Farming in the Era of Internet of Things: An Information System Architecture for Smart Farming

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Abstract. The Internet of Things and associated smart products are finding application in evermore domains. Within agriculture it is described under the term smart farming. Using smart products allows farmers to automatically record relevant information, monitor operating procedures or remotely control machines. To make these capabilities usable for added value, not only smart products but entire information systems that align to the domain and its requirements are necessary. Within the literature, various architectures can be found already. However, many lack a methodical foundation or an abstraction of application cases and technology. Against this background, the article presents an information system architecture independent of application cases or technology and oriented toward the domain of smart farming. Starting point of the development is a systematic literature review, based on Webster and Watson [1] in combination with Vom Brocke [2, 3], based on 18 existing architecture approaches that are analyzed and aggregated.

Keywords: Smart Farming, Internet of Things, Information System Architecture, Information Systems, Systematic Literature Review.

1 Introduction

As a result of ever-increasing digitalization due to the exponential nature of technological development, smart products and their related services are increasingly occupying space in both business and personal life. Even historically analog-driven domains, such as agriculture, can no longer escape the trend of digital transformation and its associated advantages [4, 5].

The starting point of this development includes smart or so-called intelligent products and their capability spectrum, which can be used for everything from simple monitoring or remote tasks [4] to dynamic, adaptive decision making [6]. The literature describes the domain-specific use of these products in combination with other technologies, such as cloud computing or machine learning-based data analysis, in the context of agriculture as smart farming, or farming 4.0 [7, 8].

To process the data collected from these products and their sensors in a manner that is timely and appropriate, and to create from these added values for the system user,

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information systems specially designed for the domain and its challenges are necessary. Within the literature, some architectural approaches are currently found in the context of smart farming ([9–12] etc.); however, in most cases, they are designed for exactly one scenario or one specific technology and are therefore not applicable to the broader range of agricultural needs. Against this background, the following research question is examined: *How must information systems be designed from an architectural point of view for the domain of smart farming?*

In the context of this publication, this research question is elaborated on the basis of a systematic literature search after Webster and Watson [1] in combination with Vom Brocke [2, 3] by presenting a generic information system architecture for the domain of smart farming. The remainder of this paper is structured as follows. First, theoretical bases for smart products, information systems, architectures, and smart farming are established. Subsequently, the applied research methodology and the results of the literature review are presented. The developed information system architecture for smart farming is subsequently presented in detail. The paper concludes with the limitations of the work and a corresponding outlook for future research.

2 Theoretical Background

2.1 Internet of Things and Smart Products

From an academic perspective, the basic idea behind the Internet of Things (IoT) and thus smart products is not new. As early as 1998, Mark Weiser characterized the concepts underlying today's IoT [13] under the heading of "ubiquitous computing." Over the years, these concepts have been continuously further developed based on the increasing computing power within information technology as well as the increasingly less expensive hardware components, and have been represented under different terms, such as Cyber Physical System, Industry 4.0, Smart Connected Products, and IoT [4, 14–16].

In general, the term "IoT" can be defined as "a worldwide network of interconnected objects uniquely addressable, based on standard communication protocols" [17]. The central focus here is on the fusion of physical and digital components that form the basis for interaction with their environment [18]. Within the work, the concept of the IoT is equated with the concept of smart (connected) products as coined by Porter and Heppelmann, which describes physical objects that include intelligent components, such as sensors, actuators, controls, microprocessors, software, and data storage, as well as a connectivity component that together enables monitoring, control, optimization, and autonomy functions [4, 19].

Based on the capability spectrum of these products, their main tasks are data collection, interaction with their environment, and communication with other

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intelligent objects [20]. The added value is created by the new interaction possibilities of the products and their possibility of value co-creation through the cooperation of users and manufacturers [4].

2.2 Smart Farming

The increasing use of technology in agriculture, such as the IoT, big data analytics, or cloud computing, is based primarily on the technical developments of recent years and the associated economic affordability of the technologies. The use of modern information and communication technologies (ICT) within agriculture is known as smart farming, or farming 4.0 [7, 8].

