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Connected Farming: An IoT enabled Solution for Uganda's Agriculture

SUNIL M R, Faculty of Information and Communications Technology,

ISBAT University, Kampala, Uganda

ABSTRACT

Agriculture is one of the concerns that never ends up being addressed. Since agriculture is one of the rural population's main livelihood sources. Therefore, it is very important to build the agricultural data-based Internet of things. Internet-of-Things (IoT) is a revolutionary technology that represents the future of communication & computing. Despite people's perception of the agricultural cycle, the fact is that today's agriculture industry needs to be more data-centric, reliable, efficient and smarter than ever before. The rapid advancement of Internet-of-Things (IoT) enabled technology has transformed practically every industry including "smart agriculture" which has transformed the market from statistical to quantitative approach. Such radical changes lift the conventional methods of agriculture and introduce new prospects amid a number of challenges. IoT helps in better crop management, better resource management, cost efficient agriculture, improved quality and quantity , crop monitoring and field monitoring etc. This paper outlines the potential of sensors and IoT in agriculture, as well as the challenges to be faced when this technology is implemented into conventional farming practices. This paper also analyzes in detail about the IoT devices and communication techniques associated with wireless sensors used in agricultural applications. The sensors are identified for specific agricultural applications, such as soil preparation, crop status, irrigation, insect detection and pest detection. How this technology can assist farmers throughout the crop processes, from sowing to harvesting, packaging and transport is also illustrated. Furthermore, this article discusses the use of unmanned aerial vehicles for field surveillance and other beneficial uses such as crop yield optimization.

INDEX TERMS: *Internet-of-Things (IoTs), Connected Farming, Smart agriculture, Modern agriculture practices, Agriculture robots, Automation, Sensor technology.*

I. INTRODUCTION

Farming/Agriculture is the essential source of livelihood of people in Uganda. Food costs are continuously increasing since crop rate is declined. There are number of factors which are responsible for this, it may be due to water waste, low soil fertility, fertilizer abuse, climate change or crop diseases, etc. Critical characteristics, like soil type, nutrient presence, flow of irrigation, pest resistance, etc., define its appropriateness and capability for a particular crop. In most of situations, the differentiations of characteristics can exist inside a single farm field, even if the same crop is being cultivated in entire farm; thus, site-specific analyses are required for ideal yield generation. Further, including the dimension of time, specific crops within the same field rotate season-to-season and biologically reach different stages of their cycle inside a year in regions where locational and temporal differences result in particular growth requirements to optimize the crop generation. To respond to these requests with a variety of issues, farmers require modern technology-based strategies to deliver more from less land and with less hands. Considering the conventional farming procedures, farmers have to visit the agriculture field as often as possible throughout the crop lifespan to have a better idea of crop conditions.

For this, the requirement of connected farming emerges, as 70% of cultivating time is went through observing and understanding the crop status rather than doing genuine fieldwork [1]. Considering the immensity of the agriculture industry, it incredibly demands innovative and exact solutions with the aim of sustainability whereas clearing out the least natural effect. Recent sensing and communication advancements give a true remote "eye within the field" ability in which farmers can observe happenings

within the field without being within the field. Remote sensors are encouraging the monitoring of crops constantly with higher accuracy and can, most importantly, identify early stages of undesirable state. This is the reason why modern farming includes the utilization of smart tools and kits, from sowing to crop harvesting and indeed amid storage and transportation. Timely reporting employing a range of sensors makes the whole operation not only smart but also cost-effective due to its accurate monitoring capabilities. A variety of smart tractors, harvesters, automated weeders, UAVs, and satellites currently benefit agriculture equipment. Sensors can be integrated and start collecting information in a short time, which is at that point accessible online for further analysis nearly immediately. Sensor innovation offers crop and site-specific farming because it supports precise data collection of each location. Recently, the Internet-of-Things (IoT) is starting to impact a wide array of sectors and industries, extending from manufacturing, health, communications, and energy to the agriculture industry, to decrease inefficiencies and improve the performance over all markets [2]-[6].

