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Increasing Agricultural Productivity in Nigeria Using Wireless Sensor Network (WSN)

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ABSTRACT

Nigeria is a country endowed with fertile soil which as a result is expected to bring forth bumper harvest of agricultural products. However, the major challenge is the farmer not having full control over the activities on farmland and its environment which in most cases, if not well managed, brings about low agricultural productivity. This paper therefore proposes precision farming solution using Wireless Sensor Network to increase agricultural productivity in Nigeria. With this, the system will be able to sense environmental parameters and thereafter transmits its findings to the base station in order for the farmer to make decisions such as to actuate irrigation scheduling, fertilization scheduling and so on. On the farmland, sensors are meant to be uniformly distributed and used for nodes localization. The proposed system is expected to proffer solution to challenges starring agricultural productivity in Nigeria at the face.

Keywords— Agriculture, Precision Farming, Wireless Sensor Network,

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1. INTRODUCTION

Nigeria has a population of over 170 million making it the most populous country in Africa. Its domestic economy is dominated by agriculture, which accounts for about 40% of the Gross Domestic Product (GDP) and two-thirds of the labour force. Agriculture supplies food, raw materials and generates household income for the majority of the people.

Trade imports are dominated by capital foods, raw materials and food [1]. Nigeria is currently preoccupied with the challenge of diversifying the structure of its economy most especially with the dwindling oil price. With attendant danger that fall in oil price poses to Nigerian economy, agriculture remains a viable option to diversifying the structure of its economy. The importance of agricultural productivity cannot, in anyway, be overemphasized in tackling this issue staring the country in the face as it remains the single largest contributor to the well-being of the rural poor and sustaining 70% of the total labour force [2].

In order to improve the low agricultural productivity in Nigeria, there is a need for more innovative solutions using modern technologies. Precision Farming solution using WSN technology is being proposed as a way out.

Sensor nodes deployed in an environment, as shown in figure 1, environmental parameters such as temperature, pressure, humidity, or location of objects. Signals from these sensor nodes are transmitted to a local sink which may be connected to a gateway in order to send the data to an external network such as internet so that a remote user can access information about the environment. The received data from sensor nodes may be analyzed and appropriate decision or action taken depending on the application itself [20]. In precision farming, information received about the farm helps the farmer in using the right input needed to improve the crop yield such as fertilizer, water, etc, on the farm. Right use of these inputs, at the right time, in the right place and in the right amount will greatly reduce cost and also improve productivity.

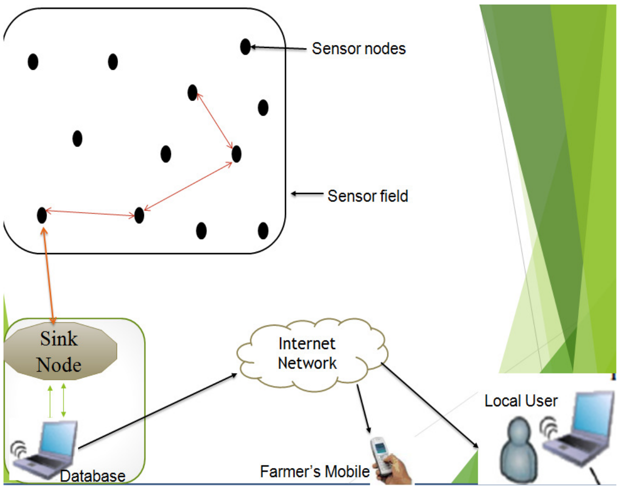

Fig. 1: A Typical Wireless Sensor Network

2. RELATED WORKS

As it were presently, the imperativeness of agricultural productivity to national economy cannot be relegated to the background especially with fall in oil price which Nigeria has relied too much in time past; due to this, agricultural sector has been facing some challenges which bore down to neglect by the government.

[3] x-rayed current situation of agricultural productivity in Nigeria; low quality of infrastructure has been identified as a bane of agricultural productivity in Nigeria; rural infrastructural development has been neglected and as a result of this, rural population has limited access to services such as schools, good road network & health centers. Due to this, there is reduction in the productivity of agricultural produce. Equally, insensitivity of the government to the plight of farmers contributes in no small measure to this menace. The poor tends to live in isolated villages that can become inaccessible during the rainy seasons and as a result, there is experience of substantial loss of productive time, low productivity and poverty in Nigeria.

