# An Internet-of-Things Solution for Food Safety and Quality Control: A Pilot Project in China

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***Abstract*—Serval shaking-world food safety incidents happened in China recently shows that Chinese are facing with a serious problem of food safety, happened in China recently. Because food supplies are decentralized in many regions and agencies, it is very hard for the Chinese government to supervise these supplies' businesses. Fortunately, with the help of the technologies of the Internet of Things, the food supplies can become more transparent and safer than before. Hence, on the basis of the Internet of Things, this paper introduces a pilot project in China: the Internet of Agricultural Things (AIoT for short), which integrates state-of-the-art technologies to provide a method to easily track and trace the supply processes of foods. So that, AIoT can counter the food safety problem. In AIoT, we leverage the enhanced technologies of service oriented architecture, global identification and parsing, and electronic pedigree. Especially, AIoT may fuse the sensed data from the supply chains of fresh vegetables to show an intuitive view for users, including end customers. These fusion may help the users make decisions more easily when they are buying foods or supervising the food supplies. In addition, we deploy AIoT in several application scenarios, including Lushang Ltd., the biggest food supplier in Shangdong Province. According to the deployment and evaluation of the whole platform, the enhanced technologies for the Internet of Agricultural Things are proved to be efficient and effective in improving the safety of food supplies.**

***Index Terms*—Internet of Things, Food Safety, Service Oriented Architecture, Object Naming Service, Internet of Agricultural Things (AIoT)**

## I. Introduction

Since 2008, the food safety problem has become a hot topic in China than before [1] due to several serious food safety incidents. In 2008, the scandal of *Sanlu melamine milk powder* occurred and drew the attention of the whole world. As a result, tens of thousands of babies were affected and several even died. In 2011, the meat from Shuanghui Group, the China's largest meat supplier, was detected containing clenobuterol hydrochloride, a chemical forbidden by China in foods. One of the reasons causing those scandals is the non-transparency of food supplies. Hence, how to offer transparent even trustworthy food supplies is a significant issue for both academic and industrial communities in China.

The Internet of Things (IoT for short) may help in resolving the food safety problem because IoT can offer more agile and more convenient management of merchandise, including foods [2][3]. After integrating IoT into traditional supply chains, food suppliers can conveniently track and trace the movement of foods. As a result, the food supplies will become transparent to users, including customers and supervisors.

Although a few architectures and applications in IoT have been proposed [4][5], we still face with several practical and engineering issues about how we can leverage the technologies of IoT to protect the food safety. (1) *Architecture*: For the natural characteristics of decentralized and heterogenous food supplies, we are required to define a suitable architecture; (2) *Global coding and parsing*: Massive and diverse items in food supplies require a global identification mechanism and a high-performance parsing service; (3) *Data trustworthiness*: When sensed data transmitted from foods and their suppliers, the trustworthiness is a cornerstone to ensure the food safety, because it is easier to modify data than to counterfeit foods.

To counter the above issues, this paper introduces a pilot project in China: AIoT, whose deployment is a big boost to the development of the Internet of Things in China. The technical contributions in AIoT are as follows:

- AIoT proposes an architecture where a central application service support platform to hold the big volume data storage and handle information processing for the agriculture industry. Especially, AIoT may fuse the sensed data from the supply chains of fresh vegetables to show an intuitive view for users, including end customers. These fusion may help the users make decisions more easily when they are buying foods or supervising the supplies of foods.
- AIoT offers a global identification service and a high-performance parsing service based on the hierarchy framework of Domain Name Service (DNS for short).

We show the performance is promising to support the large scale data processing.