If looking closely, one feels that the current applications are only scratching the surface in which the genuine impact of IoT and its benefits are not however seen. Still, considering this progress, particularly within the near past, we will anticipate that IoT technologies are going to play a vital role in different applications of the agriculture segment. This is often since of the capabilities offered by IoT, including the essential communication infrastructure (utilized to connect the smart objects - from sensors, vehicles, to user mobile devices - utilizing the Internet) and range of services, such as local or remote information acquisition, cloud-based intelligent information analysis, and decision making, user interfacing, and agriculture operation automation. Such capabilities can revolutionize the agriculture industry which likely one of the most inefficient sectors of our economic value chain today. To summarize this discussion, figure 1 gives the main drivers of this innovation.



FIGURE 1: Key Drivers of Technology in Agriculture

There are reasonable efforts that highlight the role of the IoT within the farming industry, but most of the published work focuses only on applications [7], [8], [9]. Most of the existing articles either give no knowledge or appear constrained center on the different IoT-based architectures, models, advanced strategies and other issues considering the most recent facts and figures.

The rest of this paper is organized as follows. Section II gives a profound outline of major applications of IoT in agriculture and what able to accomplish by utilizing these innovations. Section III gives understanding concerning the role of IoT in modern agriculture practices, like vertical farming (VF), hydroponics, and phenotyping, to manage the issues of the increased urban population. Section IV highlights different technologies and components, like sensors, robots, tractors, and communication technologies, being utilized to implement IoT in this industry. Accepting the worth of UAVs in agriculture, Segment V caters application accomplishments that are not possible even after utilizing other most recent advancements. Finally, Section VI concludes this article.

II. IoT APPLICATIONS IN AGRICULTURE

By implementing the most recent sensing and IoT innovations in farming practices, each aspect of conventional farming strategies can be fundamentally changed. Right now, consistent integration of remote sensors and the IoT in smart farming can raise agriculture to levels which were already unimaginable. By taking after the practices of connected farming, IoT can offer assistance to improve the solutions of numerous conventional cultivating issues, like drought response, yield optimization, land suitability, irrigation, and pest control. Figure 2 lists a hierarchy of major applications, services, and remote sensors being utilized for smart agriculture applications. Whereas, major instances in which the technological advancements are making a difference at different stages to improve overall effectiveness are discussed below.

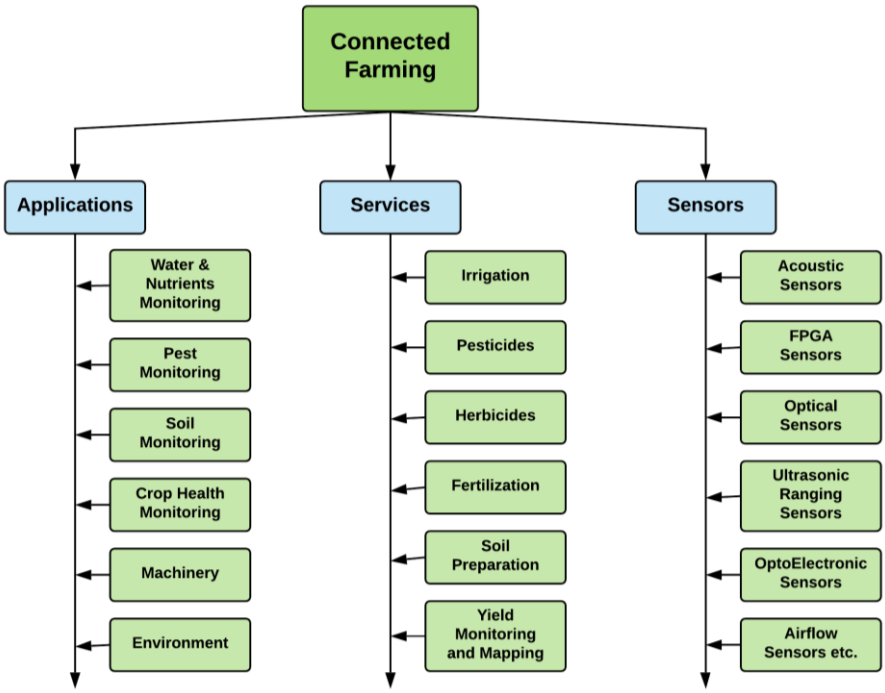

FIGURE 2: Hierarchy of possible Applications, Services and Sensors for Connected Farming

