# Technology trends in ICT – towards data-driven, farmer-centered and knowledge-based hybrid cloud architectures for smart farming

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**Abstract:** Over the past four decades, advances in Information and Communication Technology (ICT) have resulted in unprecedented opportunity and innovation for improving farming outcomes. Ongoing innovations such as mobile, social media, agricultural drones, Internet of Things (IoT), big data, and cloud computing presented new challenges and opportunities for agribusinesses to redefine and rethink the role of ICT towards achieving better farming outcomes. With recent advances in infrastructure, data (collection, storage and retrieval), and a better understanding of all aspects of the food chain, new challenges and opportunities are presented. Unstructured data is now being generated real time, in large volumes, at high speed and unknown quality that results in challenges to current approaches for decision making, and requires a focus on analytics. These new sources of data create the opportunity to inform and drive a change in decision making from one that is highly intuitive to one that is data driven and processed in real-time. This paper highlights recent trends in ICT and introduces hybrid cloud architecture for smart farming. The proposed architecture emphasizes data-driven, farmer-centered, and knowledge-based decision tools through service integration, aggregation and interoperation. As a customized solution for farmers, the proposed architecture contains components of 1) data integration of on-farm sensors and data from public sources, 2) farm management modules, 3) knowledge-based software solutions from different providers, 4) service integration, aggregation and interoperation, and 5) a customized dashboard focused on usefulness and usability. This cloud-based solution allows the integration of businesses services, things, and technology from any channel and can be used anywhere. At this time, hybrid cloud environments have shown promise to integrate these different services and provide smart farming solutions to both big and smallholder farmers.

**Keywords:** mobile, big data, IoT, farm management, decision tools

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## 1 Introduction

Agricultural development faces multiple challenges including 1) climate change, 2) sustainable natural resource management, 3) food security, 4) shortages of fresh water, 5) limited availability of agricultural land, and 6) changing consumer expectations. In this context, ICT can play an important role in improving efficiency and leading to smart farming in the future of agriculture (Guerrini, 2015).

In the ubiquitous computing world, everything we do is mediated through digital. Current ICT technology drivers include mobile, cloud, IoT, big data, and social media. According to Gartner, by 2020, over seven billion people and businesses, and 30 billion devices will be connected to the Internet (Lopez, 2014). Digital business integrates IoTs, connected and intelligent, with people and business. Today's modern farms are adopting new technologies and generating unprecedented amounts of data, including field-specific information, yield mapping, soil moisture and nutrition, weather, leaf-area index, insects, and farm management data. Data collected from farms are a fundamental block for data-driven farming decision, and it is critical to turn the

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data into value to support better farming decision making. ICT now plays increasingly important role in future farming and "in various guises, information technology is taking over agriculture." (The Economist, 2016)

To improve farm management, universities and organizations have developed many decision tools that range from crop and livestock simulation models (Jones et al., 2003; De Vries, 2016; AgrClimate, 2016), as well as extension publications (EDIS, 2016), crop disease management tools and other mobile solutions (Xin et al., 2015). In addition, a wealth of information, such as farm Best Management Practices (BMPs), is available from extension services. Many of these knowledge-based systems are developed by researchers or the extension arm of land-grant universities. Although many of these solutions have been successful, they are in general not easily transportable to a cloud-based environment.

As mobile and cloud technologies mature, the notion of each individual having their own computer has changed to every business having a cloud in which useful apps with high business value are executed. Major cloud service providers such as Amazon, Google and Microsoft* have matured, allowing businesses to create their own virtual private cloud (VPC), interface IoT devices, and integration with other trusted public or private services. Beecham Research (2014) indicates that everyday farming apps are starting to move to cloud. The concept of a hybrid cloud environment for smart farming is to provide farmers with a service catalog by 1) aggregating data for data-driven farming decisions, 2) integrating farm management tools in a single interface so they can be accessed anytime, anywhere, on multiple devices, 3) integrating farm decision tools developed by various parties, and 4) implementing predictive analytics with clear business value.