- AIoT provides an electronic pedigree service to enhance the data trustworthiness based on the improvement of pedigree standard. AIoT proposes six new types of pedigrees so as to meet the requirements of food supplies. With the supports of a centralized server, AIoT can help users, including end customers, effectively verify the trustworthiness, and then make the decisions of buying [6].
- AIoT supports the management of the full life cycle of foods. The full life cycle of foods include production, processing, storage, transportation, and sale. In addition, the life cycle of foods can be viewed by users via multiple terminals, including Web Browser, Smart Phone, base on the architecture and its implementation

The rest of this paper is organized as follows: Section II introduces the background of AIoT, a pilot project in China; Section III proposes the architecture and platform of AIoT, the key issues and the relevant solutions; Section IV introduces the evaluation of AIoT's concurrency performance, and the practical deployment of AIoT; Section V briefly discusses the lessons learnt from the implementation and deployment of AIoT; Section VI investigate the related work of AIoT; Section VII concludes the paper and presents our future work.

## II. Background

### A. Architecture for IoT

IoT is designed to connect different things over the networks easily. Hence, an IoT architecture is a decentralized and heterogeneous eco-system. As a key technology in integrating heterogeneous data or systems, service oriented architecture (short for SOA) can be applied to meet the requirements of IoT [2][7].

In general, the SOA architecture for IoT consists of three layers, *sensing layer*, *networking layer*, and *application layer* [8]. The *sensing layer* takes charge of the data collection and device control; The *networking layer* takes charge of the data transmission; And the *application layer* takes change of the data processing. Extended from the above architecture, some researches have proposed multiple layers SOA architectures for IoT. For example, the International Telecommunication Union suggested that IoT architecture should contain five different layers: sensing layer, accessing layer, networking layer, middleware layer, and application layer [4]. Besides, Liu et al. [9] described an architecture for IoT with four layers: physical layer, transport layer, middleware layer, and application layer.

### B. GS1 Standards and Electronic Pedigree

The GS1 system is an integrated system of global standards, which is widely used in current IoT-enabled supply chain systems. In the GS1 ONS standard [10], the GS1 system proposed Object Naming Service (ONS for short) to use the Internet's existing Domain Naming Service to obtain product information and related services from the Electronic Product Code (EPC for short), which is one of the GS1 Identification Keys. Besides EPC, the GS1 system also proposed the standards of some other GS1 Identification Keys, including `GTIN`, and `SSCC`. `GTIN` refers to Global Trade Item Number, which is allocated to an item (eg. product, service) that may be priced, or shipped in a supply chain. And `SSCC` refers to Serial Shipping Container Code, which is allocated to an item created for transport or storage in a supply chain.

EPCglobal [11], one of the global standards systems of GS1, introduced the notion of electronic pedigree into IoT as a trustworthy assurance of business data. Business data generated by suppliers are stored into electronic pedigrees. And the electronic pedigree technology makes use of signature chains as credentials to guarantee the authenticity and integrity of business data. However, the electronic pedigree standard of EPCglobal focuses on drug supplies rather than food supplies. Then, on the basis of the EPCglobal's work, Han et al. [12][13] made further research where they proposed and implemented an electronic pedigree system for food safety. The research can provide a more trustworthy tracking service in the application layer of the IoT.

## III. Proposed Architecture of AIoT

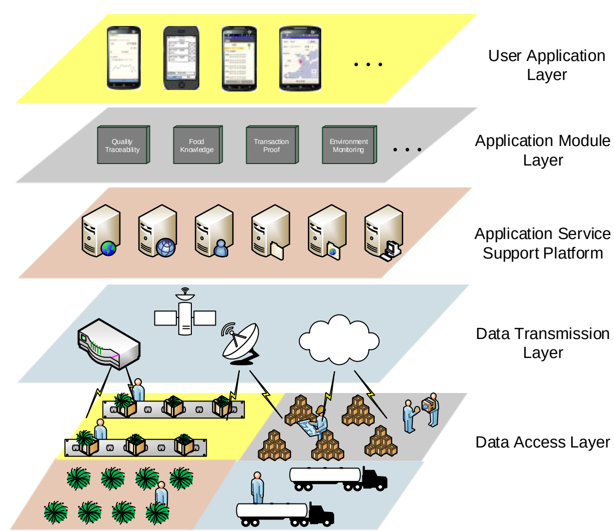


Fig. 1: Proposed Architecture of the Internet of Agricultural Things

As is shown in Figure 1, the architecture of AIoT consists of five important layers as follows:

- **Data Access Layer**: The data (such as time, place, content, farming record) in the full life cycle of agricultural products, including sensor detection data, RFID data, video recording, will be captured and pre-processed in this layer. The full life cycle of agricultural products usually contains farming period, manufacturing period, logistics period, storage period, and sale period.