A. SOIL INSPECTION AND MAPPING

Soil is the “Stomach” of plants, and its inspection is the primary step of examination to get field-specific data, which is then further utilized to form various critical decisions at distinctive stages. The main objective of soil investigation is to decide the nutrient status of a field so that measures can be taken appropriately when nutrient insufficiencies are identified. Comprehensive soil tests are prescribed on a yearly premise, ideally in Spring; however, based on soil conditions and climate consents, it may be done in Fall or Winter

[10]. The factors that are critical to analyzing the soil nutrient levels include soil type, crop history, fertilizer usage, irrigation level, topography, etc. These factors give knowledge concerning the chemical, physical, and biological statuses of soil to recognize the limiting factors such that the crops can be managed appropriately. Soil mapping opens the entryway to sowing a variety of crops in a particular field to better match soil properties in like manners, like seed suitability, time to sow, and indeed the planting depth, as a few are deep-rooted and others less. Moreover, developing different crops together could also lead to smarter use of agriculture, simply making the best utilization of resources.

As of now, manufacturers are providing a wide range of toolkits and sensors that can help farmers to track the soil quality and, based on this information, recommend remedies to avoid its degradation. These systems allow for the monitoring of soil properties, such as surface, water-holding capacity, and absorption rate, which eventually offer assistance to minimize erosion, densification, salinization, acidification, and contamination (by reducing unwanted use of fertilizer).

B. IRRIGATION

Different controlled irrigation strategies, like drip irrigation and sprinkler water system, are being promoted to handle the water wastage issues, which were moreover found in conventional strategies like flood irrigation and furrow irrigation. Both the crop quality and quantity are gravely influenced when confronting water deficiency, as unpredictable irrigation, indeed overabundance leads to diminished soil nutrients and provokes diverse microbial diseases. It isn't a straightforward task to precisely assess the water demand of crops, where factors like crop type, irrigation strategy, soil type, precipitation, crop needs, and soil moisture maintenance are included. Considering this truth, precise soil and air moisture control system using the remote sensors not only makes an ideal utilize of water but also leads to better crop health.

The current situation of irrigation strategies is anticipated to be changed by embracing emerging IoT innovations. A noteworthy increment in crop efficiency is anticipated with the utilization of IoT based strategies, such as crop water stress index (CWSI)-based irrigation management [7], [11]. For this, achieving crop canopy at diverse periods and air temperature is required for the calculation of CWSI. A remote sensors based monitoring framework where all the field sensors are associated to gather the specified measurements, further transmit to preparing center where comparing intelligent software applications are utilized to analyze the farm data. Not only this but data from other sources including climate information and satellite imaging is connected to CWSI models for water need assessment, and finally, the specific irrigation index value is delivered for each farm site. A prominent illustration is VRI (Variable Rate Irrigation) optimization by CropMetrics [12], which works agreeing to topography or soil variability, eventually improves the water use effectiveness.

C. FERTILIZER

A fertilizer is a natural or chemical substance that can give vital nutrients for the development and fertility of crops. Crops primarily require three key macronutrients: nitrogen (N) for leaf development; phosphorus (P) for root, flowers, and fruit development; potassium (K) for stem development and water movement [13]. Any sort of nutrients insufficiency or applying them improperly can be seriously harmful to the plant health. Critically, excessive utilize of fertilizer not only results in financial losses but also makes harmful impacts to the soil and environment by depleting the soil quality, poisoning groundwater, and contributing to global climate changes.

Modern IoT-based fertilizing approaches offer help to assess the spatial patterns of nutrients requirements with higher accuracy and minimal labor requirements [14], [15]. For example, the Normalized Difference Vegetation Index (NDVI) uses aerial/satellite pictures to screen crop nutrient status [16], [17]. Basically, NDVI is based on the reflection of visible and near-infrared light from vegetation and is utilized to estimate

the crop wellbeing, vegetation vigor, and density, further contributing to evaluating the soil nutrient level. Such exact execution can altogether improve the fertilizer effectiveness, at the same time diminishing the side effects to the environment.

D. CROP DISEASE AND PEST MANAGEMENT

Recent IoT based smart devices, such as remote sensors, robots, and UAVs are allowing the farmers to cut pesticide uses significantly by spotting crop adversaries. Compared to conventional calendar or prescription based pest control strategies, modern IoT-based pest monitoring gives real-time management, modeling, disease forecasting, subsequently demonstrating more effective [18], [19].

