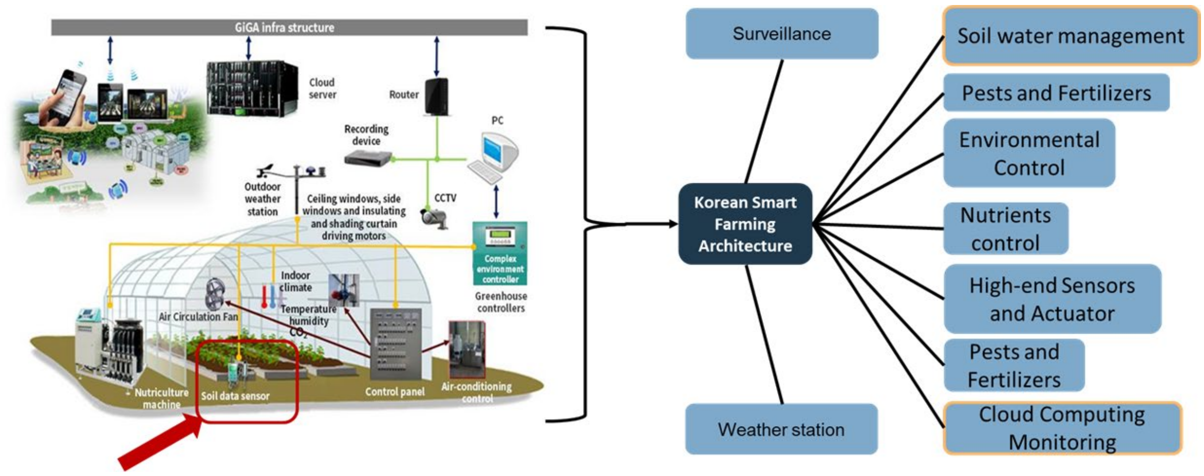

Figure 1: Popular smart farming/irrigation architecture in Korea. Source (*Smart Farm Dispersion Method*, n.d.)

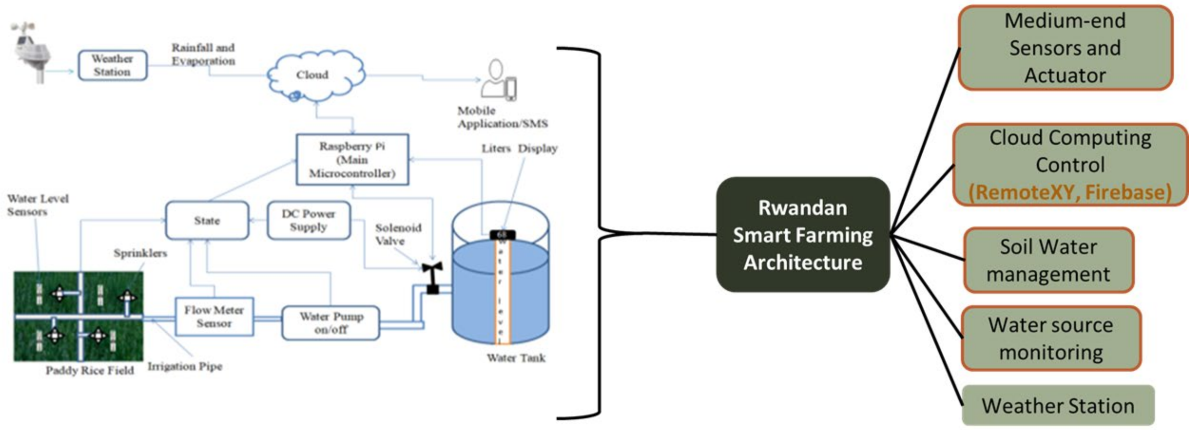

Figure 2: Smart Irrigation architecture deployed for a rice farm in Rwanda. Source (Bamurigire et al., n.d.)

Lessons learnt from the works of literature, secondary sources reviewed and the Gaps identified between Tanzania and the two countries benchmarked; Republic of Korea and Rwanda formed the pillar of our recommended architecture.