[4] identified some constraints to agricultural productivity in Nigeria some of which include aging and inefficient processing equipment, inability to install new processing equipment due to high offshore costs, high costs of production inputs and farm machinery, inadequate and untimely funding of the agriculture, agricultural Pricing policies, low access to Agricultural Credit, low and unstable investment in Agricultural Research amongst others.

[5] stated that sustainable increased rice production in the near future requires substantial improvement in productivity and efficiency. The use of innovative genetic improvement including hybrid rice and possibly transgenic rice could increase the yield ceiling, where yield gaps are nearly closed.

He also reported that a direct relationship existed between the amount of irrigation water and evatransportation rice yield indicating the dependence of yield improvement or (shortage) on the quantity of irrigation water administered and by extension the crop water use. Therefore, water application, being a dominant factor affecting growth and **grain yield** of rice needs to be properly scheduled for improved rice production. This scheduling of water and other factors responsible for rice growth can be done by the application of sensors in the field.

Going by the subject under review which is precision farming with concentration on Wireless Sensor Network, several technologies were used in the precision farming such as Remote Sensing (RS) proposed by [6], Global Positioning System (GPS) by [7], and Geographic Information System (GIS) by [8]. The most important step in Precision Farming is the generation of maps of the soil with its characteristics. These included grid soil sampling, yield monitoring, and crop scouting. Remote sensing coupled with GPS coordinates produced accurate maps and models of the agricultural fields. The sampling was typically through electronic sensors such as soil probes and remote optical scanners from satellites. The collection of such data in the form of electronic computer databases gave birth to the GIS. Statistical analyses were then conducted on the data, and the variability of agricultural land with respect to its properties was charted. These technologies apart from being non-real time involved the use of expensive technologies like satellite sensing and manual labour is usually employed [9].

[10] designed a project called Lofar Agro. It deals with fighting a fungal disease called phytophtora in a potato field; the development and associated attack of the crop depends strongly on the climatological conditions within the field such as temperature, relative humidity, luminosity, air pressure, precipitation, wind strength and direction, and the height of the groundwater table were the environmental parameters sensed in the work. The WSN data and statistics were sent to a field gateway, then to the Lofar gateway which is a simple PC for data logging via WiFi connection, then through a wired connection they were sent to the Internet to Lofar server and a couple of other servers under XML format.

[9] introduced a wireless mesh network in is work titled AGRO-SENSE The work comprise of sensors placed at different locations in a crop field where the intended characteristics of the soil or atmosphere (soil pH, soil moisture, electrical conductivity, soil temperature) need to be captured. The actuation is done based on the readings supplied by the sensors, upon exceeding a threshold, the system will generate automated alert messages on the console, upon which appropriate action can be taken.

[11] designed a preliminary study on the development of WSN for paddy rice cropping monitoring application in Malaysia. It introduced standard measurement parameters sensors such as ambient air temperature and humidity, soil pH and moisture were integrated in all nodes, there were two directions the data will go, which is first linked to server data based system to be recorded and revealed on Internet web page and real-time alert system using SMS system via GSM modem to the person in charge cell phone.

[12] designed a WSN based and Internet system for monitoring a field-environment factors in an automatic manner and dynamically transmitting the measured data to the farmer or researchers. The main part of the network acquiring unit mainly includes the sensors of temperature and moisture in air and soil, CO2, and illumination.

3. PROPOSED SOLUTION

Proposed distributed wireless sensor network

Fig. 2 shows the framework of a wireless sensor network system to monitor various parameters on agricultural farmland in order to improve the yield. The sensors on the field are to sense environmental parameters which are transmitted to the base station and stored in the database. The database is linked to the internet so that farmers can access this information remotely either through their mobile phones or laptops. The farmers phones or laptop are equipped with application which helps in making decisions such to actuate irrigation scheduling, fertilization scheduling or any other farming practices based on the information obtained from the database.

