On The Creation of Automatic Identification and Data Capture Infrastructure via RFID

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Automatic identification data capture technologies are becoming increasingly important in the management of supply chain, manufacturing flow management, mobile asset tracking, inventory management, warehousing, and any application where physical items move through location in time. Tracking these items has historically been done by the use of bar-code technologies, which suffer from lack of efficiency, robustness, difficulty in automation, inability to have secure or dynamic data, etc., whereas the electronic technology of Radio Frequency Identification or RFID has the ability to overcome several of these limitations over barcode. This paper presents a comparative basis for the creation of Automatic Identification and Data Capture (AIDC) infrastructure via RFID versus other technologies such as bar-code and sensor technologies.

1 Introduction

As the communication and computational technologies have started to become commonplace within enterprise operations, the computer-aided/managed Enterprise Information Systems (EIS) such as Enterprise Resource Planning (ERP) [1], Supply Chain Management (SCM) [2] [3], Product Lifecycle Management (PLM) [4] [5], Customer Relationship Management (CRM) [6] [7], Manufacturing Execution System (MES) [8], Warehouse Management System (WMS) [9], and Enterprise Asset Management (EAM) [10] etc are significantly improving the enterprise operational efficiency and reducing the operational cost [11]. The EIS processes information such as history, current status, location, relationships, and, destination of enterprise resources such as materials, equipments, personnel, cash, etc.
the stock level of products at various stages within a supply chain can significantly affect the operations of supply chain. Optimum stock levels result in requiring less storage space, faster processing, quicker cash flow, better customer satisfaction and sale, etc. The stock level can be monitored and predicted by tracking the movement of the on-shelf products, or the incoming shipments. As the real-time stock levels are identified, decisions such as replenish or reorder can be made timely and correctly. This is called visibility and predictability in the enterprise information system.

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To achieve visibility and predictability of the movement of these business objects, the information associated with the object, which is called identification data in this research, should be identified and monitored along the enterprise operation flows. The identification data should automatically be captured and integrated into the different enterprise process applications in real-time. Usually, the identification data capture process and the integration of the identification data with enterprise application are performed by the Automatic Identification and Data Capture (AIDC) technologies. The identification data associated with a particular business object (such as raw material, products, equipments, shipments, and personnel etc.) is collected by the data capture devices at each processing location where the business object is processed. Barcode is the most commonly used identification data capture technology in today's enterprise operations. However, traditional bar-coding approach can not achieve the real-time visibility because of the low speed of reading, the needs of line-of-sight, and unavoidable involvement of humans. The more advanced AIDC technology of Radio Frequency Identification (RFID) is becoming the promising technology to achieve real-time visibility of enterprise operations. It has several obvious advantages such as non-line-of-sight reading, high-speed reading, multiple reading and writing simultaneously, minimal human intervention etc. that make it close to ideal for providing real-time visibility of enterprise operations.

2 Identification Automation Technologies

Barcode, Radio Frequency Identification (RFID), Sensor, Magnetic Strip, IC card, Optic Character Recognition (OCR), Voice Recognition, Fingerprint and Optical Strip etc [12] are identification technologies that have been used in the enterprise environment. Among these identification technologies, barcode is the most widely used technology. The RFID and sensor hold a promise of significantly improving business operational efficiencies and increasing the visibility of the business objects. The other technologies are either lack of automation capability or lack of ability to attach to business objects. Thus, we do not categorize them as the automatic identification technology for enterprise application. Barcode, RFID and sensor technologies are addressed and discussed in this paper.

2.1 Barcode Technology

2.1.1 History

The first barcode was developed by Bernard Silver and Norman Joseph Woodland in the late 1940's and early 1950's [13]. It was a "bull's eye" symbol that consisted of a series of concentric circles. The first commercial use of barcodes was by the RCA/Kroger system installed in Cincinnati on the call of the National Association of Food Chains (NAFC). However it was not widely used until the Universal Product Code (UPC) [14] was introduced into America and adopted by the U.S. Supermarket Ad Hoc Committee. Today's barcodes have two forms: one dimensional (1D) barcode and two dimensional (2D) barcode. The 1D barcodes use bars and gaps to encode identification information such as serial numbers. The 2D barcodes consist of more complicated patterns and may encode up to 4K bytes of data. Figure 1 shows the two types of barcodes. Although 1D is the more prevalent barcode used in daily life, the 2D barcode is becoming increasingly popular since it needs significantly lower surface area to encode the same amount of data as compared to 1D barcodes.

