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Chapter 7: Incorporating IoT devices into agricultural equipment for real-time monitoring

7.1. Introduction

Agricultural monitoring, data collection, and decision-making have increasingly been assisted by digital technologies, enabled by sensors, cameras, immersive media, and even robotics. This has led to a steadily-growing interest in smart and precision agricultural components and methods to enable sustainable development while improving agricultural productivity. These tools tend to be either for local operation or for larger system-wide data collection, but with different characteristics. Few assistance tools provide real-time information that can stimulate fast decision-making processes, especially for small to medium scale agricultural operations, who still rely on local expertise-based thinking (Jayaraman et al., 2016; Kamilaris et al., 2016; Brewster et al., 2017).

Planting always has, and likely always will, be carried out in full dependence on weather conditions. Real-time local weather data are essential to share within the local ecosystem of farmers and the relevant service providers. Such weather data, suitable for decision-making, have common parameters with what is available from global meteorological companies, but provide an increased accuracy. For some extreme events still, local expertise is always going to be needed, but realtime monitoring could facilitate a better understanding of possible weather developments through monitoring key parameters.

Localized amendments to nutrients or the use of pesticides, herbicides, and fungicides are critical to increasing the efficiency and reducing the negative impacts of their use. These operations need to be carried out when the status is right for each particular crop. Realtime feedback enabling monitoring and understanding the crop status and flowering are essential to higher precision. However, most farmers lack the facilities and knowledge to do this. Also, the expense for larger scale providers of precision agriculture services could prohibit smaller farmers or fields from benefitting from these services (Wolfert et al., 2017; Tsouros et al., 2019).

7.1.1. Purpose and Scope of the Study

The adoption of digital technologies in agriculture is a way to make systems more efficient. Improving the monitoring of machines that are responsible for most agro-industrial operations, especially large tracked vehicles such as harvesters, sugarcane planters, and coffee harvesters, is essential to implement more autonomous systems. The sensors required for monitoring these machines are usually embedded in the machines. These sensors can provide a large amount of information about the operation of these systems but require a high level of investment and specific maintenance. Concepts can be applied to the incorporation of sensors in an agricultural system that allow low-cost and low-maintenance monitoring of machines that perform most field operations. This work proposes an architecture for the incorporation of devices into the function of monitoring agricultural machines. It discusses the possible sensors and technologies to be applied to these systems and the importance of generating metadata that allows comparative evaluations among different machines, for the same task, in the same period.

Fig 7 . 1 : Smart Farming The Digital Revolution

The boards can communicate in a wireless or wired way, depending on the distance the data must be sent. In this way, it is possible to install the monitoring system by communicating in a wired way with one of the boards, which in turn, communicate by wireless technology with the other boards if they are far away from the access point. The entire system can be configured to allow data collection when a connection is not available. When a connection is available again, the stored data will be sent to the database for a posteriori analysis. The work also presents the description of the communication protocols that allow data transmission between the boards and the how-to tutorial for implementing the entire system. The results presented are based on real-case experiences applied in several activities, such as the coffee harvest and the sugarcane crop.

7.2. Overview of IoT Technology

In the last decade, rapid advancement of information technology and micro-electro-mechanical systems and devices has led to increasing interest and investment in the development of a new generation of innovative devices and systems for real-time and remote monitoring of natural resources. Fast growing demands for improved user level monitoring functions, higher performance and lower power consumption of systems have fueled the development and integration of inexpensive advanced sensors based on microcontrollers, low power wireless communication devices, and cloud storage services. The sensor-enabled wireless connected devices are collectively known as The Internet of Things. Devices are being developed for real-time monitoring of important natural resource variables such as soil moisture content, soil salinity, soil temperature and pH level and also micro climate variables near earth surface such as air temperature, humidity, solar radiation, wind speed and direction, rainfall. The smart connected devices are being developed to improve monitoring efficiency, accuracy and precision of the resources used for irrigation, drainage, fertigation of crops.