- **Data Transmission Layer**: This layer transfers the data captured in the *Data Access Layer* to the servers in the *Application Service Support Platform*, making use of networking technologies including WSN, WiFi, Ethernet, even cloud access platform where the transmission abilities are abstracted from the concrete mechanism.
- **Application Service Support Platform**: The platform offers a wide range of engines and services. This platform consists of several parts, and we will introduce this layer in detail in Section III-A.
- **Application Module Layer**: The layer provides a collection of application modules. Users can select one or multiple application modules in order to meet the business requirements in agriculture. For example, users can leverage the module *Quality Traceability* to track and trace the quality of agricultural products; Users can leverage the module *Food Knowledge* to obtain the knowledge of food; Users can leverage the module *Transaction Proof* to verify the truth of a transaction; Users can leverage the module *Environment Monitoring* to monitor the environmental change.
- **User Application Layer**: The user applications are implemented with application modules for target users. The target users can be divided into four types: producers, customers, suppliers and supervisors. Each user application can be made up of multiple application modules.

### A. Design of Application Service Module Platform

In the *Application Service Module Platform*, the raw data captured from food supplies are processed and analyzed. And the platform is established in the infrastructure of existing DNS network to implement the parsing service. Figure 2 shows the design of the Application Service Module Platform.

First, the raw data, including flow data, video data, and other heterogeneous data, are processed in the module *Multivariate data computing engine*. This module takes charge of the noise filtering. As a result, many abnormal data will be removed from the raw data, before they are transmitted to the next module.

Second, the result of the module *Multivariate data computing engine* is transformed into structured agricultural data in the module *Agricultural data processing engine*.

Third, in the *Auxiliary decision-making and early warning* module, the input structured agricultural data are compared with the knowledge in the *Expert knowledge database*, which consists of the *Environmental modelbase*, the *Agricultural ideal process*, and the *Early warning and decision rules*.

Fourth, the result of the *Auxiliary decision-making and early warning* module and the structured agricultural data are transported and processed in a set of services. For example, *Electronic pedigree service* can transform the structural agricultural data to persisting static data of electronic pedigree format; *Information pushing service* can inform users of early warning message or ok message based on the result; *Statistical analysis service* can show the report of structural agricultural data to users.

TABLE I: Descriptions for the Segments in *traceability code* of Agricultural Products

| Segment | Length | Description | Connector |
|---|---|---|---|
| `GTIN` | 14 digits | Global trade item number | 01 |
| `LOT` | 1-20 digits/letters | Batch or serial number | 10 |
| `R` | 1 digit | Length of the manufacturer's identification code in `GTIN` | 91 |
| `WP` | 10 digits | Values of the weight and the money | 92 |
| `DT` | 12 digits | Data time | 93 |
| `ebID` | 5 digits | Identification code of a scale | - |

At last, the results processed by services are open to the modules in the *Application Module Layer*.

Besides, the *Comprehensive support management platform* is designed for monitoring and managing all the engines, modules, and services in the *Application Service Module Platform*.