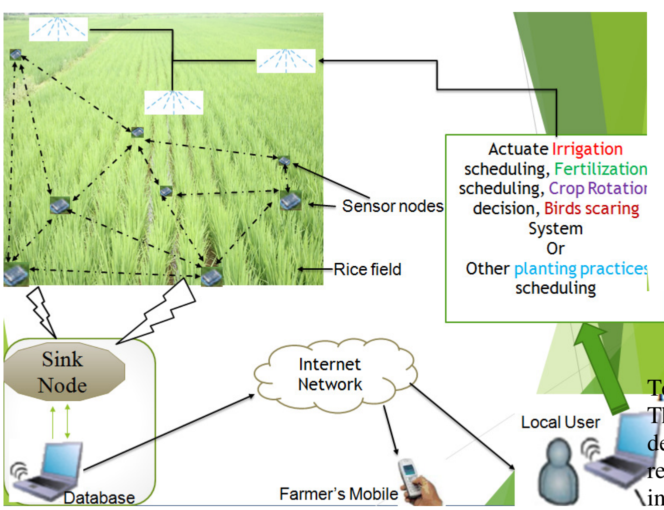

Fig. 2. Architectural framework

Sensing Parameters on a farmland

Growth can be defined as the progressive development of an organism. It is usually expressed as dry weight, height, length, and diameter. Let growth (G) be expressed as

$$G = f(X_1, X_2, X_3 \ldots\ldots Xn) \qquad (1)$$

where Xi are the growth factors.

The factors that affect plant growth can be classified as genetic or environmental [22]. A farmer has control over the genetic factor by his choice of variety. Also generic engineering at research institutes are constantly finding ways of improving the yield of crops through the genes. The farmer does not have control on the environmental factors such as temperature, moisture supply, radiant energy, and composition of the atmosphere. Other factors that cannot be controlled by farmer include soil aeration and soil structure, soil reaction, biotic factors, supply of mineral nutrients, absence of growth-restricting substances and pest and diseases that can destroy crops planted. Controlled of these factors can greatly enhance crop productivity. This research focuses on these environmental parameters which is broadly categories into three groups as shown in Fig. 3.

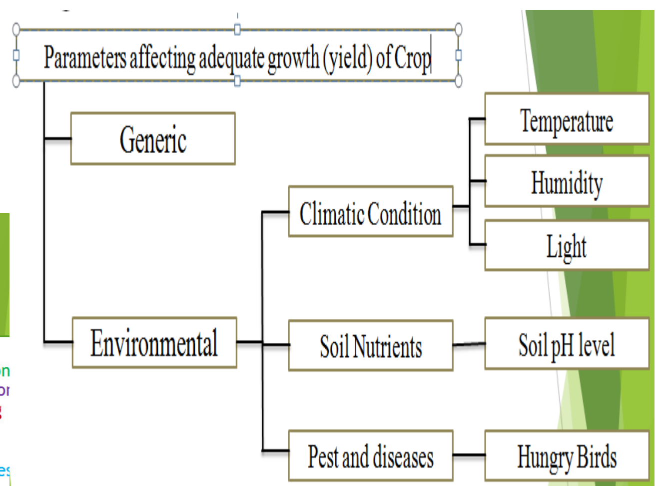

Fig. 3. Factors affecting growth of crops

Temperature can be defined as a measure of the intensity heat. The Plant growth occurs in a fairly narrow range - 60 - 100 degrees F. Temperature directly affects photosynthesis, respiratory and transpiration. The rate of these processes increases with an increase in temperature. Temperature also affects soil organisms. Nitrifying bacteria inhibited by low temperature. PH may decrease in summer due to activities of microorganisms. Soil temperature affects water and nutrient uptake.

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Water is a primary component of photosynthesis. It maintains the firmness of tissue and transports nutrients throughout the plant. In maintaining firmness of tissue, water is the major constituent of the protoplasm of a cell. By means of firmness of tissue and other changes in the cell, water regulates the opening and closing of the stomata, thus regulating transpiration. Water also provides the pressure to move a root through the soil. Among water's most critical roles is that of a solvent for minerals moving into the plant and for carbohydrates moving to their site of use or storage. By its gradual evaporation of water from the surface of the leaf, near the stomate, helps stabilize plant temperature.