The concept of IoT is simple yet complex. It is comprised of intelligent objects or devices that work towards a common goal or provide a common service. These devices can connect with the internet and communicate both with each other and share information with people or organizations. The definition is simple but IoT technology encompasses how these devices are getting connected, how they are working together, reducing human intervention, ensuring security and privacy, are remotely accessible, and are efficiently addressing a collective goal. The workings of IoT technology include a very large networked eco-system, cloud storage, processor-centric embedded technology, wireless and hybrid networking system, security and privacy technology, and interdisciplinary sensor and actuator solution. At its essence, IoT technology can seamlessly integrate smart sensors and actuators, information technology, and communication technology in a network to gather and share information without human intervention.

7.2.1. Key Components of IoT Systems in Agriculture

IoT for Agriculture is one of the rapidly developing categories of IoT solutions. Despite this, there is relatively little information about the key components of IoT systems. In this chapter, we provide an overview of the key components of IoT for Agriculture systems. The goal is to clarify key terms and concepts, summarize the current state of development of different components, and provide motivation for the design processes related to IoT solutions in agriculture. The information in this chapter is especially relevant for solution architects and developers who design and develop agricultural solutions, as well as domain experts who would like to gain a better understanding of the IoT ecosystem.

In general, IoT refers to a system of connected devices that creates a digital twin of the physical world, enabling monitoring and control. Every IoT system consists of a set of physical devices and a data communication network that connects them. While all IoT systems share these characteristics, they come in different designs and have different architectures. Some architectures are more powerful and flexible but also more complex, while others give a more limited functionality but are simpler to design. This work provides a condensed overview of the possible device and communication network architectures, as well as other issues related to key components. In particular, we focus on agriculture use cases while trying to provide a more general overview, which would also assist researchers and practitioners from other domains.

In general, IoT systems consist of a sensor network connecting sensing and actuation devices to a cloud-based data processing and storage backend with a data presentation and visualization front end. Sensor nodes are generally made up of a microcontroller, radio connectivity, a power supply, and various sensors or other modification devices. Sensor connectivity in remote applications is generally done using low-active power radio protocols, including LoRa, Sigfox, NB-IoT, or custom solutions based on IEEE802.15.4, Zigbee, or BLE. While WiFi or cellular solutions can also be used, they are energy-hungry and may require more frequent battery replacement or recharging.

7.3. Importance of Real-Time Monitoring in Agriculture

Agriculture is one of the mainstays of the world economy since ancient times. Aside from being a source of income for people, agriculture also facilitated trade between nations. The use of technology has made it convenient to conduct agricultural activities. One such technology is the Internet of Things (IoT). The IoT provides real-time monitoring and efficiency in the production process. Farmers always had issues with weather fluctuations, which can play havoc with production. Moreover, the manual monitoring and control of equipment are labor-intensive and may cause physical exhaustion. Using IoT with associated devices, farmers can remotely monitor the various activities. As access to the Internet is becoming easy, the farmers can use IoT devices and the associated technologies. Various sensors can detect soil temperature, soil moisture, humidity, and temperature around plants and send that data for analysis. This data can help in deciding the irrigation and fertilizers needed based on actual data. Thus, IoT allows the farmers to monitor environmental conditions for improving crop yield. The progressive development in technology has contributed to the digitization of many areas of applied to real-time data collection. Some of the real-time monitoring has proven to be support and to favor decision-making in various areas such as health, quality, and control of industrial processes, inventory control, and data safety. Real-time monitoring in agriculture is a practical theme with various applications. Precision agriculture practices promote optimizing the productivity of agricultural systems by integrating and collecting environmental and operational data and implementing the defined sampling interval zone to make real-time and informed decisions. Real-time monitoring has the primary target of assisting and favoring better management on multiple levels. With many activities carried out throughout the agricultural process from land preparation to crop post-harvest, it is important to recognize the path optimization and existing technological solutions to apply these methodologies. Thus, real-time monitoring in agriculture promotes greater safety, efficiency, and productivity.