Barcodes can be printed from most printers. 1D barcodes usually have coded readable ID printed along with the barcode. Barcodes can be read by barcode scanners which we see at a typical Point of Sale (POS) in retail stores.

1D Barcode 2D Barcode

Fig. 1 Two different types of barcodes

Figure 2 illustrates a basic barcode system. Barcodes are read or scanned by a barcode reader and the reader is connected to a computer. The operator has to physically align/point the barcode reader with/to the barcode to read the identification information. The software running on the computer processes the identification information picked up by the scanner. Programmable Logic Controller (PLC) is usually used to control the scanner in more automated process such as production line. The primary scanning technology for barcode is LED (Light-Emitting Diode). More advanced scanning such as CCD (Charge-Coupled Device), Laser, and Imager are used in industry automatic processing [37].

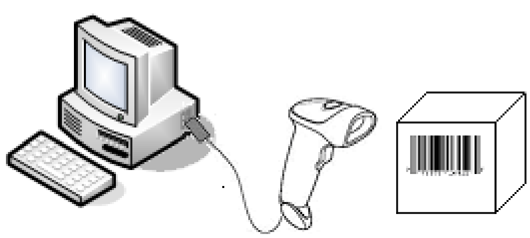


Fig. 2 A basic barcode system

2.1.2 Symbology

The coding scheme that barcodes use to encode data is called symbology [15]. A symbology defines how to encode and decode the barcode data. Some symbologies can encode numbers only and others can encode both numbers and alpha letters. Each symbology normally is designed for certain applications but it could extend beyond that. A 1D barcode usually contains only an identification number while a 2D barcode may contain customized data. Table 1.1 shows commonly used symbologies and their applications [15].

Table 1.1 Commonly used barcode symbologies

Symbology		Notes	Applications
1D	CODE39	Letters, digits, and a few special characters	Processing Industry, Logistics, Library, Manufacturing, Military and DOD, Healthcare
	CODE93	Can encode all 128 ASCII characters. It’s the enhancement of CODE39	Same as CODE39
	CODE128	Beside the 128 ASCII characters, it can encode four special function codes	Shipping, Logistic
	EAN/UCC 128	Similar to CODE128	Shipping, Logistic
	CODABAR	It can encode characters: 0123456789-$:/.+ABCD, ABCD are start and stop characters	Library, Blood Bank, Air Parcel Business, Medical/Clinical Applications
	CODE 2 of 5	Digits only, high density. Includes three variants: Standard, Interleaved and Industrial.	Automotive Industry, Good Storage, Shipping, Heavy Industry
	UPC A and UPC E	Digits only, UPC A is 12 digits and UPC E is 7 digits	Retail, Consumer Products
	EAN13 and EAN8	The Europe version of UPC	Retail, Consumer Products
	RSS	Latest barcode symbology. It is used for space constrained identification. It has different variants and could be composted with other symbologies.	Use only for necessary
2D	PDF417	High density 2D barcode can store up to 2725 characters	Shipping, Defense, Automotive
	DATA	High density can store up to	Defense, Automotive,

	MATRIX	3116 characters	
	MAXICODE	A fixed size matrix has up to 93 al Alphanumeric or 138 number characters. Supports high speed scan and orientation independent	Shipping
	AZTEC CODE	High density 2D barcode can encode up to 3750 characters.	Retail, Assets, Consumer Products