By and large, the reliability of crop disease monitoring and pest monitoring depends on three viewpoints: sensing, evaluating, and treatment. The advanced disease and pest recognition approaches are based on image processing in which raw images are procured all through the crop region using field sensors, UAVs, or remote sensing satellites. Usually, remote sensing imagery covers large regions and, consequently, offers higher effectiveness at a lower cost. On the other hand, field sensors can back more capacities in collecting information, like environment sampling, plant health, and pest situations, in every corner all through the crop cycle. For example, IoT-based automated traps [20], [21] can capture, count, and even characterize insect types, further uploading information to the Cloud for detailed examination, which isn't possible through remote sensing.

Approaches like vehicle precise spray and automatic VRT chemigation [22], commonly utilized beneath smart fertilization, can also be utilized for disease treatment and other pesticide applications. Also, the advancement of robotic technology offers new solutions. When preparing an agricultural robot with multispectral sensing devices and spraying nozzles, it can find and deal with pest problems more absolutely beneath the control of a remote IoT disease management framework.

E. YIELD MONITORING, FORECASTING, AND HARVESTING

Yield monitoring is the mechanism used to analyze different aspects corresponding to farming yield, like grain mass stream, moisture content, and harvested grain quantity. It makes a difference to precisely evaluate by recording the crop yield and moisture level to estimate, how well the crop performed and what to do another. Yield monitoring is considered a fundamental part of precision farming not only at the time of harvest but indeed before that, as monitoring the yield quality plays a vital part.

Crop forecasting is an art to anticipate the yield and production (tons/ha) before the harvest takes place. This forecasting makes a difference in the farmer for near-future planning and decision making. Besides, analyzing the yield quality and its development is another critical factor that enables the determination of the right time for harvesting. Predicting the right harvesting time not only makes a difference to maximize the crop quality and production but also allows adjusting the management technique.

III. MODERN AGRICULTURAL PRACTICES

Sensors and IoT-based advancements are making a difference to improve ordinary agriculture processes to upgrade yield production without, or with least, impact on its originality. For this reason, modern advanced and more controlled environments are anticipated to tackle the above-mentioned issues. The significance and inclusion of innovations are more critical, as we are moving towards more cultured and urban farming. In reality, it would not be erroneous for one to say that the success of these advanced practices is in question without using sensor-based technologies.

A. Greenhouse Farming

Greenhouse farming is considered the oldest strategy of smart farming. Crops developed indoors are exceptionally less influenced by the environment; most importantly, they are not constrained to getting light

only amid the daytime. As a result, the crops that traditionally could only be developed under suitable conditions or in certain parts of the world are now being developed anytime and anyplace. This was the actual time in which sensors and communication devices began to bolster different agriculture applications genuinely.

Precise monitoring of environmental parameters is the most primary task in present-day greenhouses, where a few estimation points of different parameters are required to control and guarantee the local climate. In [23], an IoT-based model is proposed to screen the greenhouses where MicaZ nodes are utilized to measure the interior parameters like humidity, temperature, light, and pressure.

B. Vertical Farming

Vertical Farming within the shape of urban farming offers an opportunity to stack the plants in a more controlled environment resulting in, most vitally, a significant reduction in resource utilization. By following this strategy, we can increase the production multiple times, as only a fraction of the ground surface is required (depending on the number of stacks) as compared to conventional farming practices. Not only for ground surface, but this framework is also profoundly effective in terms of other resources, as well. Beneath this farming strategy, many parameters are vital, but CO2 measurements are most critical; thus, non-dispersive infrared (NDIR) CO2 sensors play a critical role to track and control the conditions in vertical farms.

C. Hydroponic

To improve the benefits of greenhouse cultivation, farming specialists moved forward another step and provided the thought of hydroponic, a subset of hydroculture in which plants are developed without soil. Hydroponic is based on an irrigation framework in which balanced nutrients are dissolved in water and crop roots remain in that solution; in a few cases, roots can be supported by a medium like a perlite or gravel. When combining hydroponics with VF, a farm of 100 sq. meters can create the crop comparable to 1 acre of the conventional farm, most importantly up to 95% less water and fertilizer utilization and without pesticides/herbicides [24].