7.3.1. Significance of Real-Time Monitoring in Modern Agricultural Practices

Agriculture is one of the most ancient and significant industries for human prosperity. Recently, with the rapid growth of the human population, the question of how to meet the demand for food has become a serious concern. Therefore, new solutions such as precision agriculture and smart agriculture based on the latest technologies are required to produce food more efficiently and sustainably. Precision agriculture aims to minimize the environmental impact and maximize productivity by observing spatial variability in agriculture and managing the factors affecting agricultural production accurately. Smart agriculture utilizes devices, big data, and artificial intelligence to further automate agricultural processes and enable active solutions by predicting future events with high accuracy.

With precision or smart agriculture, timely decision making is critical to the success of agricultural business. For example, it is important to apply nutrients such as fertilizers or water at the right time to improve crop growth. If pesticide application is delayed because of difficulty in predicting pest occurrence, it would cause irreversible damage to the crops or put peoples' health and safety at risk due to toxic residues. Efficient irrigation is paramount to the growth of plants but excessive irrigation could also cause environmental issues including depletion of available water sources for other important human activities and salinization of cultivated land.

7.4. Types of IoT Devices for Agriculture

Smart Agriculture entails the use and incorporation of a vast number of IoT devices in Cropping and Livestock Systems. For instance, Smart Sensors embedded into the equipment and field can sense Soil Temperature and Moisture Contents, the Local and Seasonal Micro Weather and Land Topology Conditions, and the Plants' Crop Growth and Ripeness Index. In Coupled with Actuators, Automations, and Mechanical Controls, the Sensors can Actuate and Automate Irrigation and Fertilization Systems.

1. Sensors A Sensor is a Physical Surface Embedded into an Engine that can Detect Physical Phenomena, an Effect, a Vibration, a Temperature, and a Motion. Sensors have been widely used in Agriculture, and a plethora of Sensor Devices Embedded into Agricultural Equipment can be found.

2. Actuators In Engineering and in Physics, the Term Actuator refers to a Device that Converts a Signal into Physical Motion. Actuators can be used in Active Controls, by Using Sensors, to Perform Available Actions in Response to Sensor Signals. Actuators can also be used in Passive and Reactive Controls; using Prefixed Reactions in Response to Observed Situations Can Reduce Your Crop Maintenance Costs. Besides High-volume Automation and Control Tools that Can Help by Performing Low-level Actions, Actuators are Devices that Can Drive Low-level Needs by Keep on Working.

3. Drones Automation and Agritecture in Agriculture Have Opened a Woman's New Function and Helper: the Drone. These Flying Systems are Able to Collaborate with the Sensors, Making the Active Information Flow Permanent, or Inverting the Passive Flow, Re-Acting on the Land by Spreading Fertilizers.

4. Automated Irrigation Systems Water is a Scarce Resource Needs to Be Protected. In Response to Seasonal or Cyclical Water Needs, Within Smart Controllers, Temperature Sensors and Flow Sensors Can Open and Close a Number of Automated Valves Installed on Different Zones of the Field.

7.4.1. Sensors

Sensors are crucial elements of IoT devices, which interact with their environment through physical quantities. In other words, sensors detect environmental conditions and gather corresponding data that trigger actions in an actuator or are relayed to a server. Since they can perform remote data collection, sensors eliminate the need of burdening the farmer with constant evaluation of the variables being monitored. In agriculture, sensors are employed for various purposes, including, but not limited to: measuring the humidity level in soils and leafs; measuring atmospheric temperature; detecting plant wetting; measuring the proximity of animals and humans; monitoring the levels of certain groundwater ion concentrations; monitoring the levels of greenhouse gas concentrations; measuring radiation intensity; measuring the index of humidity in grain storage; and monitoring crop growth during plantation.