2.1.3 The Advantages and Disadvantages of Barcode

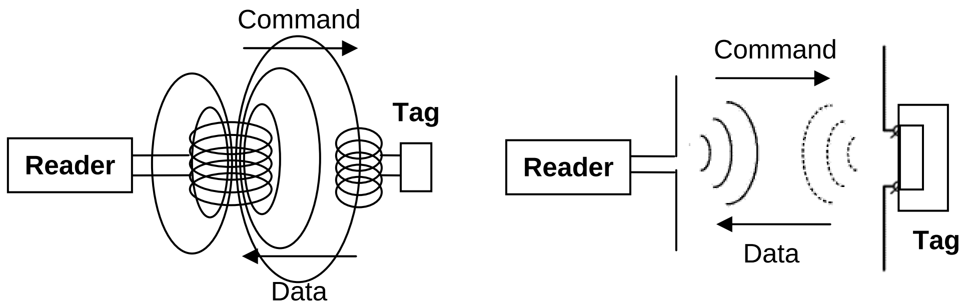
Compared to manual data entry, the barcode is fast and accurate. The barcode can be printed from any black/white printer. Since the barcode can be directly printed on an object or on paper label, the cost for a barcode is typically less than 1 cent [22]. Even after including the hardware cost, the barcode data collection system reduces the operation cost, labor cost, and the revenue loss caused by data entry errors, while improving the business process and productivity [23]. However, several weaknesses exist. Firstly, barcode label is easy to be damaged in harsh environments such as careless handling, external factors such as rain/low temperatures. Second, to read the barcode, the barcode scanner needs to be line of sight with the label. It means that the manual movement of the objects or scanner is necessary. Thirdly, barcode technology does not have ability of scanning object inside a container or a case. Thus, the operator has to open the container and scan the objects one by one, thereby involving intensive labor. Obviously, the barcode is incapable of fast processing.

2.2 RFID Technologies

2.2.1 History

The use of Radio Frequency Identification (RFID) can be traced back to World War II. A transmitter that can return proper response to an interrogator was attached to an ally’s aircraft to identify friendly aircraft from enemy aircraft. From the 1960’s to1980’s, RFID had been used in fields such as hazardous material processing and livestock-tracking [16]. During the gulf war, the RFID technology was successfully used for transporting military goods to the battlefield. A new generation of RFID surged when the retail giant, Wal-Mart, mandated its major suppliers to ship their goods to the Wal-Mart distribution center with RFID tags enabled. Similar mandates have originated from the Department of Defense (DoD) and other retailers such as Target, Metro, Albertson’s, etc. Besides the retail chain, the RFID technology is broadening to other industries including Healthcare, Manufacturing, Life Science, Transportation and Logistics, Banking, and others. Moreover, RFID is moving trading partners toward cross enterprise collaboration.

2.2.2 Existing RFID technologies



(a) Inductive Coupling (b) Backscatter Coupling

Fig. 3 RFID coupling and operation

RFID technologies can be classified into three categories: Passive RFID, Active RFID and Semi-Passive RFID [17]. Based on the radio frequency used, the Passive RFID technologies are usually categorized into Low Frequency (LF) RFID, High Frequency (HF) RFID, Ultra High Frequency (UHF) RFID, and Microwave RFID. The essential components of RFID hardware are:

(i) RFID tag. It is a tiny silicon chip attached with small antenna.

(ii) Reader Antenna. It is used to radiate energy and capture energy send back from tag. It could be integrated with the reader or connected to the reader by cable.

(iii) Reader. It is the device which talks with tags. A reader may support one or more antennas.

The passive RFID tag powers up and exchanges commands/responses by gathering energy from RF transmitted from the reader antenna in the means of inductive coupling (LF and HF) or backscatter coupling (UHF). Figure 3a illustrates the inductive coupling and Figure 3b illustrates the backscatter coupling. The inductive coupling uses the magnetic field while the backscatter coupling uses electromagnetic waves to exchange data between the reader and the tag [17]. Figure 4 shows a list form factors of RFID tags, antennas and readers.

Fig. 4 RFID hardware form factors

Table 1.2 lists the properties of passive RFID technologies. The sense (reading and writing) range of RFID technology depends on the antenna size of both, tag and reader, the power level of the radio wave, sensitivity of tag and reader, tagged object, and environment. Frequencies and power used by UHF RFID technologies are regulated. They are different form region [38]. For example, the allowed frequency is 902-928 MHz in USA while the allowed frequency in Europe is 865.6-867.6 MHz. The power levels in each region are also different. For example, 2 W ERP (Effective Radiated Power) is allowed in Europe while 4W EIRP (Equivalent Isolated Radiated Power) is allowed in USA.

