Elements of smart farming

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Abstract: In this paper, new aspects and the role of Internet of Things (IoT) technologies in farming were discussed, as well as the contribution of IoT to increasing efficiency in order to meet future requirements. The role of equipment and technologies, topologies and protocols, architectures and platforms of smart farming is presented. Also, an overview of the current challenges when applying IoT in farming is provided.

1. INTRODUCTION

Throughout human history, significant innovations have been made to improve agricultural yields while using as few resources as possible and with minimal human involvement. However, the high rate of population growth does not allow demand and food production to match. Also, agricultural production is becoming equally critical to the industry due to the growth of the market for bioenergy products that are based on food and crops. On the other hand, only a part of the Earth's surface is suitable for agricultural use, while rapid urbanization poses a threat to the availability of arable land. Due to this and other factors, there is a need for smart farming, which can be defined as "an approach to understanding the basic requirements as well as changes in the current environment based on information about the context and collected data" [1].

As a new paradigm, Internet of Things (IoT) starts to affect a wide range of human activities to increase efficiency and reduce costs at all levels. IoT requires a basic communication infrastructure to provide a range of services, such as local or remote data collection, data analysis and decision-making, user connectivity and work automation.

IoT can help improve solutions to many traditional agricultural issues such as soil sampling, irrigation, fertilization, pest control, crop or livestock health monitoring, etc. [1]. The application of IoT systems in farming or smart farming is the subject of this work.

This paper is organized as follows. Chapter 2 presents the components of smart farming, different types of technologies and equipment used in this agricultural branch. Chapter 3 provides an overview of the IoT agricultural network, architecture, topologies and protocols. Chapter 4 analyzes the current challenges. Concluding remarks are given in Chapter 5.

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2. SMART FARMING

Smart farming represents the adoption of information and communications technologies to improve and automate agricultural operations and processes [1].

A. Components of smart farming

IoT-based smart farming usually consists of four components: physical structure, data collection, processing and analysis.

The physical structure represents the structure of the system designed in such a way to enable control of sensors, actuators and other devices. Data collection is divided into two components: IoT data collection and standard data collection. IoT data collection involves the use of protocols such as Message Queuing Telemetry Transport (MQTT), Advanced Message Queuing Protocol (AMQP), WebSocket, Constrained Application Protocol (CoAP), Node, Data Distribution Service (DDS) and Hyper Text Transfer Protocol (HTTP) **Error! Reference source not found.**. For standard data collection, the following technologies are used: ZigBee, Wi-Fi, LoraWan, Sigfox, etc. Data processing consists of multiple functions including data loading, image or video processing, decision support system and mining. Data analysis consists of two main components: monitoring and controlling. Monitoring includes three applications in smart farming: animal, field and greenhouse monitoring. IoT allows farmers to monitor animals using multiple types of sensors for early detection of animal diseases. Field monitoring refers to the measurement of soil quality, moisture, air temperature, humidity, pressure and crop disease monitoring. The smart greenhouse design eliminates the need for human intervention by adjusting the climate parameters depending on the needs of the plants.

B. Equipment and technologies of smart farming

1) Cloud and edge computing

Cloud computing refers to the use of computer resources and storage capacities, that are delivered as a service for a heterogeneous group of end users [3]. The advantages of applying cloud computing in the agricultural sector relate to crop data collection, soil data collection, availability of expert consultation, access to e-commerce and efficient information exchange. Edge computing represents decentralized data processing at the periphery of the network, as close to the data source (sensors, smartphones, drones, etc.), without need to transfer data to a computer center. Edge computing has a perspective in agricultural applications, such as pest identification, agricultural product safety, autonomous agricultural machines, intelligent management, etc. [4].

2) Big data analysis and machine learning

Large amounts of data generated by sensors are used to provide real-time insights into agricultural operations and decision-making. Machine learning (ML) can be defined as a scientific area that gives machines the ability to learn directly from data and can be used to detect, quantify and understand processes in agriculture [5]. There are a large number of ML algorithms, such as logistic regression, linear regression, random forest, k-nearest neighbor (k-NN), support vector machines (SVM), neural networks, etc.

3) Robotics

Smart farming involves the use of a large number of robots to perform certain functions such as weed removal, spraying pesticides, sowing, packing fruits, etc.

4) Sensors

Sensors play a key role when it comes to gathering data. Compared to remote data collection, sensors in the field have the ability to provide more information about the environment, plant health and pests, on every part of the soil, during different crop cycles. The types of sensors used in agriculture are: acoustic sensors [6], optical sensors [7], mechanical sensors [8], electrochemical sensors [9], ultrasonic sensors [10], electrical and electromagnetic sensors [11].