3. RESULTS

Comparative analysis of the situations in Tanzania, Rwanda, and the Republic of South Korea revealed the absence of Technology-based irrigation architecture that can be adopted easily by farmers in Tanzania. Therefore, to simplify and reduce the cost of smart irrigation adoption by farmers in Tanzania, the study proposed the following IoT sensors and Architecture

3.1. Proposed IoT Sensors and other Technologies

Table 1: proposed IoT Sensors for smart irrigation farming in Tanzania

SN	Sensor	Unit	Specification
1	Arduino Uno/Mega – IoT Agent	1 per farm	Tmega2560 Microcontroller, operating voltage of 5V and flash memory of 256KB. Its approximate cost is 35USD
2	DHT22 Sensor - Temp & Humidity Sensor	8 per acre	Operating voltage is between 3.3 – 6v, temperatures between -40 to 80ºC, and humidity 0 – 100% Relative Humidity. It costs about 10 USD for each DHT22 sensor
3	YL-38 Soil Moisture Sensor	40 per acre	Operating voltage is between 3.3 to 5 Volts. Each YL-38 sensor might cost around 12 USD
4	Ultrasonic sensor (Water level in a tank)	1 per water tank?	Operating voltage 5V, operating current 15mA, 2cm – 4m measuring range
5	SSR-40 DA Solid State Relay Actuator (remote water pump control)	4 per acre	24 – 380V operating voltage,
6	Raspberry Pi	1 per farm	8GB SDRAM, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz, 5V DC, PoE.
7	Cloud Database (Firebase)	Free	Open Source
8	RemoteXY – Remote Access Controller	(Free)	Open Source
9	Adapter (Node-red) - integration platform		development fragment framework

Source: compiled by author

3.2. Proposed Architecture

The conceptual framework assumes the farmer owns two farms with different water requirements and water sources/supply. Therefore, for each farm, as indicated in figure 1 below, individual IoT Agent (Arduino Uno) is required. This IoT agent will be responsible for monitoring and controlling all sensors connected to it.

YL-38 Soil moisture, Ultrasonic sensor, actuators, and DHT22 temperature and humidity sensors are connected to the Arduino Uno as indicated in the proposed architecture in figure 1, below. This IoT agent, which is also connected to the edge/fog, will be responsible for monitoring and controlling all sensors via internet.

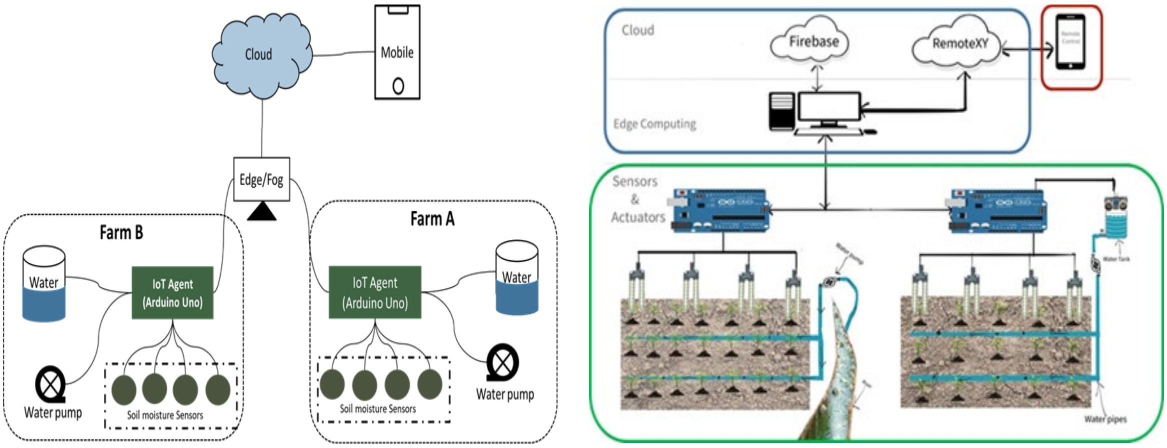

Figure 1. Proposed Conceptual Architecture for smart irrigation in Tanzania

Expected outcome/Benefit Analysis

Table 1. Estimated smart irrigation initial adoption cost per farm based on proposed architecture[1]