Sensors employed in IoT devices can be classified as external or internal, based on whether they act upon the external or internal environment of the devices. External sensors can be as simple and cheap as temperature switches, whose opening and closing depends on the temperature to which they are exposed, but are usually more complex devices, including specific gas concentration detectors, humidity, and ambient luminosity sensors. Internal sensors are cheaper and simpler microcontroller integrated circuits that measure variables that are internal to the devices, like the temperature of the interior light, vibration levels, battery voltage, and relative humidity. IoT systems for agricultural applications usually include a number of external sensors used to measure environmental variables relevant for predictive models of the growth of the different crops. Temperature and humidity sensors are the most commonly used sensor types in IoT for precision agricultural monitoring, followed by gas sensors, temperature sensors, and ultrasonic distance sensors.

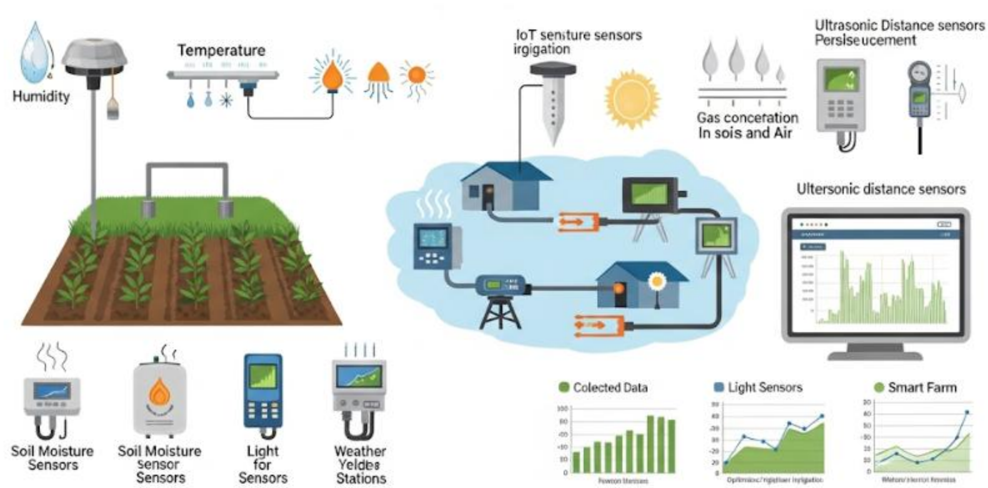

Fig 7 . 2 : Smart Sensors, Smarter Farms

7.4.2. Actuators

Actuators are electromechanical devices capable of acting on an environment, changing its state. They are responsible for making corrections in a system, responding to instructions from the control logic and based on the information received by sensors. Therefore, actuators have great importance in the operation of control systems since they are responsible for changing the system’s physical properties. Actuation practically transforms the vision from a human being into action since they exercise a mechanic function that requires a physical entity. The most commonly used types of actuators are electromagnetic solenoids or electro-pneumatic and electro-hydraulic cylinders. These devices act as a physical interface between sensors used to obtain some kind of information from the atmosphere and present in intelligent control systems that decide whether or not to take any action concerning the supplied information. Typically, actuators have numerous applications that range from easing the movement of an object to provide security to equipment or devices through the locking or unlocking of some piece when the supplied signal states it is necessary. Among its functions, its most common applications perform just the opposite of what was mentioned above, which is to lock one piece or any mobile object or element releasing it with the help of a spring when it is made vacuum using a coil energized by a certain amount of voltage. Various types of sensors, transmitter, and receiver modules, relay drivers, relays, RTC, and LED indicators are generally utilized in such applications.