5) Controllers and actuators

Controllers receive signals from the sensors, process and transmit data, and send command signals to the actuators. Actuators carry out some actions based on sensor readings and the specifications needed, which vary depending on the application.

6) Smart phones

Recent progress in development of smartphones and their increasing availability facilitate some of the agricultural works. Applications of smartphones in agriculture include: soil analysis (SIFSS, SOCiT), water analysis (iDee), irrigation (PocketLAI, RaGPS, SWApp), fertilization (Ecofert, Baikhao), weed control (Weedsmart), crop health monitoring (BioLeaf), vehicle monitoring (SafeDriving), etc. Also, smartphone sensors such as microphone, camera and accelerometer can be a huge relief when keeping a farm management diary.

7) Unmanned aerial vehicles

An unmanned aerial vehicle (UAV) is an aircraft without a human crew, which is controlled from Earth. By monitoring agricultural areas with UAVs, it is very easy to determine the shape of the agriculture plot, the morphology of the soil, planting density, as well as the parts where water is retained. Also, it is possible to spot potential outbreaks of diseases and pests on time, and avoid the application of chemical agents over the entire surface, which is desirable from the ecological and economic points of view.

8) IoT tractors

Many agricultural equipment manufacturers, such as John Deere, Hello Tractors, Case IH and New Holland, offer tractors with auto-start and cloud connectivity capabilities. One of the main advantages of self-driving tractors is their ability to avoid re-cultivating the same area. They can make very precise maneuvers without the physical presence of the driver.

3. IOT AGRICULTURAL NETWORK

The IoT agricultural network has its own architecture, topology and uses specific protocols to transmit agricultural data.

A. IoT Agricultural Network Architecture

Most IoT applications follow a four-layer architecture (physical and MAC layer, network layer, transport layer and application layer), illustrated in Fig. 1.

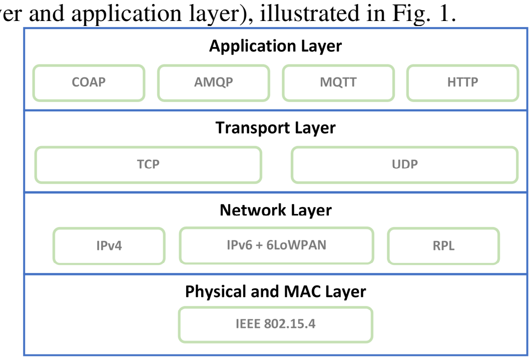

Fig. 1. Four-layer architecture of IoT agricultural network

1) Physical and MAC layer

One of the most common physical and MAC layer standards is IEEE 802.15.4. Many low-power and low-cost protocols such as ZigBee, WirelessHART, Mi-Wi, and 6LoWAN use this standard. IEEE 802.15.4 can operate in one of three possible frequency bands (868/915/2450 MHz), with a transmission rate of 250/40/20 kbit/s [12]. IEEE 802.15.4 uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

2) Network layer

Internet Protocol (IP) is the main choice of this layer. There are two versions of IP in use: IPv4 and IPv6. Although IPv4 is the dominant protocol, due to rapid growth in the number of addressable devices, introduction of IPv6 was necessary. In order to apply IP even to the smallest devices [13], the 6LoWPAN working group, founded by the IETF, created a protocol that enables transmission of IPv6 packets over an IEEE 802.15.4-based network. This was possible by defining the Adaptation Layer (AL) between the MAC and the network layer. Routing protocol for Low Power and Lossy Networks (RPL) is known as a key protocol when implementing routing on 6LoWPAN. RPL enables point-to-point, point-to-multipoint and multipoint-to-point communication.

3) Transport layer

Two most commonly used transport layer protocols are Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). TCP ensures reliable data transmission and delivery of packets in the same order in which they were sent. On the other hand, UDP does not ensure reliable transmission; it continuously sends datagrams to the recipient, whether they are received or not.

