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Cotton Crop Cultivation Oriented Semantic Framework Based on IoT Smart Farming Application

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Abstract— The fact that each technological concept comes from the advances in the research and development, Internet of Things (IoT) grows and touches virtually every area of human activities. This has yielded the possibility of analyzing various types of sensors-environment from any kind of IoT platform. The existing IoT platforms focuses more on the area related to urban infrastructure, smart cities, healthcare, smart industry, smart mobility and much more. In this paper, we are focusing on the architecture of designing the application of IoT based solution in agriculture with more specific to Cotton farming. Our specific approach on farming is relevant to cotton crops cultivation, irrigation and harvesting of yields. In the context of cotton crops cultivation, there are many factors that should be concerned which includes weather, legal regulation, market conditions and resource availability. As a result, this paper presents a cotton crops cultivation oriented semantic framework based on IoT smart farming application which supports smart reasoning over multiple heterogenous data streams associated with the sensors providing a comprehensive semantic pipeline. This framework will support large scale data analytic solution, rapid event recognition, seamless interoperability, operations, sensors and other relevant features covering online web based semantic ontological solution in an agriculture context.

Keywords: Internet of Things (IoT); Smart Agriculture; Smart Farming; Remote Sensing; Precision Agriculture

1. INTRODUCTION

The emergence in the advancement of nano-embedded sensors, wireless network technology, cloud computing and big data analytics revolutionize the integration of Internet of Things (IoT) enabled applications in various domains. The idea of integrating IoT in agriculture for improving traditional agriculture methodologies to a new spectrum of smart agriculture opens multi-dimensional horizon of technological impact on sustainable agriculture. The use of high-tech embedded sensors for measuring the surrounding environmental context inside the farms and livestock has initialize the emergence of IoT into precision agriculture [1]. Precision agriculture provides a way for the automation of Information and Communication Technology, Geoscience and Remote Sensing into Site-specific management (SSM). The idea of SSM requires observing, measuring and responding using remote sensing methods for real-time situations in the focused fields. It supports improvements in crop productivity, growth in the yields, financial profitability, reducing environmental hazards, pesticides protection techniques, efficient irrigation methods and food management for livestock animals. The vision of smart farming requires data gathering, processing, analysis and automation on the fields for improving the overall operations and management of farming in real-time environment [2].

The IoT is a suitable match for smart farming due to its large-scale interoperability, scalability and flexibility in implementing into multiple domains of agriculture [3]. The IoT based infrastructure provides a revolutionary approach in transforming traditional farming practices into smart farming horizon which has higher potential of growth and sustainability. Similarly, the impact of IoT in developing smart cities, autonomous vehicles, smart industries, smart homes bring seamless connectivity and advances in this revolution as shown in Fig. 1. By using open IoT standards and protocols for Infrastructure (e.g. IPv4/IPv6, 6LowPAN, RPL), Identification (e.g. EPC, uCode, URLs), Communication (e.g. LPWAN), Discovery (e.g. mDNS, DNS-SD), Data Protocols (e.g. MQTT, CoAP, AMQP, REST), Data Management (e.g. TR-069, OMA-DM), Semantic (e.g. RDF, JSON-LD) and Multi-layer Framework (e.g. IoTivity, Homekit) [4], these open standards and protocols revolve around the various multi-functional components, devices, processes and platforms supporting IoT implementation.

Agriculture is highly sophisticated due to its large dependency on natural environment. To be more specific, the area of cotton farming is also highly unpredictable due to its high dependency on climate and natural environmental conditions (e.g. temperature, humidity, rain), unpredictable events (e.g. natural disasters, animal disease, resource scarcity) and market conditions [5]. Cotton is one of the most importance plant for producing fibre. It has large application in textile industry specific to fibre production. Similarly, apart from fibre production, the use cotton seed demands heavily in oil and feed industries with its rich nutrient composition of protein (40%) and oil (24%) [6].

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It is an important export of Pakistan resulting in second most producing crop after wheat for the its agriculture sector. It is known as the silver fibre of Pakistan with its higher cultivation rates in the areas located in southern part of Punjab and Sindh [7]. Furthermore, the use of cotton seed extensively in milk production is also gain much importance which is an essential ingredient used as livestock feed.