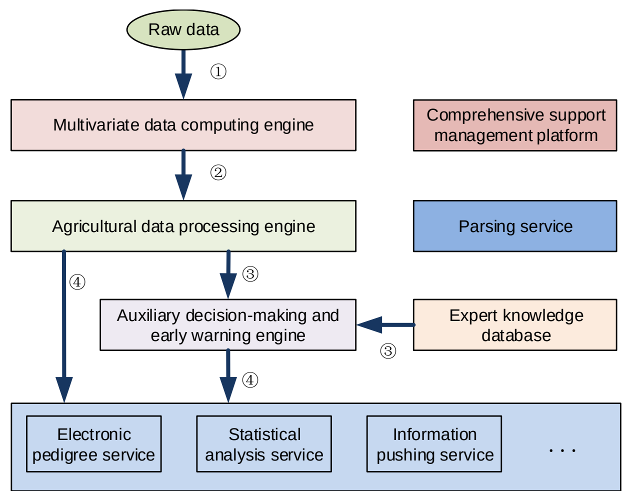


Fig. 2: Design of the Application Service Module Platform

### B. Global Coding and Parsing

In AIoT, we design two different global coding mechanisms to meet various requirements of food supplies respectively. One is *traceability code*, which can help users to track and trace agricultural products. The other is *logistics traceability code*, which can help users to track and trace shipping containers, which are used to transport agricultural products. On the basis of *traceability code* and *logistics traceability code*, we propose our parsing service.

*Traceability code*: It is compatible with the GS1 standard and is a variable length coding mechanism. Usually, *traceability code* can consist of `GTIN`, `LOT`, `R`, `WP`, `DT`, and `ebID`. Table I shows the detail descriptions for the segments in *traceability code*.

In AIoT, *traceability code* can be transformed to three models to fit in with different situations as follows:

1) Traceability code for ordinary products: The code which is allocated to identify ordinary agricultural products, consists of GTIN, LOT, and R. The code format is 01+GTIN+10+LOT+91+R. For example, 01 02320206010107 10 201304240 91 9 represents the cabbage of the Batch 201304240 generated by Lushang Ltd..
2) Traceability code for products which have weight: The code which is allocated to identify agricultural products and record their weight, consists of GTIN, LOT, R, and WP. The code format is 01+GTIN+10+LOT+91+R+92+WP. For example, 01 02320206010107 10 201304240 91 9 92 0100000400 represents the cabbage of the Batch 201304240 generated by Lushang Ltd.. And the cabbage has one kilogram and values 4 RMB.
3) Traceability code for bulk products which have weight: The code which is allocated to identify agricultural bulk products and record their weight, consists of GTIN, LOT, R, WP, DT, and ebID. The code format is 01+GTIN+10+LOT+91+R+92+WP+93+DT+ebID . For example, 01 02320206010107 10 201304240 91 9 92 0100000400 93 130424085000 00001 represents the cabbage of the Batch 201304240 generated by Lushang Ltd.. And the cabbage has one kilogram and values 4 RMB. The weight of the cabbage was calculated by the 00001 scale in 8:50 4/24/13.

*Logistics traceability code*: It is allocated to identify shipping containers of agricultural products in transportation. *Logistics traceability code* is made up of SSCC, which is defined by GS1, and R, which represents the length of the manufacturer's identification code in SSCC. The code format is shown as follows (here, 00 and 91 are the connectors of SSCC and R respectively):

$$00\ N_1N_2N_3N_4N_5N_6N_7N_8N_9N_{10}N_{11}N_{12}N_{13}N_{14}N_{15}N_{16}N_{17}N_{18}\ 91\ R$$

*Code parsing*: On the basis of the above two global code mechanisms, we propose our code parsing mechanism. In AIoT, we extend the GS1 ONS standard, and propose the parsing method in the company level. In the parsing method, simple DNS A/CNAME records are used to return the address of discovery service server so as to reduce the cost of DNS record maintenance, to accelerate the speed of parsing, and to reduce the server load.

### C. Data Trustworthiness

AIoT extends the standard [11] of EPCglobal and uses the digital signatures attached to an electronic pedigree to verify the electronic pedigree. When a supplier generates business data and creates an electronic pedigree to store the data, the supplier uses his private key to encrypt the data in the electronic pedigree and get a digital signature as the result of the encryption. The digital signature will be attached into the electronic pedigree with the data. When a user wants to verify whether the data in the electronic pedigree is true, he makes use of the relevant public key to verify the validation of the signature. If the digital signature on the electronic pedigree is verified to be true, then the data in the electronic pedigree can be trusted. Otherwise, the information could be counterfeited and untrustworthy. Note that, the management of various keys is assumed to be secure under a certificate authority. And that transmission between suppliers and the certificate authority is assumed to be secure under existing security protocols such as TLS/SSL.