In particular, the use of smart products is the central focus of change. Through the use of sensors and actuators, an increasing amount of data is being collected from a wide variety of areas [21]. Specifically, data from different machines, plants, animals, greenhouses, or other farms is now collected. For example, field or soil sensors can measure crop-relevant parameters, such as solar radiation or the nitrogen content of plants, and can inform farmers if the standard values are not yet met or are exceeded so that appropriate countermeasures can be taken [21–25]. The generation, recording, and consolidation of this information relevant to the process is automated and thus enables almost continuous monitoring of farm operations [7, 26].

In addition to pure data acquisition and monitoring, smart products also offer the farmer the option of actively intervening in processes or controlling them. For example, drones can be used to visually reach inaccessible areas more quickly or to carry out agricultural measurements [23]. Appropriately equipped drone models armed with thermal imaging cameras and audio systems currently support farmers in preventing wildlife accidents by locating animals in the field and driving them away before mowing operations [27].

Other standard agricultural processes, such as variety selection, pest control, and irrigation, can also be controlled and carried out more precisely with the help of smart products. Through this targeted use of technology, natural resources can be conserved and the use of operating materials, such as fertilizers, reduced [23]. This in turn has a positive effect on productivity as well as on the quality of the harvest and the economic yield [8, 26, 28].

The use of smart products has led to significant technological progress within agriculture [21]. Farms not only benefit from increased productivity and sustainability but the need for human intervention and the associated probability of human error are also reduced [21]. Furthermore, the ICT-controlled, targeted, and site-specific use of resources and inputs (e.g., pesticides or fertilizers) can reduce the ecological footprint within agriculture and the environmental impact of greenhouse gas emissions [8, 28]. Ultimately, the digitization of agriculture has a positive impact not only on farms but also on the environment as a whole; in turn, increased networking and transparency along the value chain offers the possibility of new value creation in the form of insurance and business models [8, 23].

2.3 Information Systems and Architectures

Currently, the computer-based support of companies by information systems (IS) is indispensable. This development began in the 1960s with the first computer systems in the form of Material Requirements Planning Systems and Management Support Systems used to solve operational problems [29–31].

Today's information systems are based on the basic idea of these systems and have the goal of connecting all resources available within a company that are relevant for its success, from financial planning to personnel management [29–33]. Thus, information systems represent not only a piece of hardware or software but also represent socio-technical systems, which include technical but above all human or in the case of smart farming, animal or plant components. The central task of this system is the collection, processing, and provision of data to support the system user in the monitoring, control, or decision making of primary and secondary value-creation processes [32–35] .

A standardized procedure in the form of an information system architecture (ISA) is necessary for the targeted and reproducible mapping of these complex socio-technical processes. The primary goal of the ISA is to describe the objects relevant to knowledge and their relationships, functions, and the overall context [34]. ISA thus represents a construction plan based on both the terms for the construction and further development of the information system within the framework of a specification. Therefore, the goal can be the organization, holistic analysis, or purposeful use of an information system [36]. The primary quality feature of architecture is reusability [36]. To ensure this, the ISA contains the corresponding construction rules for generation in addition to the blueprint itself [36–38]. This blueprint visualizes a model system in which the IS represents the associated object system [36].

The term “information system architecture” can also be considered in the context of enterprise architecture (EA) [39]. Thus, Lapkin et al. [40] describe enterprise architecture as “[...] the process of translating business vision and strategy into effective enterprise change by creating, communicating and improving the key requirements, principles and models that describe the enterprise’s future state and enable its evolution.” A comparison of the definitions reveals a high degree of overlap between the terms. Winter and Fischer describe EAs with the five fundamental levels of business, process, integration, software, and technology architecture, which can also be found in ISA approaches [39]. The primary definitional difference lies in the scope of the basic system under consideration. In contrast to information system architectures, enterprise architectures consider not only IT-relevant artifacts of the basic system, such as software components or services, but also business-relevant objects such as business objectives, organizational units, or market indicators [39].

3 Research Method

Many architectural approaches discussed in the literature lack a profound and proven research approach. Therefore, the proven approach of a systematic literature search after Webster and Watson [1] in combination with Vom Brocke [2, 3] was conducted. The starting point of the selection process (Table 1) was an initial keyword search based on the search string "*"smart farming" AND ("reference model" OR architecture)*" within the fields title, keyword, and abstract in seven common databases (AISeL, IEEE, ACM, etc.).