4) Application layer

Due to strict computing and energy limitations of most IoT devices, several application layer protocols with relatively low overhead have emerged, such as MQTT, HTTP, CoAP, AMQP, etc. MQTT was developed to provide connectivity between applications on one side and the network on the other side **Error! Reference source not found.**. The MQTT architecture consists of three components: publishers, subscribers, and brokers. From an IoT perspective, publishers are sensors that send data to the broker, the brokers classify them and send them to the subscribers. The architecture of AMQP is similar to MQTT. The only difference is that the broker is divided into two parts: exchanger and a queue. The exchanger accepts publisher messages and distribute them to queues based on the predefined roles and conditions. HTTP is a web messaging protocol built on the client/server model. Like AMQP, it assumes that TCP is used as the underlying and stable protocol. The CoAP structural model consists of two layers: the message layer, which takes care of communication via UDP, and the request/response layer.

B. IoT agricultural network topologies and protocols

IoT agricultural network usually comprises sensor nodes and gateways for spreading information over longer distances. Sensor nodes are deployed in the field and consist of various types of sensors and the necessary electronics. Sensor nodes are organized in a topology and connected to a gateway using communication protocols. The data collected by the sensors are sent to the base station, which analyzes them and provide feedback to farmers or actuators. Figure 2 presents a typical IoT agricultural network designed to monitor and control various agricultural factors.

Network topology is also important aspect of an IoT solution. Different topologies can be used, such as star, tree and mesh. Star network consists of central node and several peripheral nodes. Peripheral nodes transmit data to the central node, which acts as a gateway and retransmits data to a cloud-based applications. On the other hand, in mesh networks, each node has routing capability, increasing the network coverage. Tree network is a combination of multiple star networks.

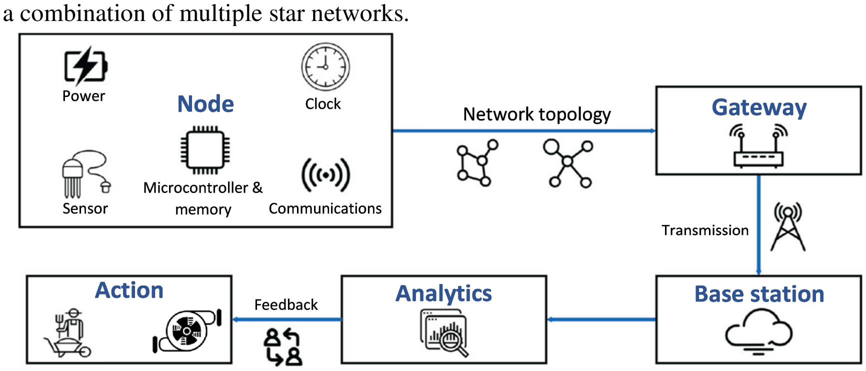

Fig. 2. IoT agricultural network [14]

There is a wide range of communication protocols that allow devices to exchange agricultural data over the network.

LoRa (LongRange) wireless technology is a low-power platform widely used in IoT applications. LoRaWAN is a standard protocol for WAN (Wide Area Network) communication using the LoRa method. LoRaWAN creates an IoT network over a wide geographic region, providing long-range (15km) and low-power two-way communication between sensors that typically run on batteries. LoRa and LoRaWAN are an excellent choice for practical applications that require the transmission of a small amount of data.

Bluetooth is a wireless communication standard for connecting devices over a short distance, which generally operates in the unlicensed ISM (Industrial Scientific and Medical) band of 2.4 GHz. The two most commonly used versions of Bluetooth are Bluetooth Classic and Bluetooth Low Energy - BLE. Bluetooth Classic is usually installed in devices that transmit large amounts of data, whereas BLE is used in priority devices with low power consumption. BLE has a longer transmission range than Bluetooth Classic, which makes it more suitable for wireless sensor networks. The minimum delay with BLE is 3ms compared to 100ms with Bluetooth Classic. This, however, comes at the cost of slower transmission: 1Mbit/s theoretical maximum for BLE and 3Mbit/s for Bluetooth Classic [15].

ZigBee is a very reliable and secure wireless communication protocol with low consumption and low cost, built on the basis of the IEEE 802.15.4 standard. ZigBee represents a set of specifications for devices that have a low data transfer rate (250 kbit/s), consume very little energy and therefore have a long battery life. The maximum operating range for ZigBee devices is about 80 meters [16].

Sigfox technology is based on long-range radio communication (30-50km in rural areas, 3-10km in urban areas). This data transmission system uses unlicensed frequencies (US 915 MHz, Europe 868 MHz). Sigfox wireless systems send small amounts of data (12 bytes) slowly (300 baud), using standard radio transmission methods. The solutions offered by Sigfox are low cost, use very little energy to run on batteries for years, and are extremely easy to set up.