Due to these concerned factors, there is a need to harness a modern agriculture framework compatible to integrate with high-tech sensors, automation technologies, big data analytics, cloud infrastructure, GIS/GPS support systems and Decision Support System (DSS). By considering the potential benefits and future reliability on IoT applied in smart farming, we proposed a model which support large-scale data processing and analytics, real-time data gathering from cotton crops and integrated online platform with highly customizable features. It has the capabilities to analyze and predict streams of data for efficient decision-making for farmers about the fast-reactive changes in the environment and sudden happening of unpredictable events in the field. It combines the sensory data with web services to forecast climate changes to predict the feasibility of irrigation and fertilization of the crops. In this paper, we elaborate the overall architecture of model and explain its operation together with evaluating its performance by implying real-time crop cultivation and harvesting scenarios and lastly, we open a brief discussion on the future impact and further advancement in our proposed model which could open new opportunities in modern farming industries. The multi-tech blended framework helps farmers to become aware around the environmental circumstances and mitigate the possible risk factors early to initialize effective counter-measures for protecting their agriculture assets. Furthermore, it can bring multiple benefits ranging from production to the supply of crops from the fields in to the markets. It will alleviate the high dependency on single vendor, support easier data exchange, increasing automation with less human resource required, geographical sensing and spatial data analysis for effective monitoring and response.

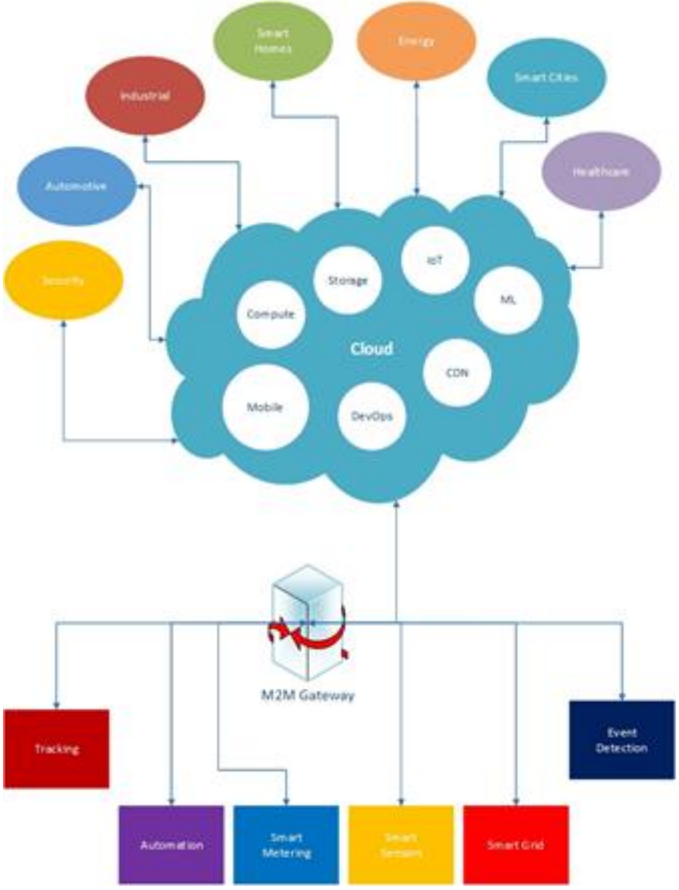

Fig. 1. IoT Network Architecture

2. INTERNET OF AGRICULTURE

The implementation of IoT into agriculture is still in its early stages. The emergence of IoT enable frameworks and platforms are also in their developing stages which shows that the maturity level of these developments is still immature [8]. IoT is being implemented in many domains such as smart homes, smart industries, smart mobility but our approach focuses only on considering IoT implementation towards smart city due to its close nexus with smart agriculture requirements e.g. urban infrastructure, network scalability, support for heterogenous streams of data, large-scale data processing, multi-actor based real-time decision support systems and services from embedded sensors. The proximity between these two domains respectively explains the relevance of smart village concept into its practical implementation provided that the supporting ideas need to be considered.