Table 1. Literature review process

Database	**Initial**	**Abstract & Keyword incl. duplicates**	**Cleared of duplicates**	**Full-Paper**
Scopus	40	24	**36**	**10**
AISeL	0	0		
IEEE	13	6		
Science Direct	7	4		
ACM	8	6		
SpringerLink	6	5		
WebofScience	14	8		
Sum	**88**	**53**		
			Forward search	2
			Backward search	6
			Sum	**18**

The central search term of "smart farming" results from the domain itself and is refined by the terms "reference model" and "architecture." In contrast to the central search term, these terms are not derived from the domain but from the object of investigation and the underlying interest in knowledge. The term "architecture," in contrast to the term "reference models," does not represent a fixed terminology. However, in order to include the greatest possible variance of the most diverse types of architecture in the result set and at the same time to avoid excluding any homonymous or synonymously used terminology, a refinement of the term "architecture" was omitted.

To guarantee an appropriate level of quality, further exclusion criteria were added during the search. Only peer-reviewed publications published between 2009 and 2019 in German or English were considered. Likewise, publications were excluded that showed a purely technical view of the object of investigation without any consideration of the socio-technical point of view or that offered a fundamentally differentiated understanding of the term "information system". The initial search resulted in 88 publications that met the given inclusion and quality criteria.

In the next step, the initial results were searched on the basis of their abstracts and existing keywords, and irrelevant articles were filtered out. After removing the duplicates, 36 relevant publications were identified. These were then completely searched and analyzed in the context of a full-text analysis. Particular attention was paid to the traceability, level of detail, and validity of the architectures presented. Finally, ten publications and their architectural approaches were included in the result set. To identify as broad a spectrum of potential architectural approaches as possible, a forward and backward search based on the results of the keyword search was carried out on the basis of Webster and Watson [1]. The aim of this search procedure was to identify architecture approaches and ISAs that cannot be found via the keywords. After the completion of the searches, the result set was extended from ten architecture approaches to 18 (Table 2).

Table 2. Result of the literature review

Author	Architectual Layer							
Khan et al. 2019 [10]	Data Wrapper	Device Manager	Exploration Module	Data Aggregation	Data Federation	Event Recognition	Real-time reasoning	Outward Agent
Ray 2017 [11]	Physical Layer	Network Layer	Middleware Layer	Service Layer	Analytics Layer	User Experience Layer		
Ibayashi et al. 2016 [12]	WSN Tier	Actuator control tier	Real-time data analysis tier	Data storage tier	User interface tier			
Cadavid et al. 2018 [9]	Sensors	Internet-gateway	Thingsboard Backend	Data Processing	Thingsboard Client			
Debauche et al. 2018 [48]	Weather Station	Sensors and Actuators	Time related-data processing	Data storage (sound, image and video)	Application sharing and hosting plattform			
Kruize et al. 2015 [52]	ICT Components	Platform	Open Software Enterprise	Business Services	Actors			
Zamora-Izquierdo et al. 2018 [22]	Crop CPS Tier	Edge computing Tier	Access Network	Data cloud	Analytics			
Verma et al. 2018 [21]	Perception Layer	Network Layer	Middleware Layer	Application Layer				
Carpio et al. 2017 [42]	Sensors and Actuators	Fog Computing Devices and Clients	Plattform Controller	Cloud Agent				
Cambra et al. 2018 [25]	Sensor Description	Network Architecture	Platform Controller	Cloud Agent				
Colezea et al. 2018 [43]	Local Farm Controller	Cloud Farm Controller	Back-end-applicaton	Front-end application				
Ferrández-Pastor et al. 2016 [47]	Things	Edge Computing	Local Gateway	Network and Cloud				
Koshy 2018 [49]	IoT/WSN Node with Sensors	IoT/WSN Gateway	Storage Cloud	Analysis Cloud				
Mocanu et al. 2015 [51]	Local Farm Controller	Cloud Farm Controller	Architecture Components	Business Level				
Raikar et al. 2018 [50]	User Layer	Proximity Network	Public Network	Provider Cloud				
Lopez-Morales et al. 2019 [45]	Device and Data Acquisition	Information Management	Service					
Li et al. [46] 2010	Node	Base station	Data Center					
Liu 2016 [41]	Perceptive Layer	Network Layer	Application Layer					