Relative humidity – Relative humidity (RH) is the amount of water vapor in the air compared to the amount of water vapor that air could hold at a given temperature. A hydrated leaf would have a RH near 100%, just as the atmosphere on a rainy day would have. Any reduction in water in the atmosphere creates a gradient for water to move from the leaf to the atmosphere. The lower the RH, the less moist the atmosphere and thus, the greater the driving force for transpiration. When RH is high, the atmosphere contains more moisture, reducing the driving force for transpiration. Plant growth restricted by low and high levels of soil moisture can be regulated with drainage and irrigation. Good soil moisture improves nutrient uptake.

Light, a visible portion of the solar radiation or electromagnetic spectrum, is a climatic factor that is essential in the production of chlorophyll and in photosynthesis, the process by which plants manufacture food in the form of sugar (carbohydrate). Other plant processes that are enhanced or inhibited by this climatic factor include **stomatalmovement, phototropism, photomorphogenesis, translocation, mineralabsorption, nd abscission** [13].

Soil pH can be defined as a measure of the acidity or alkalinity of the soil. It is one of the most important soil properties that affects the availability of nutrients. Macronutrients are usually less available in soils with low pH while micronutrients are usually less available in soils with high pH [14]. Fig. 4 shows the plant nutrient availability chart [15].

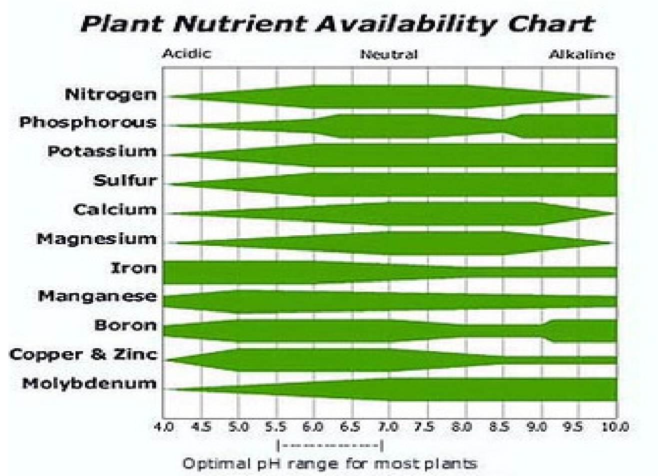

Fig. 4. Plant Nutrient Availability Chart.

Lime can be incorporated to the soil making it less acidic and also supplies calcium and magnesium for plants to use. Lime also raises the pH to the moderate range of 6.0 to 6.5. In this pH range, nutrients are much more available to plants, and microbial populations in the soil increase. **Microbes** exchange nitrogen and sulfur which the plants can use. Lime also enhances the physical properties of the soil that allow water and air movement [14].

Hungry birds are a major factor in the growing of crops in Nigeria. Farmers considered birds as the major constraint in crop production, Study shows that up to 75% of total output could be consumed by birds, and up to 50% of production costs went into bird scaring [16]. [16] also noted that many scaring devices exist on the international market. A few of them have been tried in Nigeria but without success because of the tendency for the birds to habituate to them after a few days. The devices that seem to be worth testing are the reflective ribbons and the black threads stretched across the fields. This had been very successful in area investigated by the researcher. The reflective ribbons reflect light when sun rays falls on it. A light reflecting system making use of sun rays could be developed to reflect light in order to scare aware the birds.

Sensing modalities and Sensor node hardware

The choice of sensing hardware is prompted by through study in section 3.2. This sensing hardware is can be divided into 3 categories:

1) Sensor node: There are various sensors such as temperature, light intensity, relative humidity and pH sensor. A typical soil moisture sensor is as shown in Fig. 5.

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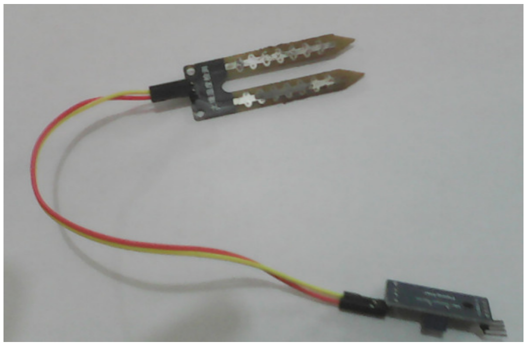

Fig. 5 Soil moisture sensor

Other sensors that can detect the presence of soil nutrients like Nitrogen and phosphorus can be obtain and attached to the sensor node in order to extent its sensing ability. The sensor nodes are setup on the farmland to monitor the chosen environmental factors.