Table 1.2 Passive RFID technologies

	LF	HF	UHF	Microwave
Frequency	Typically 125 or 134.2Khz	Typically 13.56Mhz	Typically 868Mhz – 928Mhz	2.45Ghz and 5.8Ghz
Reading/Writing data rate	Slower	Moderate	Fast	Faster
Ability to read/write multiple tags in field	No tag will be read if multiple tag present	Can read/write moderate dense tags	Ability to read/write high-dense tags	Similar to UHF
Approximate range	Up to ~1 meter	Up to ~1.2 meter	Up to ~6 meters	Up to ~2 meter
Limitations (Can not work on)	Metal	Metal	Metal, Liquid	Metal, Liquid
Applications	Animal Tracking, Access Control,	Smart Card, Access Control, Item Level Tagging (Supply	Pallet and Case Tagging (Supply Chain). Item Level Tagging is	Similar to UHF.

	Vehicle Immobilization	Chain, Asset Tracking, Library Application, Pharmacy Application, Personnel Identification etc)	working in progress.	

An active RFID tag uses on-board battery to support reader-tag communication. Currently, there is lack of standard on active RFID technology. Most active RFID technologies are proprietary. Typical active RFID operates at 333Mhz or 433 MHz. Wi-Fi based active RFID works at 2.4GHz. Compared to passive RFID, the active RFID usually has a longer reading and writing range (up to several hundreds meters), bigger data storage space (up to a few megabytes) and faster reading and writing speed. The active RFID operations are less affected by environmental factors. Thus, active RFID is widely being used for tracking and locating large objects such as containers and trucks. It could also be good for tracking livestock.

Like the active tag, the semi-passive (semi-active) tag also contains a battery. However, the battery is usually used to assist in collecting environmental parameters such as temperature or humidity. The communication between the reader and tag still uses the RF energy transferred from the reader. It has the same characteristic as passive RFID.

2.2.3 A Basic RFID System

A combination of RFID technology and computing technology that brings value to a business or engineering process is called an RFID system. The simplest RFID system contains tags, an RFID reader, and a host computer as shown in Figure 5:

- Tag: Depending on its final form factor, the tag can be categorized into labels, transponders and inlays as shown in Figure 6. To simplify the description, the term “Tag” is being used to represent all three types of tags. The tag is attached to an object.
- Reader: A Reader has one or more antennae that are either external or internal. The interfaces that connect the reader with the host computer are one or more of the following: RS232, RS485, USB, Ethernet, Wi-Fi, PCMCIA, and CompactFlash etc. The reader reads the data id of a tag through the antenna. The data is then sent to the host computer for further processing. Traditional RFID reader only has the function of capturing data.
- Host computer. Host computer controls the reader behavior and dispatch the data captured by the reader to right application.

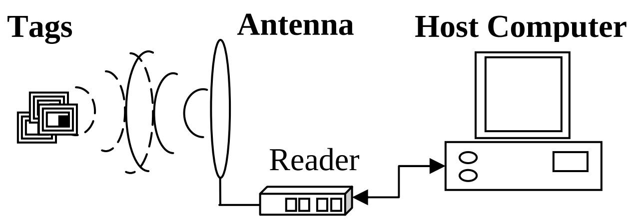


Fig. 5 A basic RFID system

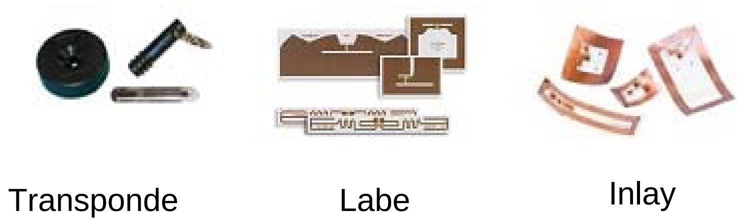


Fig. 6 Tags

2.2.4 Standards

To achieve interoperability of RFID device and exchangeability of RFID information, various standards or protocols are proposed for different applications [18]. These standards include hardware physics specification, tag-reader air interface specification, reader-host command specification, reader network standards, and data formats.