Besides, AIoT offers more featured functions to handle the processes in the production and supply of foods. These functions include: The Initial Environment Pedigree and Environment Pedigree which records the monitor data of the production environment; The Transportation Pedigree which records the sensing data in food transportation and is particularly important when fresh foods are transported; The Processing Pedigree which records the transaction data when raw foods are processed; The Inspection Pedigree which records the inspection data of foods. The functions enable AIoT not only to cover more processes in food supplies than the standard of EPCglobal, but also to meet the requirements of complicated food supply chains.

Different from the contributions in [12], AIoT integrates the work into a global network of identified items based on the service oriented architecture. As a result, AIoT is the total design which includes the electronic pedigree sub-system.

## IV. Establishment and Evaluation

### A. Concurrency Performance Evaluation

For evaluating the performance of the concurrency of AIoT, we have employed several servers which have the same configurations. The configuration of servers is DELL R810, XEON E7-2803, RAM 16G, and HDD 2T. The operation system of the servers is Windows 2008 64BIT. And that database is MS SQL SERVER 2008.

We design three experiments and the experiments aim to compare the concurrency performance in different numbers of servers which have the same configuration.

- E1 experiment: The web service, the ONS/DS service, and the IS service are deployed in one server.
- E2 experiment: The web service, the ONS/DS service, and the IS service are deployed in three servers. Each service is in an isolated server.
- E3 experiment: The web service, the ONS/DS service, and the IS service are deployed in four servers. Compared with E2 experiment, one more server is added into the ONS/DS service.

We make 1,000 to 7,000 concurrent requests about the traceability of an object. The evaluation results of the concurrency experiment are shown in Figure 3.

In Figure 3, the horizontal axis represents the amount of concurrent requests in the experiment; The vertical axis means the average responding time which is spent in a single request.

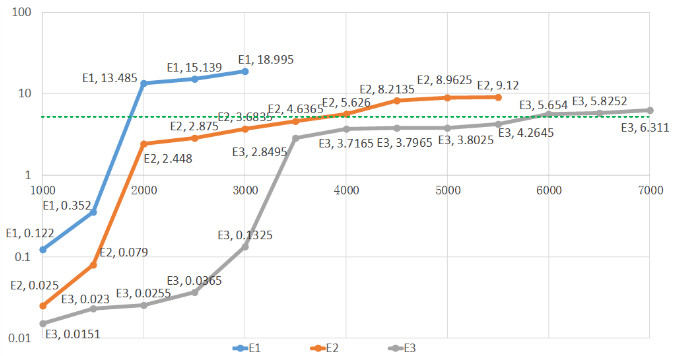


Fig. 3: Concurrency Performance Evaluation for AIoT. Three broken lines represent the results of three experiments, and the dashed line represents the upper limit of reasonable responding time.


Fig. 4: The snapshots for three implemented user applications (the left is 'Mobile traceability software', the middle is 'My crop', and the right is 'Recalling assistant'.).

In E1 experiment, the concurrent requests range from 1,000 to 3,000. In E2 experiment, the concurrent requests range from 1,000 to 5,500. In E3 experiment, the concurrent requests range from 1,000 to 7,000.

When the average time to respond a request is below 5 seconds, the system is considered to be under a reasonable server load. If the average time is over 5 seconds, then the system is overloaded. According to the results of the concurrency experiments in Figure 3, the reasonable server load in E1 experiment is lower than 2,000 requests. When three services are deployed in different servers in E2 experiment, the reasonable server load can be up to 3,500 requests. When two servers are provided for the ONS/DS service in E3 experiment, the reasonable server load can be up to 5,500 requests which increase over 57% than those in the second experiment.