## 2 Technology trends


Figure 1 Elements of smart farming

Digital technologies are changing or even disrupting businesses everywhere by revolutionizing the role ICT plays in our everyday lives. Gartner (2012) and the IEEE Computer Society (2015) have presented their predictions for the top technology trends for 2016. Innovations in smart devices are driving radical changes in business practices. Additionally, the "Nexus of Forces" - the convergence and mutual reinforcement of mobility, social media, cloud, and information (big data) (Gartner, 2012) – drives new business scenarios and continues to evolve as it combines with the IoT. "Cloud first, mobile first" have become widely accepted IT strategies for businesses. While mobile apps have provided unprecedented solutions at users' fingertips, the cloud offers a promising infrastructure for integration of data, services, and applications. It becomes an enabler for unified solutions to aggregate various pieces of new and existing solutions in a cloud environment.

Cloud computing has transformed the IT landscape for both individuals and businesses. It has changed the nature how we access, store, and share information in a way that fundamentally alters how business is conducted. As the cloud paradigm has matured, businesses are shifting their applications to cloud environments and the growth of adoption is fast, particularly for the hybrid cloud (RightScale, 2016). As we move forward, the

* Mention of trade names does not institute endorsement by authors or the University of Florida.

"Nexus of Forces" will continue evolving and expand into a new set of business scenarios. A clear trend is that "smartness" is everywhere: smart phones, smart houses, smart cities and smart farming. As agribusinesses are embracing innovations in ICT, there are clear technology trends towards smart farming (Wehrspann, 2016). Figure 1 illustrates technology elements related to smart farming. Among these elements, IoT is in the beginning of a huge wave of growth, and could be one of the key technologies to transform agriculture towards smart farming.

## 3 Proposed cloud-based agriculture

Cloud platforms such as Amazon's AWS provide excellent infrastructure with the capability of virtual servers in the cloud (EC2), isolated virtual private cloud (VPC), scalable storage (S3), managed relational and NoSQL databases, and mobile and enterprise apps. These cloud platforms are mature and enable hybrid and multi-cloud applications. The proposed cloud-based architecture is an infrastructure to provide a unified solution for data, farm management, and knowledge-based decision tools. A key principle is that any cloud architecture has to be flexible enough to support services provided by different parties and allow users to configure the set of services that brings the best value to their business. Figure 2 shows the proposed architecture, and it is divided into five layers as described below.

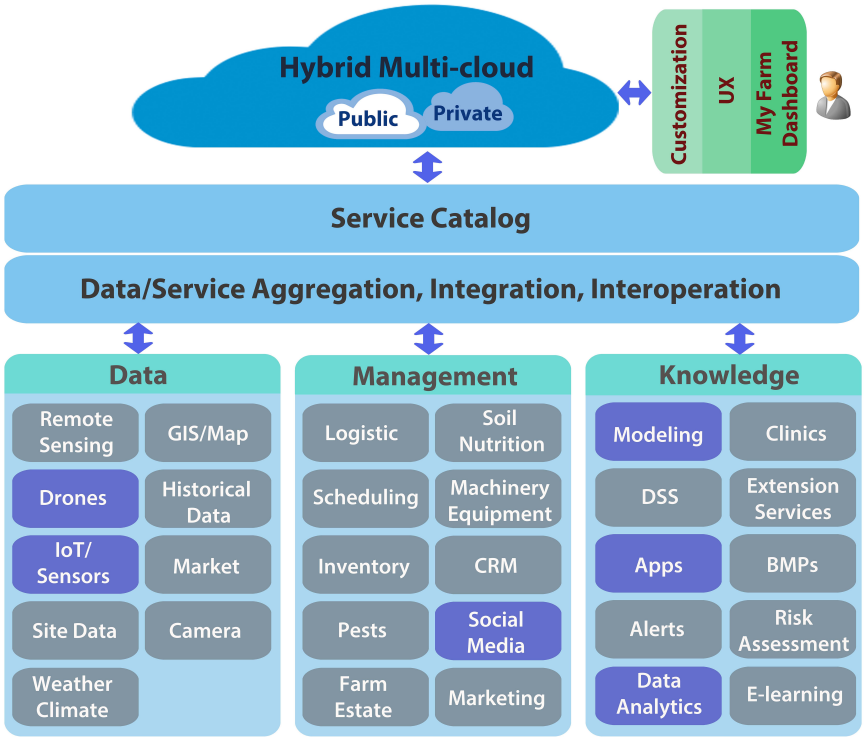


Figure 2 A cloud-based architecture for smart farming.