7.4.3. Drones

The application of UAVs, commonly referred to as drones, stands as one of the foremost IoT applications in the agricultural sector, garnering heightened interest, a growing impetus for innovation, and a corresponding increase in creative uses. UAVs deployed in agriculture serve two primary functions: agronomic support and security. While some UAVs are equipped with multispectral or thermal cameras to assist in tasks such as crop monitoring, pest detection, and irrigation management, others are outfitted with PTZ cameras to enhance security and protection by monitoring properties and assets, including warehouses, fences, and livestock. UAVs have gained traction in the agricultural sector due to recent technological advances. Drones for precision agriculture are rapidly becoming commercialized. UAVs can be used for real-time air surveillance of crops, from monitoring crop growth to the detection of disease. Agricultural-mounted UAVs can be equipped with visible light, near-infrared, thermal cameras, multispectral, or hyperspectral sensors to acquire crop images in real-time. UAVs can provide near-real-time feedback to the farmer regarding the crop status and the need for pesticides or fertilizers using crop proclamations or vegetation indices maps. UAVs equipped with an infrared camera can also assist with irrigation planning in agricultural fields. Since the infrared camera can see the amount of water contained in the ground, it allows it to be able to recommend an appropriate irrigation depth and tell you which field is saturated or needs irrigation. Moreover, UAVs are cost-effective and inexpensive in comparison to traditional aerial monitoring for crop scouting or mapping.

7.4.4. Automated Irrigation Systems

Recent advancements in agriculture-related systems have seen the integration of IoT devices into contemporary work practices. Researchers and designers have employed actuators, devices that mediate tangible physical interactions with the environment, to develop automated irrigation systems. Such systems turn irrigation into an automated process that prescribes an adequate watering program based on an evaluation of selected qualitative attributes of the soil environment. To that aim, such actuators, connected to IoT devices and suited for the real-time monitoring of soil quality, propose and control the appropriate time for the supply of a certain amount of water needed to improve the soil factors, such as a pH in the acid or versatile ranges, hydrolytic activity, organic carbon content, or the concentrations of potassium, phosphorus, nitrogen, and sulfur.

Irrigation is a crucial element of crop management because the correct level of soil humidity helps to optimize crop yield and avoid crop loss. Consequently, precise understanding of environmental and climatic changes, as well as of the impact of irrigation practices, is needed to provide the right measure at the right time. As lack of humidity can lead to crop loss, irrigation replaces atmospheric transpiration and protects plants from wilting. Additionally, the supply of a certain amount of water may facilitate the dissolution of certain elements in the soil, improving the existing conditions.

7.5. Integration of IoT Devices into Agricultural Equipment

In addition to the sensors, radars, and relays involved in precision agriculture, there are also several other classes of IoT devices that will support and enhance the gathering of feedback, control, and monitoring functions. These include drones, tractors, vehicles, control systems, and edge devices.

As a deluge of IoT and 4IR data become available, real-time research, data analysis, control, and supervision become paramount features of future farming and agriculture, combining the physical and digital realms of precise, informed, and more intelligent agri-ecosystems. Research has resolved many of the failures of traditional automation, embedded control, and remote data collection using various communication protocols. In recent years progress in the Fourth Industrial Revolution (4IR) has led to new smaller and lighter, blended and contained sensors and edge computing modules that are enabling the increased deployment of IoT connected devices working on multiple defined communication protocols.

1. Compatibility Challenges

Technically, in order to achieve the most beneficial approach to integration, the electronic devices and systems must be configured to support all of the communications protocols that have been employed in the current infrastructure deployments along with any newer prosthetic hair and whisker-like devices that may not have been originally envisaged. The integration of embedded control, IoT, fiber networks, and 4IR systems will create a hostile and efficient infrastructure. Challenges will inevitably occur that involve security, availability, latency, and patience, with the introduction of increased numbers of devices requiring more demanding real-time precise performance, coupled with the unforeseen reliance on agri-ecosystems development and support on every device.

2. Data Communication Protocols

Two classes of communication protocols have been used thus far in the multiple telecommunications infrastructures. These are the traditional embedded and fieldbus data communications control protocols including various serial connection formats, and new-wire-per-fiber-based data communication protocols. Each supports the device types, their locations, and the requirements of the edge and embedded remote physical signal and relay controls that have been previously installed. Each offers many advantages and constraints of physical size, distance, throughput, data redundancy, and error-checking properties.