ISO18000 series of standards define RFID air interface operations which include physical layer electronic characteristics and data link layer for data communication. ISO18000 contains seven parts: Part 1 defines general parameters; Part 2 specifies the parameters for frequency under 125KHz (LF); Part 3 specifies parameters for 13.56Mhz (HF); Part 3 and Part 4 work on 2.45GHz and 5.8GHz, respectively; Part 6 works on frequency between 860MHz-930MHz (UHF); and Part 7 works on 433MHz (Used for active RFID). Besides the ISO 18000 series of standards, ISO 14443 and ISO 15693 define the air interface and communication protocols for proximity system and vicinity card. ISO14223 defines the air interface for identification of animals in agricultural applications.

Along with the air interface definitions, there are additional standards for rectifying the processes of tagging, packaging, data coding, and other special applications. For example, ISO15961-15963 series define the concept, data syntax, business process, and information exchange for item level management; ISO17363-17368 define the different types of packaging processes for the logistic and supply chain. ISO11784 and ISO11785 define the code structure and application concept for animal identification. For each RFID technology, there is a conformance test standard to guide its use and test.

The Electronic Product Code (EPC) [19] was originally developed by the Auto ID Center at the Massachusetts Institute of Technology (MIT). In 2003, the Auto ID Center licensed the EPC technologies to EPCglobal, a joint venture between European Article Number (EAN) International and the Uniform Code Council, Inc. Since then, EPCglobal has taken the mission of standardizing and developing hardware physics, communication protocols, the EPC network infrastructure specifications, the supported software specifications, and data formats.

EPCglobal defines the EPC classes according to the functional characteristics. The classes are [26]:

- Class 0: “Read Only” passive tags. The ID is programmed by the manufacturer
- Class 1: “Write-Once, Read-Many” passive tags. The ID is programmed by the user and locked to prevent re-write
- Class 1 Generation 2 (Gen 2): An updated version of the generation 1. It supports more secure operations and contains optional user memory
- Class 2: Multiple Read/Write passive tags. It contains user memory that allows updating and encrypting.
- Class 3: Multiple Read/Write semi-passive tags with user memory
- Class 4: Active tags
- Class 5: Readers

The information exchange of the EPC-complaint application is based on the data structure or coding scheme defined in the EPC standards. The first generation of the EPC coding scheme is quite simple. The 96 bits or 64 bits of RFID tag number has been divided into four segments which include: Header, EPC Manager, Object Class, and Serial Number. However, this scheme can not represent the current global trading business related identification numbers. The latest EPC coding scheme supports more coding that is being used in current global trading business. These coding schemes include: Serialized Global Trade Identification Number (SGTIN), Serial Shipping Container Code (SSCC), Serilized Global Location Number (GLN), Global Returnable Asset Identifier (GRAI), Global Individual Asset Identifier (GIAI) and General Identifier (GID). The identification coding scheme for the U.S. Department of Defense (DOD) are also supported in the EPCglobal EPC tag standard document [35]. The EPC Gen 2 air interface protocol for UHF communication has been proved as ISO 18000-6C [36].

2.2.5 Advantages and Disadvantages

Compared with other identification technologies, RFID has the following advantages.

(i) High reading speed, multiple reading and writing simultaneously - Depending upon the technology being used, the reading speed of RFID can be up to 1000 tags/second [19]. Higher reading speed leads to higher throughput in the system. For example, in a high speed sorting system, the throughput could be improved significantly by improving the speed of identifying an item, which could be the bottleneck of the system. Inventory management would be improved by using

RFID because the item-by-item manual checking may be substituted with an automated method.

(ii) The RFID technology does not need to be line-of-sight. For example, when shipping a container with RFID tags installed on products within the container, it is not necessary to open the container and read the tagged items one by one since the readers can typically read tag data through or around blocking materials.