Within the result set, there is a large variance in architectural characteristics [10, 41]. Most of the approaches are based on the classical three- or four-layer model and the separation between data management, business logic, and presentation layer. Regardless of the application area or scenario, the architectures correlate in their basic components. Based on the concept matrix approach of Webster and Watson [1], four central architecture components for smart farming (smart product, network connection, data, smart service) were identified by examining and aggregating the individual components of the architecture approaches of the result set (Table 3).

Within the framework of a detailed analysis of the literature, two of the four basic components (network connection and data) could then be further refined. The network component can be further divided into long range or near field (Wi-Fi, etc.). The long range category includes all architectures whose network topology can no longer be implemented with classic (near-field) network technologies such as Wi-Fi or Bluetooth and therefore requires, Low Power Wide Area Networks. Something similar is visible for the data layer. Here, a differentiation according to location and functional scope can be seen. Most of the architectural approaches rely on a cloud solution supported by a local duplicate. The range of functions is primarily geared toward data storage and evaluation, whereby pure storage in only one of the architectures was recognizable [12].

Table 3. Aggregation of architecture concepts

Architectural Component	**Smart Product**	**Network Connection**		**Data**				**Smart Service**
				Location		**Function**		
Reference		Long Range	Near Field	Local	Cloud	Analytical	Storable	
Khan et al. 2019 [10]	X	X			X	X	O	X
Ray 2017 [11]	X	X	X		X	X	X	X
Ibayashi et al. 2016 [12]	X	X	X		X		X	X
Cadavid et al. 2018 [9]	X		O		X	X	X	X
Debauche et al. 2018 [48]	X	X			X	X	X	X
Kruize et al. 2015 [52]	X				X	X	X	X
Zamora-Izquierdo et al. 2018 [22]	X		X	X	X	X	X	X
Verma et al. 2018 [21]	X		X		O	X	X	X
Carpio et al. 2017 [42]	X		O	X	X	X	X	X
Cambra et al. 2018 [25]	X	X			X	X	X	X
Colezea et al. 2018 [43]	X		O	X	X	X	X	X
Ferrández-Pastor et al. 2016 [47]	X		X	X	X	X	X	X
Koshy 2018 [49]	X	X			X	X	X	X
Mocanu et al. 2015 [51]	X			X	X	X	X	X
Raikar et al. 2018 [50]	X		O		X	X	X	X
Lopez-Morales et al. 2019 [45]	X	X	X		X	X	X	X
Li et al. 2010 [46]	X	X			X	O	O	X
Liu 2016 [41]	X	X	X		O	X	X	X

X = Consensus O = Assumption

4 Information System Architecture for Smart Farming

In most cases, the common architectures described thus far in the literature focus on special applications from the domain of agriculture, such as pig breeding [42] or tomato cultivation [12]; however, many existing architectural approaches have a strong focus on hardware and technology [11, 43], which in turn is limited to specific technology and adapted scenarios. To overcome these limitations, the following information system architecture (Fig. 1) is highly methodologically sound and independent of specific technologies or use cases.