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The relevant work in IoT based smart farming as proposed in [9] shows the architecture of an information system for smart agriculture. This paper explained the idea of smart farming which has some relevance towards the concept of precision agriculture but there is no nexus stated with the implementation IoT into smart farming. Similarly, to have an interoperable ecosystem for an IoT based smart farming idea, there is a need to have a semantics of information and ontologies elaborating the relationship between the data requirements. The proposed work in [10] uses the semantic approach in web technologies to define the unpredicted conditions inside the fields and respond back to the management information system. The embedded middleware for sensors arranged in Global Sensor Network topology is attached and the sensor data from the located streams are to be translated into Resources Description Framework (RDF) on the Semantic Sensor Network (SSN) ontology. But this approach is a high-level outline of network and required a low-level approach for deeper analysis.

We can identify relevant, powerful and scalable network closer to smart cities for better performance and scalability. Similar to IBM Start City [11] which provide a real-time support for IoT data analytics for event recognition more appropriate to traffic domain. Moreover, the CityPulse [12] blend a Service Oriented Approach (SOA) along with complex processing of event for on-demand exploration and integration of data stream. Furthermore, OpenIoT [13] and IoT-A [14] provide software platform for exploring and annotating semantically all the sensor data gathered. Lastly, FIRWARE [15] provides powerful APIs for rapid application development of smart platforms in various domain of technology. The mentioned framework provides features and services to sensory data processing and analysis semantically. But they are more concerned toward urban environments designed for large city specification only.

Our proposed work is an effort to bring IoT in agriculture sector for the advancement of the concept of smart village the same way as the smart city concept were developed. Furthermore, the reusing of the existing software components as a complete interoperable, flexible and adaptable in a large-scale data analytic model for cotton farming based on semantic ontologies and IoT standards.

3. PROPOSED FRAMEWORK

The proposed data analytic platform for cotton crop is comprised of multiple levels and can integrate large amount of streaming data coming from variety of cross-domain sources and process these data in a flexible and efficient way by using open standards for data acquisition in the domain of IoT principles and semantics. These levels are classified into three broad categories namely: low-level, middle-level and top-level respectively. Each level has some digitally supported internal surfaces named as planes. Each level is equipped with these planes. The Lower level is assembled with required devices and communication planes, the middle-level have data stored and data analytic planes, lastly, the application level have cross-platform applications and end users planes respectively. There will be various components of software's performing different operations at each level. These operations include but not limited to data acquisition, data modeling, data analysis and data visualization respectively. Since there is already exist a large number of open-source software components and these components has been used in various IoT and smart city related projects [16]. Therefore, we are applying the reusability paradigm in our model to avoid reinventing the components from the beginning. Every software component is to be considered as a unique single entity supported with its own API with open connectivity which provides other devices to be easily connected with the device components showing vast interoperability in a distributed architecture.

3.1 *Components for Proposed Model*

In this proposed model, we identify major components which are essentially the foundation in stepping up the model into a working example. The following are the proposed components as below:

a. Data Wrapper: It provides a collective path to describe the sensors into various domains using meta-data information containing sensory information about streams of data for multiple sources.

b. Device Manager: It provides the management of IoT enabled devices automatically by eliminating the requirements of human workforce. It also supports with all the necessary tools for automatic processes to enforce decision in the upcoming stages.

c. Exploration Module: It implies a scalable platform for plug and play feature for the enrollment and discovery of IoT enabled devices and services in a real-time manner. These devices can be located at a remote physical location and can be accessed through remote connectivity.

d. Data Aggregation: It deals with the large volumes of data along with applying time series and data compression techniques to reduce the size of the raw sensory data sent by the data wrapper component.

e. Data Federation: The primary purpose of this component is to respond back to the user queries generated. Secondly, it will locate the relevant streams of data in complying with the requirements as requested. It further transforms the users request and translates it into RDF Stream Processing (RSP) queries. The RSP technology is an appropriate choice due to the rapid changing requirement of IoT based infrastructure for smart farming. The RDF based query processing is supported with CSPARQL[] and CQUELS [] respectively. These two RDF query languages manages to maintain the continuous flow of data streams in the infrastructure.

f. Event Recognition: It provides tools to marginalize and assemblage for processing data streams to obtain crop field events.

g. Real-time reasoning: It provides a real-time accurate, reliable, fast and optimal decision support in the context of cotton crop preference and dynamic information processing.

h. Outward Agent: It provides an interoperability with data heterogeneity, data handling and support for protocol.

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It has an insight support by considering authentication and authorization for the virtualization of objects, services, methods and processes.