(iii) The data carried by an RFID tag is re-writable. The memory storage ranges from several bytes to few mega bytes. With the user memory, the business information carried by the tag can be changed during at any point of process dynamically. More data can be carried on the tag itself so that the tightly-coupled back end database may not be required, which is not the case in traditional AIDC approach

(iv) RFID has longer reading/writing range compare to barcode and most other identification technologies. The sensing range of RFID tags varies from a few centimeters to hundreds of meters [17].

(v) Security checks could be added into RFID tags to prevent unauthorized reading and writing. Frighten of the disclosure of privacy slows down the practice of many advance technologies. The RFID is unexceptionally one of them. Fortunately, more sophisticated authentication, encryption algorithm is being implemented in the RFID tags and readers. By adding such security check function into the implementation, RFID is becoming the dependable technology to prevent ID theft and counterfeiting. On the contrary, its close counterpart – barcode does not have such capability.

(vi) The combination of RFID and Sensor technology could bring more value to enterprise applications. For example, during the food transportation, it is important that the temperature of the food be monitored and/or controlled. Normally the temperature is set on the refrigeration device. In a large container, the temperature may vary at different points within the containers especially when large numbers of items are being transported. An RFID tag combined with a temperature sensor could locate and monitor the status of each individual item precisely.

Therefore, RFID is more effective when faster processing, longer read range, flexible data carrying capability and more secure transactions are required. Some of the widely acknowledged benefits of RFID are that it could

(i) improve warehouse and distribution productivity,
(ii) improve retail and point-of-sale productivity,
(iii) reduce out-of-stock and shrinkage, and
(iv) help prevent the insertion of counterfeit products into supply chains, etc. [24]

However, despite these obvious advantages, there exist some disadvantages as follows:

(i) A major drawback of RFID is its cost. The current price for each UHF tag is still costly. The RFID industry is trying hard to reduce the manufacturing cost. Within a few years, the industry hopes to reduce the cost to about 3 cents per tag for UHF tags. 5-cent RFID tag is already available today [27].

(ii) Reading and writing reliability are largely affected by the material of the tagged object and its surrounding environment. For example, it is difficult to read a UHF RFID tag surrounded by liquid or metal. By studying the physics and doing experiments, we observed that by proper place or encapsulate the RFID tag, the reading performance is improved [28]. New methodologies are being developed to overcome the challenges faced by environmental factors. For example, new UHF tag and reader based on Near Field Communication (NFC) developed by Impinj demonstrates that NFC UHF RFID tag can be read even when the tag is in liquid [31]. Various tag encapsulation methods and RF technologies are being researched to improve the performance of RFID. We believe that these problems will be solved by technological advancements in this field.

2.3 Sensor Technologies

The sensor is a device that can measure and collect environmental parameters (such as temperature, humidity, chemicals, vibration, density, etc.) or system runtime parameters (such as position, location, speed, acceleration, etc.) [20]. Sensors have been used in a variety of applications, especially for automation and control in industries such as aerospace, automotive, healthcare, environment, transportation, etc. As the smallest unit of an automation system, a single sensor could be used for fulfilling certain functions. But in most cases, a sensor system consists of a large number of sensors normally that must work together to achieve awareness of the physical world.

Recently, new technologies including wireless sensors, MEMS sensors, smart sensors, bio sensors, etc., have changed the type of sensors that can be made. Sensors made today with advanced techniques are smaller and can measure and collect information that is beyond the capability of traditional sensors. New sensor system infrastructures such as sensor network [21] with wireless connection capability are gradually replacing the traditional wire-connected sensors.

In an enterprise environment, sensor technologies combined with ID technologies would significantly improve the enterprise resource visibility and thus improve the enterprise operation efficiency. For example, along the supply chain flow, a GPS sensor could help the enterprise system track and monitor the location of the raw material at real times [39]. A better decision on the related enterprise operations could then be made based on information of not only on the location of an asset, but also its condition, and potentially the condition of the asset could itself alter where the asset was being sent next (example if ice-cream being shipped sees high temperatures, then perhaps it may be disposed instead of continuing to be shipped to the final destination).