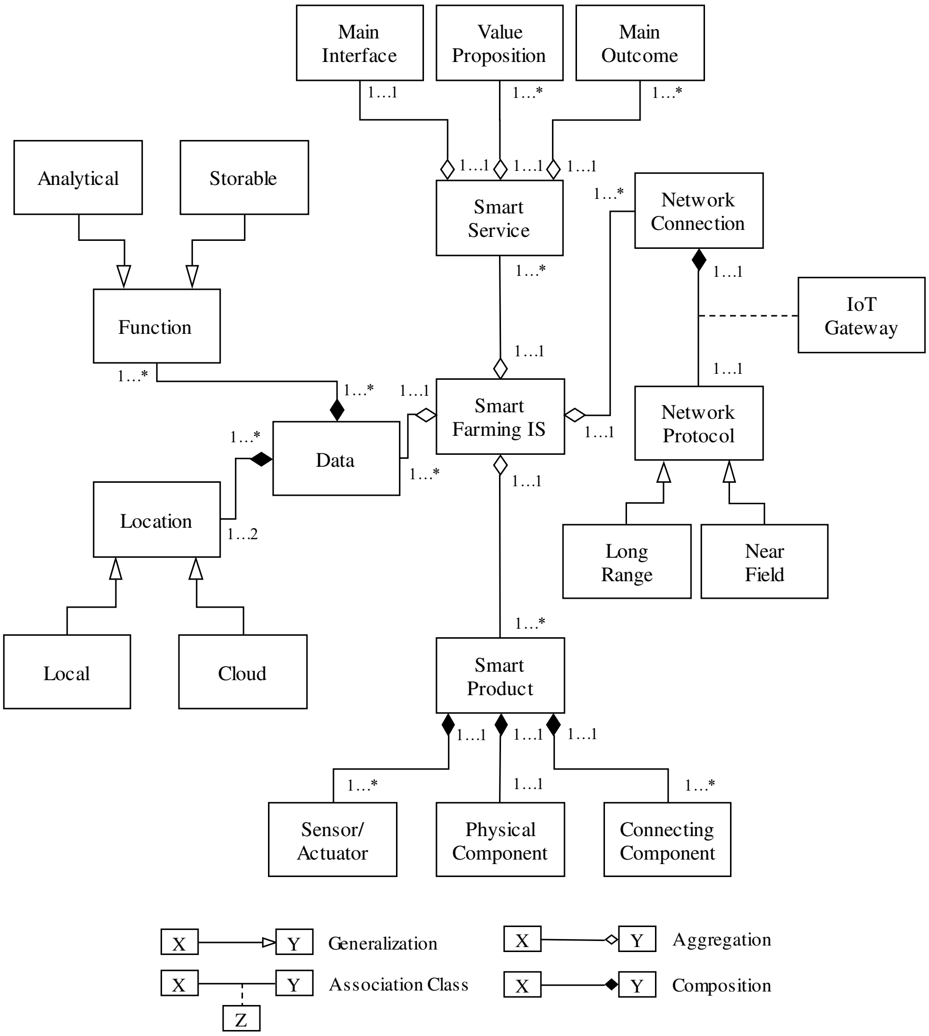

Figure 1. Information system architecture for smart farming

Smart products form the base of the architecture. They consist of a physical, a sensory or actoric, and a connectivity component [44]. In the context of smart farming, these products can represent the most diverse classes of equipment or hardware devices from the agricultural sector, which are placed at different positions on the farm such as in the field, in the greenhouse, or on animals and serve as information sources for measuring points, images, or videos [21, 41, 45, 46]. The capability levels of these products (monitor, control, optimize, automate) described by Porter and Heppelmann are reflected in the product classes used, such as sensors, thermometers, cameras, or drones [4]. As described, there are numerous other types of sensors and actuators that record environmental parameters in real time and exchange them with each other via an integrated communication component or use them to make autonomous decisions [11, 12, 47].

To guarantee these possibilities and the resulting advantages, a stable network connection is required both within the farm and between the farm and the environment. In order to ensure smooth data transmission and communication between the products themselves, and also between the products and the corresponding systems for data storage, analytics and visualization, a wide range of different network protocols are used in the context of smart farming. The difficulty lies in the physical context of farming. Agricultural enterprises usually extend over large areas, and the smart products are often located at the most distinct or faraway places within that area. To overcome this difficulty, users rely in most cases on a hybrid solution of a Low Power Wide Area Network [48], which allows to overcome distances of up to 15 kilometers, and the use of classic wireless network protocols such as Wi-Fi, Bluetooth, or Zigbee for the near field communication of devices [21, 49]. Smart products operate on corresponding protocols and communication paradigms ranging from one-to-one to many-to-many connections [4]. For large sensor landscapes with different types of network protocols, the use of IoT gateways is recommended for decentralized data collection and network relief [41, 50]. The focus within these architecture components is on not only the pure data transfer and the generation of the necessary connectivity but also the manageability and security between the other components [47, 49].