7.5.1. Compatibility Challenges

Keywords: IoT devices, compatibility, agricultural machinery, retrofitting

When evaluating an Internet of Things (IoT) device, two major areas are of concern to our research: the role of high-level communication protocols and the implications of the physical integration of sensors and actuators into the agricultural machines ecosystem. Several protocols specify how sensor data can be collected, transferred, processed, and made available to other components in the IoT ecosystem. They are either communications stack protocols or standard data schemas used – usually packaged using Javascript Object Notation syntax – to represent available data and actions that can affect an object. IoT standards specify how IoT components interact to provide some context to sensors deployed around the field.

However, the IoT is not about connecting sensors and actuators to other devices; it is about transforming information generated by the sensors into information that can be used by the farmers to help them in their daily activities. Our main focus is on fitting low-cost devices inside the constrained ecosystems of agricultural machinery. Retrofitting in the agricultural machinery ecosystem poses many challenges. Given the different life spans of sensors and machines, it is important to avoid semantic isolation or obsolescence of transducers, such that the data delivered by an in-field sensor can still be used in a meaningful way when the machine is in the authorized circulation for a specified period of time. The design of these interfaces must bridge the current physical incompatibilities (both mechanical and electrical) between old and contemporary electronic devices. Physical retrofitting might involve mitigating gross mismatching of sizes between devices, bandwidth, communication protocols, and electrical levels. It could also provide stated advantages in device provenance and verifications of functioning.

7.5.2. Data Communication Protocols

The concepts related to the Internet of Things (IoT) foresee the interconnection of any object to the Network and not only computers, within a framework of universal communication and interaction between the objects. Nevertheless, two crucial factors slowed down this development for years: on one side, the Network expansion would require a huge and expensive amount of energy; on the other side, all electronic objects needed a power supply, which goes against the concept of autonomy desired for the IoT. The advancement of Integrated Circuit technology and the Digital Era have favored the emergence of the IoT. Technological advances have increased exponentially the available processing capacity while dramatically reducing the cost. Advances in low-power, low-cost wireless communication technologies have made it feasible and, in fact, commercially viable to interconnect each object, such as industrial equipment, in an intelligent and low-cost way.

Low-Power Wide Area (LPWA) Data Communication Technologies were developed, specifically designed for the needs of the IoT and its applications. These technologies have reduced costs and consumption and increased coverage in relation to other mobile telecommunications alternatives. Furthermore, many LPWA technologies implement an unlicensed band operation model. There are many existing data communications solutions depending on specific characteristics of the project at hand, such as the data volume to transmit, the range, transmission time, power consumption, etc. More complex LPWA implementations could use several wireless transmission technologies, such as Narrowband Internet of Things (NB-IoT), Long Range (LoRa), Sigfox, Weightless, or Long-Term Evolution (LTE) departing from Narrowband and Long-Term Evolution, LTE-M.

7.6. Real-Time Data Collection and Analysis

The rapid development of IoT devices has led to the generation of large volumes of heterogeneous, dynamic, critical, and timely data from multiple sources to support real-time decision-making. Being capable of collecting and providing real-time reliable information via sensor networks is extremely useful for agricultural practitioners and exporters. For example, when there are strong indications of rainwater at the harvesting stage, real-time moisture status can accelerate the supplier's decisions. Additionally, IoT-based agriculture responds to the questions when and where we have pests or diseases. This is achieved using prediction models using the inputs of the continuously exchanged data via wireless communications developed from IoT devices such as unmanned aerial vehicles and IoT field nodes, among others. The implemented predictive models are generally four different types: (1) Predictive models focusing on the plant, which predict the plant's behavior based on the plant's conditions, such as temperature and humidity; (2) Predictive models that predict the pests' incidence caused by the insect population monitored by pheromone traps; (3) Predictive models that predict the pest's incidence on crops based on connected sensors implemented on the crop, which send temperature and humidity data to be processed; and (4) Predictive models that predict the insect population's behavior based on historic data of pest populations.