D. Phenotyping

The previously discussed smart strategies look more promising for the future of farming, as they are already being used to create distinctive crop products beneath precise environments. Other than these, some advanced methods are under experiment to further improve the crop capabilities by controlling their limitations with the help of advanced sensing and communication technologies. Among these strategies, the more prominent is phenotyping, which is based on emerging crop engineering, which joins plant genomics with its ecophysiology and agronomy, as appears in Figure 3. The progress in molecular and genetic tools for different crop breeding was significant within the last decade. In any case, a quantitative examination of the crop behavior, e.g. grain weight, pathogen resistance, etc., was constrained due to the need for efficient techniques and innovations that we can now enjoy.

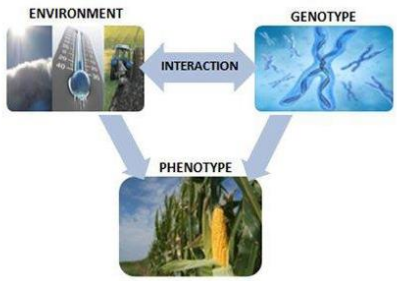

FIGURE 3: The Process of Phenotyping

IV. MAJOR EQUIPMENT AND TECHNOLOGIES

Most of the tasks in modern, large-scale farming are being done by heavy and urban equipment, such as tractors, harvesters, and other robots which are completely or in part backed by remote sensing and other communication technologies. Agriculture has transformed during the last few decades from small/medium farming operations to highly industrialized and commercial cultivating. The key technologies and equipment that are as of now accessible for this reason are discussed in the following.

A. WIRELESS SENSORS

Sensors are the most crucial and play a vital role when it comes to collecting the crop conditions and other data. Remote sensors are being utilized standalone wherever required, further integrated with nearly every portion of advanced agricultural tools and heavy machinery, depending on application necessities.

1) **ACOUSTIC SENSORS:** Acoustic sensors offer a miscellaneous appliance in farm management, including soil cultivation, weeding, fruit harvesting, etc.; the main benefit of this technology is its low cost solutions with fast response, especially when considering portable equipment. Acoustic sensors are commonly used for pest monitoring and detection and classifying the seed varieties according to their sound absorption spectra.

2) **FIELD-PROGRAMMABLE GATE ARRAY (FPGA)-BASED SENSORS:** FPGA based sensors are starting to be used in agriculture recently due to their flexibility of reconfiguration. The major options where these can be employed include measuring real-time plant transpiration, irrigation, and humidity.

3) **OPTICAL SENSORS:** These sensors use light reflectance phenomena and help to measure soil organic substances, soil moisture and color, presence of minerals and their composition, clay content, etc. These sensors test the soil's ability to reflect light based on different parts of the electromagnetic spectrum. The changes occurred in wave reflections help to indicate the changes in soil density and other parameters.

4) **ULTRASONIC RANGING SENSORS:** Sensors of this category are considered a good choice being low cost, potential to operate in a variety of applications, and ease of use and adjustability, such as the sampling rate. Common uses are tank monitoring, spray distance measurement (e.g., boom height and width control in order to perform uniform spray coverage, object detection, and collision avoidance), and monitoring crop canopy

5) **OPTOELECTRONIC SENSORS:** Optoelectronic sensors can differentiate plant type; hence, they help to detect weeds, herbicides, and other unwanted plants, especially in wide-row crops. When combining, an optoelectronic sensor and location information, it can map the weed distribution and resolution. Optoelectronic sensors are also capable of differentiating between vegetation and soil from their reflection spectra.

6) **AIRFLOW SENSORS:** These sensors are capable of measuring soil air permeability and percentage of moisture and identifying soil structure to distinguish different types of soils. Measurements can be made at singular locations or dynamically while in motion, e.g., can be used on a fixed position or in mobile mode. The desired output is the pressure required to push a predetermined amount of air into the ground at a prescribed depth.

7) **ELECTROCHEMICAL SENSORS:** These are mostly used to assess the significant soil characteristics to analyze the soil nutrient levels, such as pH. The standard chemical soil analysis, which are mostly expensive and time consuming, can be easily substituted with these sensors.

8) **MECHANICAL SENSORS:** Mechanical sensors assess the soil mechanical resistance (compaction) to indicate the variable level of compaction. The mechanical sensors enter or cut through the soil and record the force assessed by strain gauges or load cells.