Another central architectural component (data) represents the data storage and analysis layer of the IS. The aim is to store and process the large amounts of data generated by smart products. The focus here is on data cleansing, i.e., the elimination of insufficient and inconsistent data, to carry out extensive real-time analyses, such as with the aid of machine-learning algorithms or big data analytics, and to use these analyses to create operational forecasts. Both current and historical data are used for this purpose [11, 48]. If required, external data can also be included [42, 51]. This includes, for example, data on the current economic situation, weather, the course of diseases or plagues, animals or plants, or from other companies along the value chain. By combining all data, essential information for the farmer and the farm can be derived and potential risks minimized, thereby increasing the overall efficiency of the farm [11]. The data are stored both in local data store and within a cloud store [42, 50]. The duality of data storage ensures data security on the one hand, and on the other hand, it enables analysis and access to mission-critical data even in the event of network failures [22, 42, 43, 52]. Cloud-based storage reduces the management overhead for data storage and enables data access from any location [42].

Smart services represent the main interface between the system user and the platform itself [22, 45]. Following Paukstadt et. al [53], smart services can be consumed by the user in three different ways: device-based, smart product-based, and human-based. In the context of smart farming, the device-based approach is primarily applied through the use of smartphones, tablets, a web browser, or other internet-enabled devices such as smartwatches [53]. The information transfer is device-independent and can be individually adapted to the given situation. Regardless of the type of use, however, every smart service should deliver outcome and also a value proposition for the user [19, 54]. In contrast to other mostly end-user-oriented domains, smart farming focuses primarily on the functional value by increasing efficiency or creating new opportunities for the farm operator. The goal is to make the processed data directly available to the end user as precise, reliable, and optimal decision-supporting information in real time or as correction plans for problems arising on a farm [10, 45]. This provides the farmer with new opportunities, such as monitoring the current status of the entire farm from any location and, if necessary, initiating corrective measures with the help of intelligent suggestions [11, 21, 49, 51]. Furthermore, administrative functions, such as user administration or system condition monitoring, can be carried out to provide more functional value to the system operator [49].

5 Discussion and Conclusion

The use of smart products will increase rapidly over the next few years due to constantly evolving technological developments. According to Gartner [55], by 2020, around 20.4 million smart products will be in use in a wide variety of domains, such as smart homes, smart energy, and smart farming [4, 5]. It is therefore essential for companies and developers to understand smart products, their structure, and their range of capabilities; above all, they must understand their interaction within system landscapes to develop new smart information systems or to transform existing ones.

Against this background, this work offers a systematic and methodologically sound framework for the analysis and development of information systems in the form of an information system architecture for the domain of smart farming. By aggregating 18 architectural approaches available in the literature and abstracting specific use cases and technologies, the presented IS architecture can serve both as a tool for the analysis of existing information systems and as a blueprint for the development of new systems.

Although the research presented in the paper provides theoretical and practical implications, it is not free of limitations and offers room for expansion. For instance, the result artifact is limited through the available literature that presents the existing architectural approaches on the basis of which the present IS architecture was developed. To overcome this limitation, a wide range of both technically and business-oriented databases were used as a basis for the literature research, and a forward and backward search was applied to the result set as a secondary search

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strategy. Furthermore, despite all quality and inclusion criteria, the literature selection process is based on a certain degree of subjectivity. To ensure the highest possible degree of objectivity, a three-stage traffic light system was implemented within the framework of the literature selection process, and if doubts arose, the selection decision was discussed within the framework of collegial consultation.

The presented information system architecture provides researchers with a methodologically grounded framework and thus represents a starting point for future research and the development of dedicated solutions in the context of the domain of smart farming. The central focus for further research could be a specification of the architectural components. Thus, it is conceivable to further develop individual parts of the architecture by developing an appropriate domain-oriented classification scheme, like a taxonomy, based on existing and validated research approaches, such as that of Nickerson et al. [56]. A starting point for this could be the smart service component of the architecture. Regarding these components and their corresponding smart services, the literature contains a variety of specially designed taxonomies (e.g., Wünderlich et al. [57, 58] or Pauckstadt et al. [53]) that are also based on smart products.

In conclusion, the presented architecture offers new insights and information related to the development of smart information systems in the context of smart farming as well as strengthens the conceptual basis for future research in this field.

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