7.6.1. Data Types and Sources

Data collection is an essential component of smart farming operations. Farmers have traditionally relied on historical weather patterns and feedback from farm staff or experts to manage their production systems, even though decisions made using such information could be flawed. Additionally, the current decision-making processes are no longer adequate since more variations in the relationships between different factors are becoming important. Agriculture has become increasingly dependent on real time information. Some areas involve a near-continuous monitoring of the influencing conditions in order to protect business interests. By introducing modern technologies into the agricultural equipment, farmers can become more informed and can exploit the data using software tools.

The traditional method to collect, store and process data consumed a lot of time and labor. The emergence of IoT technology has made it possible to do these processes with the help of smart devices. The word “smart” is referred to technologies that have the ability to process data and optimize their action based on the processed data. Current agricultural smart devices use different types of sensors to collect data from the surrounding environment and transfer it over to some processing unit, which could be a cloud server or an edge computer. Two types of devices are available in the market: simple devices without any data processing capabilities or “smart” devices able to process their data, take decisions, and act accordingly without supervision. The first system needs constant monitoring and dependency on the stability of the communication network. The second system eliminates the need for constant human supervision of the devices.

7.6.2. Data Processing Techniques

This section focuses on the topic of data processing techniques to further promote the appeal of the collected data, providing suggestions and ideas on data exploration and visualizations. IoT is a promising area to improve production in the agricultural and livestock sectors. However, adopting a digital transition is not an easy task, especially for medium and small-scale producers. This transition needs to be designed and presented in a way that allows producers to perceive it as a value generator and therefore want to adopt it.

Even though we are witnessing the hype of some relatable and disruptive technologies, a good amount of agtech solutions that have been adopted in the agricultural and livestock sectors are based on concepts, processes, and technologies that have been around for some time. They have been able to prove the value they generate and earn producers' trust. The data-driven processes that have been around for some time have been proven to be matured solutions providing relevant value to producers. The successful adoption of Data-driven parts in the Digital Transition Process is dependent on techniques and experiences from related Data Science disciplines.

This chapter is, therefore, suggested to cover Data Processing techniques and how related techniques contribute to value generation from data processing along with the user experiences so far. Translating collected IoT data into relevant information for making informed decisions requires an analysis of how queries are created and structured over the data. The data processing techniques presented here are therefore focusing on how to prepare the datasets for Data Processing Techniques because how the datasets are configured directly affects the processing techniques deployed on top of the dataset.

7.7. Conclusion

Agriculture has undergone major upheavals in recent years, driven by the need to feed a fast-growing global population in the face of uncertainty created by climate change. Facing new environmental and logistical demands, the agricultural sector has been forced to develop new strategies to improve productivity while reducing the impact on natural resources and local economies. Adoption of precision agriculture models, initially circumscribed to specific technology-driven areas, is now gaining momentum and becoming widespread. This has been made possible through the reducing costs and growing availability of a wide range of sensor technologies sensitive to different physical and chemical measurements in the soil, plants and atmosphere. Satellite and aerial remote sensing, employing advanced spectral analysis techniques and now including applications utilizing drones, LiDAR and other optical approaches, are increasingly opening up countless new opportunities for the development of precision agriculture and its many applications.