SN	Item	Quantity	Unit Price (USD)	Total Price (USD)
1	Arduino Uno	1 per farm	35.00	35.00
2	SIM900 (GSM MODULE)	1 per acre	25.00	25.00
3	DHT22 SENSOR	8 per acre	10.00	80.00
4	YL-38 SENSOR	40 per acre	12.00	480.00
5	Ultrasonic Sensor	1 per water Tank	10.00	10.00
6	DA Solid State Relay	4 per acre	15.00	60.00
7	Water Valve	4 per acre	40.00	160.00
8	Raspberry Pi 4 B	1 per farm	250.00	250.00
9	Drip Pipes	per acre	1,009.67	1,009.67
10	Water Pump	1 per farm	300.00	300.00
11	Water Tank – 200liters	1 per farm	300.00	300.00
	Total (Smart Irrigation cost per farm)			**2,709.67**

Source: compiled by author based on market survey

Table 2. Estimated yearly management cost comparison between traditional and proposed irrigation system

		Traditional Drip Systems	Proposed Smart irrigation System
SN	Item	Price (USD)	Price (USD)
1	Labor Cost[2]	5,400.00	0.00
2	Power Cost	900.00[3]	300.00
3	Internet (20GB)	0.00	290.20
	Total	**6,300.00**	**590.20**

[1] Labour cost for installation excluded

[2] Labour cost for 10 workers for three planting seasons per year. Tasks includes, routine checks, watering, control of pumps etc.

[3] Estimated based on power and alternative sources costs in Tanzania and power requirements of equipment

Source: compiled by author based on market survey

3.3. Quantitative analysis of proposed Architecture.

On IoT-based smart irrigation projects with farm size ranging from one to 20 acres, (Nawandar & Satpute, 2019; Sales et al., 2015; Tiusanen, n.d.) achieved water savings varying between 20% and 70%. On similar projects between 0.5 to 15 Acres, (González Perea et al., 2018; Newman, 2012; USBR, 2008) achieved management cost savings of between 25% and 80%. The proposed architecture, with adoption cost of USD2,709.67 offers a 90.63% reduction in management cost when compared to traditional irrigation methods, and an estimated 30 – 50% water loss savings.

4. DISCUSSION

This study is proposing the adoption of IoT in improving irrigation systems in Tanzania. The study proposed an IoT-based irrigation architecture that considerably reduces the initial cost of adoption and management cost for traditional drip irrigation methods will promote personal and national socioeconomic development. A smarter and more efficient use of available water resources will ensure universal and equitable access to safe and affordable drinking water and food security by increasing yield and making all-year-round farming a possibility for Tanzanian farmers.

Although quantitative analysis of the proposed architecture estimates 30-50% water loss savings and, 90.63% management cost savings, A field evaluation of the proposed architecture has not been executed.

5. CONCLUSION

Agriculture plays a major role in the socioeconomic status of Tanzania. It employs 60% of its total workforce and contributes between 25 to 30% to the National GDP every year. However, farmers in Tanzania face several challenges, one of which is the seasonal dependence agriculture, stemming from unstable rainfalls, making it difficult to obtain water for crops. Due to abundant water bodies around the country, farmers are adopting alternatives such as irrigation farming. However, Adoption and Management cost of such systems are high. In addition, human errors and drawbacks of some irrigation systems can lead to over-irrigation or under irrigation and possibly water loss.

This study proposed an IoT and Cloud based smart irrigation architecture that adopts various low-cost IoT sensors and cloud technology to provide a need-based automated irrigation of farm that is low-cost, and significantly reduces management cost when compared to the traditional irrigation systems.

The limitations of this study includes, most of the data gathered and used in this report are secondary data. The report lacks primary data in making recommendations, which makes a little bit gap between the situation presented and the reality. Furthermore, the cost suggested is based on online marks, which may be slightly higher or lower than the actual cost. The cost analysis should be done in detail by the suppliers of the technologies to determine the actual cost before committing the implementation budget.

AUTHOR CONTRIBUTIONS

Emmanuel Fredy Mwakasege sourced all secondary data that was used in the paper, designed, and carried out the quantitative assessment of the proposed architecture.

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