2) Base Station: Nano Arduino board as shown in Fig. 6, can provide a USB Interface for data communications between the base station and the database.

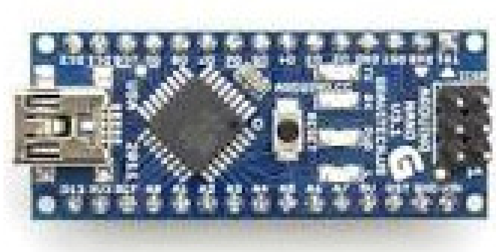

Fig. 6. Nano Arduino board

3) Database: the personal computer will be used to for the database. The PC will have the monitoring software such as Arduino Sketch. This provides topology map, data export capability, Mote programming and a command interface to sensor networks.

4)

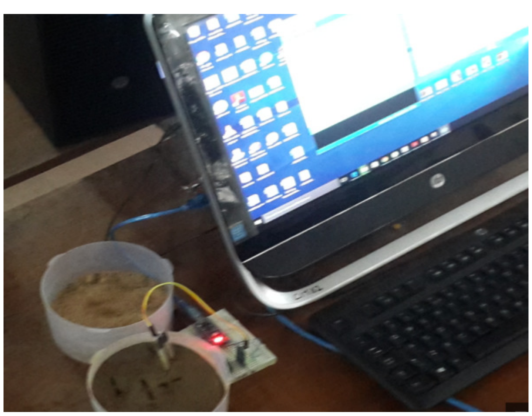

Fig. 7. PC with Ardinuio Sketch running

Sensor node deployment

There is a need for optimum sensor node placement in a monitored area in order to have a cost-effective node deployment. Also, the positions of sensor nodes in a monitored field must be able to provide maximum coverage with longer lifetimes. This can be done by utilizing an effective planning mechanism in arranging the limited number of sensor nodes. Recent research focuses on artificial intelligence (AI) approach particularly on biologically inspired techniques in solving optimization problems in WSN. The sensing model of a sensor node determines its monitoring ability. This is important in the optimum deployment of sensors in a field. There are two types of sensing model in WSN: binary sensing model and probability sensing model [17].

The binary sensing model assumes that the events can be detected by the sensor nodes if they are within sensor range (Rs) [17]. However, in the actual application environment, the detection ability of the sensor nodes is unstable due to the interference of environmental noise and the decrease of the signal intensity. The probability sensing model assumes that sensor nodes are distributed in a certain probability as proposed by [6].

Based on this model, the common method of irrigation farming in Nigeria entails dividing irrigation farmland in to sections. This division can be used to distribute sensor nodes uniformly, and nodes localization.

Determining the number of sensor nodes

Number of sensor nodes to be deployed is varied. The minimum number of sensor nodes can be determined by using equation 1 which was derived by [18].

$$Number\ of\ Sensor\ Nodes = \frac{A}{3\sqrt{3}\,\frac{R_s^2}{2}} \qquad (3)$$

where A is the monitoring area and Rs is the sensing range of the sensor node.

Determination of a suitable Communication Protocol

There is a need for networks to respond immediately to the changes in the sensed attributes. WSNs should also provide the end user with an ability to dynamically monitor and control the trade-off between energy efficiency, accuracy, and response times. Precision Farming solution needs a comprehensive, easy-to-use querying system, so that reliable and accurate answers can be obtained with minimal delays.

Several routing protocols had been proposed by researchers. XMesh [23], is a multi-hop routing protocol developed by Crossbow to run on the MICA family of motes using the TinyOS environment. It is an ad-hoc mesh networking protocol capable of network formation without the need for human intervention. It is also capable of adding and removing network nodes automatically without having to reset the network. It uses a routing beacon from the base station to establish route paths back.