3 AIDC Infrastructure

The advantages identification technologies can potentially improve the enterprise operation efficiency and reduce the operation cost. However, simply deploying data capturing devices, assigning identification data to the business object, and capturing the data from the business object can not bring the value to enterprise operations. A set of software components which assist the devices management, identification data preparing, capturing, formatting, and associating with physical objects are required. The software components and devices together are called identification resources. Further, these identification resources are networked and collaborated with each other to form the AIDC infrastructure.

3.1 Definitions and Components

The Automatic Identification Data Capture (AIDC) infrastructure is defined as a set of networked devices and software components which include:

- Devices. Devices include various identification technologies such as RFID reader, RFID printer, barcode scanner, sensors, and Programmable Logic Controller (PLC) etc.
- Services. Services are software components that enabling the data preparation, capturing, and processing.

Essential components of an AIDC infrastructure are identified [33] [34] and illustrated in Figure 7. It contains the following components:

- Barcodes, Tags, and Sensors: barcodes, tags and sensors are the smallest units that are attached to an enterprise entity or resource to be identified.
- Device Controller or Edge Server: A device controller is used to manage and control identification hardware (Readers, Scanners, Sensors and other Manageable Devices), aggregate, pre-process and cache the identification information. It is difficult to manage a device in a planer space. Putting all the functions such as capture, process, and representation of identification data into a single server could increase the burden of the server. Hierarchical, layered and distributed architecture is an effective way to balance the load and deliver the best overall performance. Using the Edge Servers, the devices can be clustered and distributed. Functional roles can be separated so that the Edge Servers could be dedicated to the data capture requirements, where the core/central servers can be used for data intelligence.
- Identification Network: The identification network is the infrastructure that connects all the hardware resources and enterprise information systems together.
- Enterprise Information Servers: Enterprise information server provides enterprise activities related data which can be used along with the identification information for business operations. It provides real-time, aggregated identification data and events to client applications. As discussed earlier, the identification data capture process may contain business events. The Enterprise Information System provides interfaces so that the application can define, register and look up events. It also provides interfaces that the end application can register and lookup production information, business information, and transaction information that is associated with a particular identification data.
- Enterprise Application: Enterprise applications are functional modules that fulfill certain enterprise activities. For example, a Warehouse Management System uses the data captured by the Edge Server to monitoring the inventory level; an Asset Management System uses the data to look up a particular asset; etc.