### B. Platform Deployment

We have deployed an instance of AIoT in China, and the physical deployment includes five IS servers and one DS server. Besides, in order to provide a national scale parsing service, we establish our parsing service in the ROOT DNS service which is maintained by CNNIC. The domain name is *tnsroot.cn*. The detailed physical deployments of the IS servers are shown as follows:

- The IS server of Binzhou City, Shandong Province is deployed in the network center of Binzhou Technology Bureau;
- The IS server of Wuxi City, Jiangsu Province is deployed in the network center of Wuxi Institute of Fudan University;
- The IS server of Wangdian Town, Jiaxing City, Zhejiang Province is deployed in the Tongpu IDC of Shanghai Telecom;
- The IS server of Lushang Ltd., the biggest food supplier in Shangdong Province, is deployed in the Lushang network center of Jinan;
- The beef/cattle IS server of the Nei Monggol Autonomous Region is deployed in the network center of Hohhot City.

### C. Implemented User Applications

We designed and implemented some user applications to meet the requirements of several application scenarios, which are proposed by our cooperative partners, including Yijiakang Ltd. and Lushang Ltd.. Here are some designed samples[1] of the applications:

- Mobile traceability software: mobile traceability software is designed for ordinary consumers, as shown in the left of Figure 4. The software allows ordinary consumers to use their mobile devices to sense the traceability code attached to an agricultural product, and acquire the traceability data about the agricultural product.
- My crop: my crop is designed for producers, as shown in the middle of Figure 4. The software allows producers to obtain the current status and history trends of the sensors which are leveraged in the cornfield managed by the producers. Besides, the software allows producers to subscribe the exception information of sensors in order to better handle unexpected events during production.
- Recalling assistant: recalling assistant is designed for supervisors, as shown in the right of Figure 4. The software allows supervisors to quickly obtain the distribution information of the agricultural products of the same batch and connect the person in charge, when an accident of food safety happens.

## V. Discussion

With the implementation and deployment of AIoT, many kinds of foods can be monitored efficiently in the target regions. As a research project, we can obtain the following lessons, which would be useful for the further research or industrial projects.

[1]More information can be accessed through our website http://www.isafefood.cn/

- Separation business logics from technologies: In the current AIoT, business logics of agricultural products are tightly combined with the system. Thus, AIoT could not be flexible to meet the further requirements. *E.g.*, when we need to assign to different types of data to different types of business, the dissemination mechanism with authorization consideration is under designed.
- Data management for agricultural produces: The current AIoT considers little on how to manage an agricultural product which is processed. Although the proposed electronic pedigree format made some improvement, there are still data generated in the processing phases that require more attention. Furthermore, the security of data fusion in AIoT should be a serious problem. Data fusion will merge the massive data into several events or pieces of knowledge, then promote the values of AIoT, but the data veracity should be ensured. Otherwise, these events could be fabricated, and the knowledge would mislead users [6].
- Code compatibility: Although we have proposed global coding rules and a parsing service. But in China, other ministries and agencies have published several standards to encode agricultural products. Therefore, it is a hard work for our parsing service to be compatible to the current standards.
- Business data confidentiality and personal privacy protection: When the supply chains are transparent, the supply structures, including the supply points, the flow of each supply point, even the customer's buying record could be disclosed. Thus, how to protect these sensitive data may be a big challenge for the further research.

## VI. Related Work

The Internet of Things [8] is proposed as an evolution technology since 1999. IoT was developed with the sensing technology and the wireless sensor network technology (WSN for short). Sensing technology, including Radio Frequency Identification (RFID for short), and the WSN technology can help information systems to easily capture the movement and environment of target objects [14]. Thus the physical objects can connect each other via Internet connections.

Many applications have been proposed after the Internet of Things was proposed. For example, smart logistics is considered as a kind of *killer-apps*. In smart logistics, a merchandise will be equipped with a sensible tag, such as a RFID tag. When a reader detects the tag, it then will records the time, location combined with the tag's ID, and sends back to an end-server. The sensing process can effectively manage various kind of merchandises. Thus, smart logistics can be applied to many scenarios in the real world, such as food safety [3][12][12]. In addition, patients [15] can also be considered as extensions of smart logistics.