9) **REMOTE SENSING SENSORS:** Sensors belong to this category are used to capture and store the geographic information, further analyze, manipulate, manage and present all types of spatial or geographical data. these sensors also found significant use in agriculture applications including crop assessment, forecasting yield dates, yield modelling and forecasting, identification of plants and pests, land cover and degradation mapping etc.

10) **OTHER SENSORS:** This include Mass-flow Sensors, LIDAR Sensors, Telematics Sensors, Electro-Magnetic Sensors etc.

B. IOT BASED TRACTORS

With technological advancements, most of the vendors are offering tractors with automated-driving and also with Cloud-computing capabilities. This technology isn't new, as self-driving tractors have been within the market even before semi-autonomous cars. One of the main benefit of self-driving tractors is their capacity to avoid returning to the same area or row by lessening the overlap even less than an inch. In addition, they can make exceptionally exact turns without a driver's physical presence. This facility offers better accuracy with reduced errors, particularly when spraying pesticide or targeting weeds; those are mostly unavoidable when a human controls the machinery.

C. HARVESTING ROBOTS

In order to automate the harvesting process and make it more accurate, the role of robots has been increasing over the recent years. Programmed harvesting of fruits requires deep examination of modern sensors that are able of collecting accurate and unambiguous data of that specific crop and fruit. The task of detecting the correct target in natural scenes isn't simple since most of the fruits are blocked somewhat - sometimes indeed completely - under the leaves and branches or are overlapped with other fruits [25].

D. COMMUNICATION IN AGRICULTURE

Communication and reporting the data on a timely basis are considered the backbone of connected farming. The objective cannot be accomplished unless a firm, dependable, and secure connection among various participating objects is provided. Depending on availability, scalability and application requirements, different communication modes and technologies are being utilized for this reason, most common are discussed here.

1) **LORA:** LoRa wireless technology is a long-range, low-power platform used extensively in IoT applications. Being low in power consumption, it offers LPWAN connectivity between the wireless sensors and the Cloud. It has proved itself much more effective and reliable than Bluetooth, Wi-Fi, etc. especially in restaurants or kitchen environments. Sensors based on LoRa can be installed in smaller devices for reliable monitoring. Most importantly, LoRa signals can penetrate thick and insulated objects, even buildings, and can, hence, cover a larger network area. Overall, LoRa-based networks perform higher in terms of lifespan and, at the same time, pose reduced maintenance and upkeep burden [26].
2) **ZIGBEE:** Zigbee is primarily designed for a wide range of applications especially to replace existing non-standard technologies. Depending on the application requirements, the devices based on this protocol can be one of three types including Coordinator, Router and End User. Further, three different topologies are supported by Zigbee networks named, Start, Cluster Tree and Mesh [27]. Based on these characteristics, and further considering the agriculture application requirements, Zigbee can play vital role especially targeting the greenhouse environment where usually short range communications are required.
3) **BLUETOOTH:** Bluetooth is a wireless communication standard that connects small-head devices together over shorter distances usually cooperating in a close proximity. Due to its advantages of low power requirements, easy to use and low cost, this technology is being utilized in many smart farming

applications. Further, Bluetooth making advancements in many IoT systems with the release of Bluetooth Low Energy (BLE) or commonly known as Bluetooth Smart.

4) **CELLULAR COMMUNICATION:** Cellular communication modes from 2G to 4G can be suitable, depending on the purpose and bandwidth requirement; however, the reliability, and even availability, of a cellular network in rural areas is a major concern. To tackle this, data transmission via satellite is another option, but, here, the cost of this communication mode is very high, which makes it not suitable for small- and medium-sized farms. The choice of communication mode also depends on application requirements, such as some farms required sensors that can operate with low data rate but need to work for long periods hence demand long battery life.

Figure 4 gives an idea that how end-to-end communication possibilities can be divided in various layers to interact with each other in order to provide the services for connected farming.