3.2 Semantic Data Annotation

The semantic annotation of data streams can be optimized by using lightweight information models such as SSN [17] and OWL-S [18]. By implying these models, the streams can be easily be described which flows from sensors deployed inside the cotton fields using Stream Annotation Ontology [19] and Complex Event Ontology [20]. The agriculture related vocabularies and ontologies comprises of AGROVOC [21] and Agriculture Ontology Service (AOS) [22]. Another ontology named AgOnt which focuses on farming, agriculture terminologies and lifecycles. These are the most popular vocabularies and ontologies in agriculture related domain.

We semantically elaborate the real-time sensory data streams, its meta-data and possible event occurring on the field. The RDF Stream Processing (RSP) techniques is used to easily process heterogenous streams of data by considering semantic annotation of real-time data streams.

4. PERFROMANCE ANALYSIS

The evaluation of proposed model determines the feasibility of using RSP in agriculture application specific to smart farming for cotton crops to achieve the goal of real-time processing, analysis and event recognition. A realistic scenario was considered for the evaluation of queries performance. The actual potential of IoT is revealed from sensing data from integrated sources relevant with online services. The focus of this analysis is mostly on performance and scalability of the model for managing and analyzing large number of streams.

4.1 Scenario: Fertilization of Soil for cotton cultivation

The process of Soil fertilization is a part in cotton crop cultivation. By following various indicators present in the composition of the soil, it is possible to measure the quality and condition of the cultivating soil. The measuring indicators includes phosphorus, potassium, magnesium also known as soil composition, salinity and moisture levels. The process of soil fertilization is a result from the measurement of those parameters which are highly essential during the phases of cultivation, irrigation and fertilization for the improvement of yields.

For our analysis, we considered a soil index composed of numerous soil sensors for salinity, soil composition and moisture. It is assumed that the cultivators are implementing our proposed model and they are assuming for a relevant time for cultivation. Since there is a requirement for various queries to be initialized, there will be more aggregation and filtering function to be used in the reporting process. The query will count the data from sensors whenever there is a suitable condition for cotton cultivation. The notification is issued to the crop cultivator when the required threshold percentage of the total sensors deployed in the land by considering heterogenous edaphological terminology.

This experiment tested the queries into merged order due to the requirement of aggregation function by only considering the CSPARQL results. Since the CQELS was not able to handle queries after some time due to having a large number of sensors. Therefore, some queries become terminated due to the instability of the engine.

5. FINDINGS AND DISCUSSIONS

The proposed model shows the satisfactory performance with large data stream simultaneously. It also satisfies the performance analysis even in demanding circumstances. Similarly, providing the support for the integration of different sizes of cotton crop fields for performing real-time stream processing and reasoning in an IoT and semantic web context for efficient decision making to rapidly occurring events. The performance of CQELS is more flexible in context with query latency and memory consumption but CSPARQL is has more scalability as compared with the latter.

There are some limitations of the proposed model which include overall dynamicity, autonomy and comprehensive adaptability. The required demands for the discovery and exploration, integration and complex processing of the occurring events become optimized to provide real-time analytical solution over heterogenous data streams originating from field sensors. For future work, we will overcome these limitations focusing more on flexibility and adaptability for numerous scenarios of cotton crop cultivation. The involvement of comprehensive web technologies for integrating, processing and reasoning of data streams including management of event services will be planned for future updates. The improvement on RSP performance for parallel and concurrent queries, high stream rates and large triple window sizes by considering experimental results in this paper will also be considered. Lastly, the improvement in ontologies and semantic models relevant to agriculture for a comprehensive knowledge representation model for IoT streams and its different domains.

6. CONCLUSION

In this paper, we proposed an IoT based model applying real-time stream processing, analysis and reasoning in the domain of cotton crop using smart farming based on semantic web ontologies. It will provide the real-time results which will help the cultivator for efficient decision making on occurring event detection. We have reviewed the emergence of IoT in agriculture through smart agriculture by integration of high-speed network and combination of heterogenous technologies as well as semantic ontologies from variety of sources. Our proposed model achieves interoperability among sensors, processes, data streams, fields as entities and web-based services integrating open-data, semantic technologies and linked data. The performance analysis efforts focus on realistic scenarios indicating the good performance of the proposed model by introducing open standards and semantics based on IoT architecture.

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