Growers can easily obtain information related to weather, marketing and other advisory services through better use of mobile technology. Most companies offer 3G and 4G technologies for their customers that allow them to access the Internet on their mobile phones. The fifth-generation mobile network (5G) is the latest version of mobile technology, designed to significantly increase the speed and responsiveness of wireless networks. The difference between the existing 4G and the newer 5G is much faster communication between devices. 4G works at 100 Mbit/s, while 5G works at 10 Gbit/s [17].

Z-Wave is a low power physical and MAC layer protocol designed for automation and IoT communication. It enables point-to-point communication with a range of about 100 meters and is suitable for small messages in IoT applications. It uses CSMA/CA for collision detection and ACK (acknowledgment) messages for reliable transmission. It is based on a master/slave architecture in which the master controls the slave devices, sends them commands and handles the layout of the entire network.

WirelessHART is a safe and reliable protocol based on the IEEE 802.15.4 standard. The architecture consists of network manager, security manager, wireless devices, access points and routers. The standard offers end-to-end, per-hop or peer-to-peer security mechanisms. End-to-end protection mechanisms enforce security from the source to the destination, while per-hop mechanisms ensure security only until the next hop.

WiMAX is a wireless technology that enables wireless access to the Internet using the 3.5GHz radio frequency spectrum. It is similar to the Wi-Fi technology, with one key difference - a much larger signal range, which ranges from 15 to 50 kilometers [18]. It is also possible to connect a much larger number of users to one base station.

4. CURRENT CHALLENGES

When implementing IoT in agriculture, various challenges limit or affect the performance of the implemented system.

A. General challenges

Accessibility to users. Investment in IoT-based solutions is often large and it represents a challenge for small farmers, while larger farms can easily acquire IoT technologies by investing in new equipment.

Diversity of data. Different data sources imply the use of different system units, data structures and terminologies, resulting in reduced interoperability between IoT environments.

Flexibility. Many IoT systems are centralized, closed, difficult to integrate on the existing platforms, or difficult to implement at larger scales.

Fault tolerance. When designing an IoT-based solution, it is necessary to take into account errors and unpredicted events, in order to ensure the reliability of the system.

Complexity. An agricultural system is complex and can be challenging to work with. It is complex not only because of the multiple nature of physical, chemical and/or biological processes in the soil-crop-air system, but also because of the technical complexity of the hardware and software that operate in it.

B. Challenges of the physical layer

Energy consumption. The use of wireless devices has great advantages over wired systems, as they are easier to install and can cover much wider areas. However, power consumption, along with limited battery life, is a major drawback of many wireless systems and needs to be taken into account.

Device environment. The environment in which sensors and other devices are installed challenges their functionality and durability. Harsh weather conditions, such as large temperature differences, intense rain or high humidity can cause water condensation inside the device, corrosion and short circuits.

C. Challenges of the network layer

Latency. Large amounts of data generated in IoT applications not only cause problems related to storage or handling, but also problems with the transmission latency. In agriculture, latency issues can be of great importance in some IoT solutions. For example, in WSNs, where high latency implies higher energy consumption.

Wireless connection quality. Low quality of wireless connection greatly affects the functioning of an IoT system, because it causes unreliable communication. This can be caused by background noise, routing problems, limited bandwidth, or even harsh environmental conditions that affect the transceivers and quality of the sent data.

Network maintenance. WSN maintenance may include battery changes, software updates, sensor calibration or replacement, and similar maintenance activities, which have to be considered when designing IoT solution.

D. Challenges of the application layer

Data security and privacy. Data security and privacy raise a concern of farmers who, in general, have little confidence in the use of data by service providers. Also, data ownership should be considered, as raw and processed data in IoT systems have different ownership, which affects the necessary data security and privacy requirements.

Data quality and availability. Poor data quality or reduced availability can limit many applications involving data analysis, modeling and machine learning, which can affect the success of some IoT solutions.

5. CONCLUSION

The rapid development of IoT-based technologies has redesigned almost every industry, including agriculture. IoT changes existing methods and creates new opportunities. However, the use of IoT in agriculture faces numerous challenges. The farmers skills and their education can become a major obstacle to the implementation of IoT in agriculture, so it is important that the ease of system management is a priority of the technology provider. In addition, suppliers must develop flexible solutions that can be easily integrated in accordance with already accepted standards.

It should be kept in mind that smart farming technologies are not intended exclusively for large farms, but can also improve other forms of farming, such as small family farms and organic production. It is clear that the application of advanced IoT solutions can further expand the results of agriculture.

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