### 3.1 Data services

Data collection on modern farms is becoming a common operational task (Vogt, 2016). Figure 2 shows the diverse types of data that can be collected on a farm. With the explosive adoption of farm-based "smart" devices, solutions are needed that process farm data and provide insight for decision-making. This could be provided by cloud-based data integration services. It is very appealing that cloud platforms, such as Amazon's AWS, have integrated IoT as a cloud solution to connect smart devices.

Whenever dealing with data collected from a farm, data confidentiality issues must be addressed in any cloud-based service. Some agronomic data may be only

shared with trusted advisors, and the hybrid cloud architecture may address this problem by segmenting data not only virtually but also physically. In addition, an open data standard is important to facilitate interoperability so that we can turn data into value and achieve data-driven decision-making.

**3.2 Farm management services**

Farmers may use applications to manage their daily operations, such as tracking field activities, managing machinery and inventories, book keeping, accounting and scheduling. These services could be readily available from different vendors, but they have to be customized and tailored to their needs in a cloud environment.

**3.3 Knowledge-based services**

Knowledge-based decision tools, such as crop simulation models, decision support systems, BMPs, extension services, education modules, and pest and disease management are widely available and they are valuable resources for smart farming. However, many of these apps lack useful APIs or are not easily configured for site-specific farm information. While cloud computing provides a solution as Infrastructure-as-a-Service (IaaS), knowledge-based software systems should be designed as Software-as-a-Service (SaaS) for better cloud integration. Effort is required to extend these decision tools to cloud environments and leverage these existing solutions for smart farming.

**3.4 Farmer-centered dashboard**

Ease of use and user experience (UX) are often the most important factors for end users. UX design should be farmer-centered and tailored for end users in the environment that they work in. A customized solution is key so that farmers can select apps they need and use their farm specific data. The effectiveness of user adoption largely rests on the quality of UX, and quality of the apps is equally important. The concept of a dashboard and mobile friendly design should be considered to enhance data visualization and deliver a fluid UX. Mobile friendly interfaces are particularly important if a task needs to be conducted in the field.

**3.5 Service integration and aggregation**

Service integration, aggregation, and interoperation are essential elements that enable multi-sourced data and software services provided by various service providers to operate as one tailored smart farming solution. Through service integration, a service catalog that contains data services, farm management, and knowledge-based decision tools can be used by end-users. As data and services may come from many sources, an open and secure data standard, robust software APIs, or SaaS must be implemented to achieve integration, aggregation, and interoperability of cloud-based applications. However, a challenge remains in the implementation of service brokers that result in the effective integration of multi-sourced services into a unified cloud-based solution.

## 4 Conclusion

The drivers of digital transformation create new opportunities to provide intelligent tools for future farming. Farmers are increasingly interested in the adoption of smart farming technology. Cloud-based solutions, through integration and aggregation of multi-sourced services, could provide a comprehensive service catalog to meet farmers' needs. The cloud-based service catalog could change vertical and isolated applications into a centralized and coherent set of smart farming solutions. Successful integration of IoT, mobile, farm management and knowledge-based software solutions, and real-time analytics in a cloud environment will create new solutions for smart farming. Given that many decision tools developed in the public and private sectors are already available, an integration of these tools into a cloud environment could serve farmers better, especially smallholder farmers. By making farm specific data and analysis tools available, farmers can assess different scenarios resulting from different farming decisions. However, creating such type of cloud

environment requires multidisciplinary expertise and collaboration amongst service providers that are often in competition with each other, and overcoming technical issues such as the definition of a common language, creation of standards, service buses, and API's. The adoption of such an environment largely depends on features, ease-of-use, services, and more importantly the business value that the system can provide for farm. Although such work remains to be done, it is clear that future of agriculture will be data-driven, knowledge-based, and farmer-centered smart farming solutions in a cloud or mobile cloud application models.

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