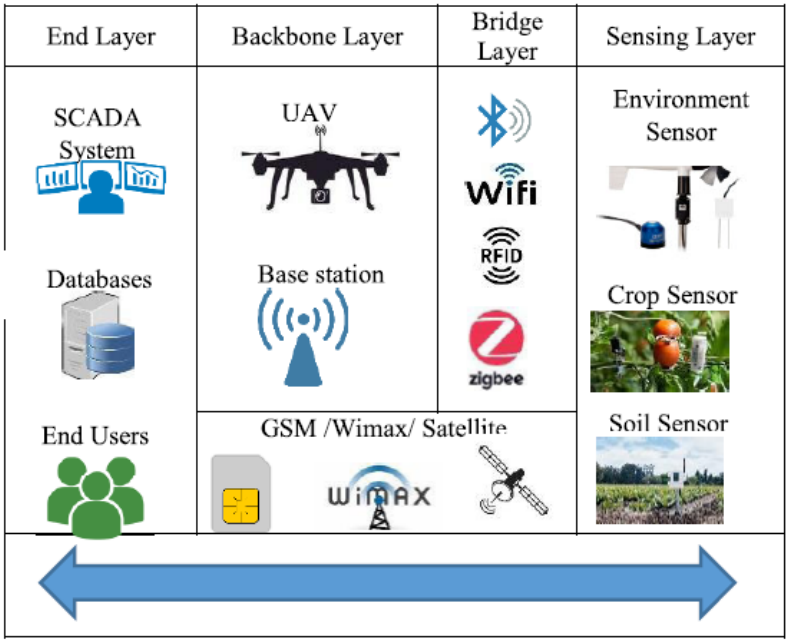

FIGURE 4: End-to-End Communication for Connected Farming

E. CLOUD COMPUTING

Connected farming is showing its potentiality and benefits by progressing farming processes through better data-driven decision making. However, to continue this success, connected farming not only requires better technology and tools to process data effectively but also at a reasonable cost such that the received data can be used to form field choices effectively. For this reason, farmers can use Cloud services to get to data from predictive analysis institutes so that they can select the right product available according to their specific requirements. Cloud computing offers an edge to farmers to utilize knowledge-based repositories that contain a treasure of data and encounters related to farming practices as well as on hardware options available within the market with the essential details.

V. UAVs IN AGRICULTURE

Recently, the IoT has made exceptional progress in numerous businesses, including farming divisions like poultry, fishing, etc. but when we talk about agriculture, the communication facilities like base stations or Wi-Fi are very constrained, which prevents the growth of the IoT in this segment. The

information procured through the remote sensors cannot be transmitted in the absence of dependable communication infrastructure.

For such Scenarios, UAVs offer an alternative, as they visit and communicate with the remote sensors spread over large areas in order to gather information for further processing and investigation. Besides, UAVs, better known as drones, fitted with high-resolution cameras and sensors, can be flown over thousands of hectares of farms. The role of surveillance in all agriculture applications is highly critical, particularly in forestry and crop monitoring due to the need to cover large regions [28]. In this manner, a fast, low cost, real-time, and large-scale surveillance supported with an accurate data acquisition and transmission office is significant for farm production.

Right now, agriculture is being considered one of the most favorable area where UAVs can offer solutions to resolve many overwhelming and long-lasting issues. A few of key areas in which UAVs are already playing key roles to help farmers all through the crop lifespan are as follows:

- SOIL AND FIELD ANALYSIS
- PLANTING
- CROP MONITORING
- IRRIGATION
- PLANT COUNTING AND GAP DETECTION
- PESTICIDES SPRAYING
- HEALTH ASSESSMENT
- DETECTION/RECOGNITION OF PLANT SPECIES etc.

VI. CONCLUSION

Farming can be made more effective & precise with the adoption of IoT technology. The focus on more intelligent, better, and more effective farming techniques is required in order to meet the growing food demand of the increasing world population. To attain this, we need to develop an ideal IoT architecture for farming in order to improve quality and quantity of production, save resources like water and electricity, economically efficient crop that cost less and make more profit as in nation like Uganda, where farmers play a major role in GDP so this way the overall GDP can too be improved. This article considered all these aspects and highlighted the role of different technologies, particularly IoT, in order to make the farming smarter and more effective to meet future demands. For this purpose, remote sensors, UAVs, Cloud-computing, communication technologies are discussed thoroughly. Based on all this, it can be concluded that effective utilization of farm land is important to maximize crop production. However, to deal with each inch accordingly, the use of sustainable IoT-based sensors and communication technologies isn't optional - it is essential.

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