As is shown in Table II, many researches, which are led by governments around the world, are focusing on the food safety problem. Liu *et al.* [16] attempted to use the characteristic of cattle to verify the geographical origin of beef, but their solution has a big limitation that the characteristic they found in cattle cannot work in other food. Feng *et al.* [17] developed a RFID-based cattle traceability system which can reach real-time traceability management along cattle/beef production flow, but they did not solve the inefficiency of data input and communication mechanism with a RFID reader. Besides, Supply-chain Pedigree Interactive Dynamic Explore (SPIDER) [18] was developed to verify, inspect and investigate the pedigree of food. In order to automate the tasks including water quality monitoring and daily business flow for aquaculture, a traceability system of aquaculture integrated with Wireless Sensor Network was proposed in literature [19]. Segregation and identity preservation systems are proposed for the separation of genetically modified and non-modified products from *farm-to-fork* [20]. Koutsoumanis *et al.* [21] took advantage of actual risk evaluation at important points of the chill chain to develop a safety monitoring and assurance system for chilled food products. Schroeder *et al.* [22] analyzed the traceability systems of major exporters for beef industry in the world, and reminded the United States of the importance of a widely adopted effective animal ID and traceability system. Liu *et al.* [23] presents the vulnerabilities of the modern supply chains supporting a public query interface.

As an important project funded by the Ministry of Science and Technology of the People's Republic of China, *Internet of Agricultural Things* was started up in 2011. Over six universities and institutes in China are involved. As is highlighted in Table II, AIoT proposed in the project of *Internet of Agricultural Things* can offer full features for large-scale food supplies.

Compared with the above solutions, our AIoT in this paper differs in the following aspects:

1) The current standard of electronic pedigree technology is extended in AIoT to enhance the trustworthiness protection of data in food supplies.
2) With the help of DNS network, a global identification and parsing service is offered by AIoT to track and trace agricultural products.
3) A large and scalable service oriented architecture is designed for AIoT to meet the requirements of decentralized nature of food supplies in the real world.

## VII. Conclusion and Future Work

This paper introduces a pilot project in China: AIoT, which aims to leverage the technologies of the Internet of Things to ensure the food safety. AIoT is featured to provide a global identification service, a scalable service oriented architecture, and the trusted data assurance by the extension of electronic pedigree. As a result, AIoT can help users, including customers, supervisors, and suppliers, to easily monitor and manage supplied foods.

In our future work, it is very important to deploy AIoT in more application scenarios. In addition, although the data trustworthiness can be ensured by the extension of the electronic pedigree technology, the data generated in a supply chain can

TABLE II: Related Projects and Their Features

| Project | Nation/Region | Sponsor | Start Year | Features |
|---|---|---|---|---|
| *Internet of Agricultural Things* | *China* | *Ministry of Science and Technology of the People's Republic of China* | *2011* | *Full life cycle management for food supply; Global identification and parsing; Large and scalable service oriented architecture; Trusted data assurance based on the extension of electronic pedigree.* |
| Modeling Method for Tracing the Safety of Agricultural Food | China | National Science Foundation of China | 2007 | A model of traceability information acquisition and transmission; A set of RFID-based cattle/beef traceability system (RCBTS); Real-time and accurate data collection and transmission. |
| Traceability System For Aquaculture | China | Tianjin S&T Extension Project | 2009 | Automating many tasks including water quality monitoring and daily business flow; A cross-communication information flow between the manager, the worker and the consumer. |
| Supply-chain Pedigree Interactive Dynamic Explore | Hong Kong | Hong Kong Polytechnic University | 2012 | Supply-chain Pedigree Interactive Dynamic Explore (SPIDER); Monitoring each process of the food chain in real time; Case-based Reasoning, Rule-based Reasoning, Fuzzy logical and Neural Network. |
| International cattle ID and traceability | America | US Meat Export Federation (USMEF) | 2012 | A standard for cattle identification and traceability. |

be viewed by everyone in our platform, which might be the biggest obstacle to deploy AIoT to more application scenarios. Thus, it is another point of our future work to ensure the confidentiality of the data generated in a supply chain.

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