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In the XMesh routing algorithm, the cost metric is one that minimizes the total number of transmissions in delivering a packet over multiple hops to a destination and is termed the Minimum Transmission (MT) cost metric. This differs from the traditional cost metric of distance vector routing which is hop count. In highly reliable links, retransmissions are infrequent and hop count would suffice in capturing the cost of packet delivery. However, with links of varying quality, a longer path with fewer retransmissions may be better than a shorter path with many retransmissions. That is, the energy required to transmit a packet over a distance with a single hop will be far greater that the energy required transmitting a packet over that distance with multiple hops.

Decision Support System (DSS)

A decision support system for precision farming is needed to assist farmers, agricultural experts, research workers or any intellectuals with guidance in making various farming related decisions and help them to access, display and analyze data that have geographic content and meaning. According to [19], the concept of precision farming is not only related with the use of technologies but it is also about the right use of input such as nutrients, water, fertilizer, money, machinery and so on, at the right time, at the right place, in the right amount and in the right manner. There is need to have accurate information and suitable decisions regarding the right inputs required for the farming practices and to initiate the step towards the precision farming.

The proposed DSS calculates irrigation, fertilizer and other farming practices scheduling such as crop rotation that will be required on the farmland. Fig. 8 shows the architecture of decision support system. The proposed DSS mainly consist of a knowledge base, reasoning engine, user interface and developer interface which are explained thus:

1) Knowledge based: This database stores such knowledge as empirical rules, analyzed cases, parameters sensed from the agricultural field, and other information used while reasoning.
2) Develop interface: The developer interface allows system developer to modify the knowledge database and reasoning engine from external resources
3) User interface: This interface allows users to interact with the system through a user-friendly operation.
4) Reasoning engine: This engine uses information from the knowledge database to diagnose questions asked by users and search for suitable solutions.

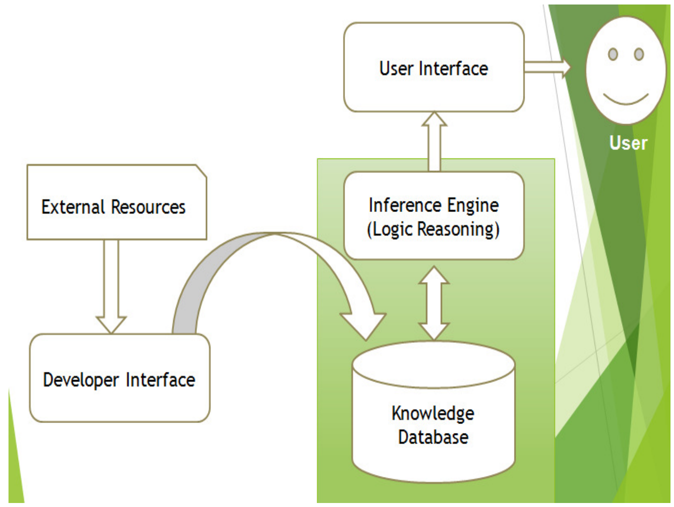

Fig. 8. Decision Support System

4. CONCLUSION AND FUTURE WORK

This paper shows the importance of using the wireless sensor network in precision farming field. Also this paper sheds the light on the agriculture in Nigeria and how precision farming using wireless sensor network will help to solve a lot of Nigerian agricultural problems by improving the crops yield and reduce wastage of resources.

This paper presents the design Wireless Sensor Network that can monitor environmental factors such as soil temperature, humidity, ambient light intensity in a crop field, and soil pH. This can help the end users such as farmers in the better understanding of agriculture practices to be adopted for crop management. Since, hungry birds are a major factor in crop production in Nigeria, bird detector and scarcer system suitable for this part of the world had been proposed. The Graphical User Interface of the decision support system has been proposed to be very user-friendly keeping in mind that the system will be used predominantly by farmers. Energy is a major constraint in rural and remote areas in Nigeria, thus the need to run this system on solar energy.

As a future work, it is planned that proposed system will be deployed in a rice field and the feasibility of the network will be tested by evaluating the field results. The proposed system to be implemented will addresses a wide range of agricultural concerns from detecting sensor node failure, power management and data reliability considerations.

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Authors' Brief

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