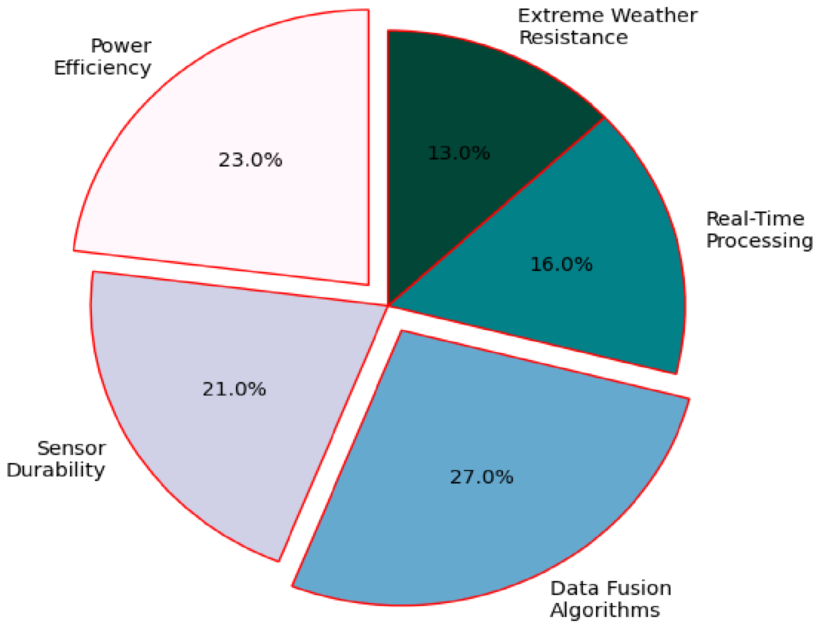

Fig 7 . 3 : Future Development Priorities

Real-time monitoring of the status of agricultural crops, through data-inferencing devices and systems is a key part of these developments. This chapter presents a new procedure and preliminary developments for incorporating IoT devices in the harvesting machines. An initial prototype has been presented, the validation of which was performed on a soybean harvester combined with a speed-suspended flexible table. The proposed developments are still in their first stages of exploratory validation in lab tests but nevertheless, they have performed satisfactorily. They allowed for running initial wireless field tests that opened up new implementation possibilities of more advanced data fusion integration schemes for real-time monitoring of mechanical harvesting processes. The presented modular IoT capable device can read data from several types of diverse and low-cost low-power sensors and it has an adequate data transmission range. Further developments are foreseen in the near future, to build new versions with improved readout time, power consumption and ambient temperature resistance.

7.7.1. Future Directions and Implications for IoT in Agriculture

The IoT is a promising technological paradigm as it enables a continuous and efficient monitoring of the increased number of agricultural data in real-time through deployed

IoT devices in Smart Farming. These data could be analyzed and interpreted to deliver required actions to make better decision-making in agriculture. However, huge amounts of information need some new effort to be developed and explored in order to maintain a sufficient data quality for analysis and interpretation purposes. Several key concerns need to be highlighted here related to the current developments of IoT in Agriculture.

First, it is noted that more data were collected by sensors, acting independently from each other, in a less calibrated way, which also generated less interest from researchers and practitioners beyond the sensors' developers. Remote Sensing technologies and data analytics have to be better calibrated and combine more than one data. Second, information overload and rapid technological changes have prompted the development of new strategies to combine, discipline and organize available IoT in agriculture data. The data collected need to be transmitted to a Cloud computing platform or database system and actualized by Agriculture managers and implemented in decision support systems to be used by farmers. However, many farmers are not aware of such systems or they do not want to pay for such services. Agribusiness ecosystem players, either public and private, have to incentivize cooperatives or individual farmers to use those data in order to minimize the risks associated with the agricultural business.

Third, collecting data raw from the ground sensors or even drones are not enough. Data quality and management, including periodical replacement of instruments and pesticides testing in the soil, should have priority on collecting large amounts of raw data. Data sensed and transmitted should then be careful selected, classified and actualized by users in order to achieve a more precise and accurate data analysis through models that take into account the specificities of the region and/or of the crop planted. Fourth, the new data to be collected mentioned above should also have to be directed toward more sustainable agriculture that balances resources managed by Agriculture players with the global growth in food demand for a growing world population.

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