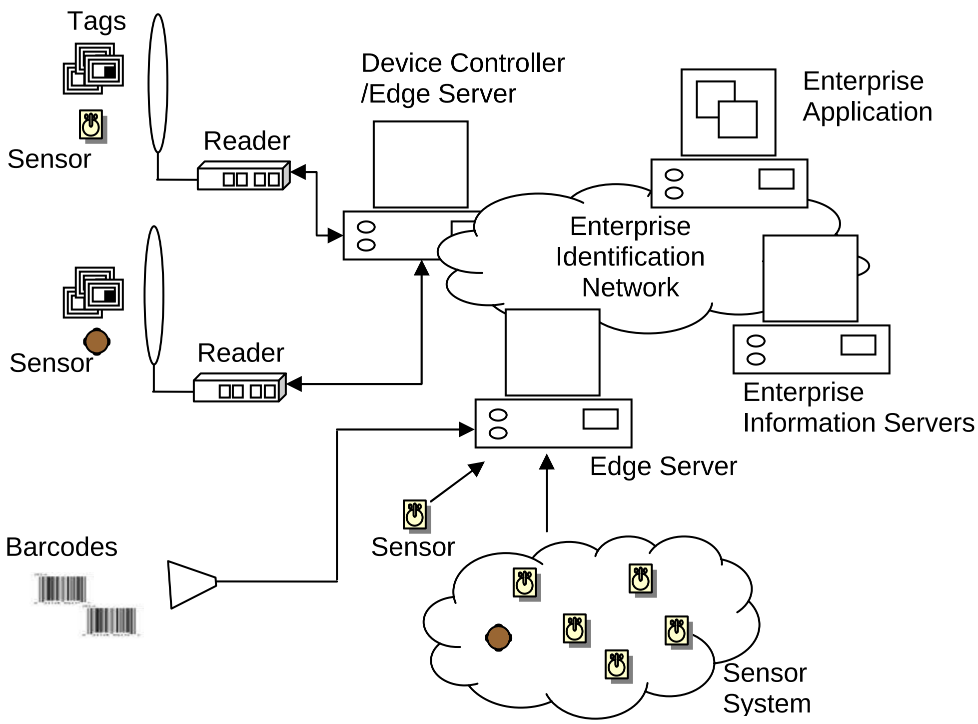


Fig. 7 The AIDC infrastructure

Identification data carried by barcodes, RFID tags and sensors is collected by a data capturing devices and passed on to the edge servers or device controllers. It is processed at the edge server before being sent into the network. The components are not standalone – they are networked with other components. They can exchange information with each other. For example, the identification data captured by one edge server can be used as the reference to generate an event by next edge server. If the number of IDs on a same pallet has been read differently by different edge servers, an event indicating that there is a missing product would be generated.

3.2 Challenges of Creating RFID Oriented AIDC Infrastructure

As advanced AIDC technologies such as RFID are introduced, the challenges of creating AIDC infrastructure are presents. The challenges are:

(i) The performance of data capture and processing. High volume of data is required to be captured and processed at high speed. Firstly, RFID system reads data 10-100 times faster than traditional Barcode scanning [22]. Secondly, the ability to read at much larger distances and in larger region volumes around the reader result in greater volumes of data generated due to larger numbers of tags in the read-range of a reader. For example, if a carton has 100 tagged items. An RFID reader is able to read all the items less than one second because the UHF RFID reader has ability to reads up to 1000 reads/second [19]. Thus, it is important that the AIDC infrastructure has ability to capture such high volume data and send the data to the end application rapidly. Providing real-time, accurate, and consistent data is the key of a streamlined enterprise operation. If the data is not accurate or out of date, the decision that is made based on the data would be wrong and costly to the enterprise. For example, consider the case of a supply chain in which the data captured during the transportation of goods can not be sent to the ordering system timely. To control the inventory at a given level, the ordering system may request another order to fulfill the inventory control and this may result in duplicate orders.

(ii) The manageability and extensibility of heterogeneous devices. Co-existing of various identification devices makes the devices extremely difficult to manage, deploy and configure. The diversity of RFID technologies (various standards, different frequency, utilizing passive technology and active technology) increases the difficulty of managing the data capturing devices. How to effectively manage devices and how to adopt new devices without significantly modify the AIDC infrastructure needs to be researched.

(iii) Scalability and performance of the AIDC infrastructure. As the high volume data is being captured by the data capturing devices at high speed, how to ensure that the performance of the system would not degrade dramatically as the AIDC infrastructure growing. For example, seven terabyte data generated by the Wal-Mart RFID trial every day is reported [40]. How to handle such high volume data in an AIDC infrastructure is challenging.

(iv) Discoverability and availability of resources. In a large scale enterprise environment, various services may be deployed in a logically and geometrically distributed environment. The client needs to find the right resource and obtain useful data from it. Either using the on-demand request (pull) or the real-time event (push) approach to provide the data and resource, the identification resources should be available and consumable to the client at any time.

(v) The integration of various identification resources with the diverse EIS. The tasks of an AIDC infrastructure are not just to capture identification data. It acts a bridge which flawlessly connects all EIS together. However, the diversity of the data formats, especially when customized data involves, increase the complexity of the data processing for the end application. The identification data should be associated with physical object or business transaction so that it can be used in the EIS system.

4 Summary

A variety of identification technologies have been used in the enterprise systems to improve the enterprise operation efficiency and reduce the overall operation cost. Barcodes, RFID, and sensors are the most commonly used and important technologies that have been addressed. Because of its low cost, today, the barcode is the major identification technology used by most enterprises. The emerging RFID technology brings significant new opportunities as well as challenges to the AIDC infrastructure. The combination of RFID and sensor technology brings additional value to the enterprise operations. For example, by combining the temperature sensor and RFID tag, the reader obtains the environment temperature of the tagged object. This is useful in cold chain, where the temperature of the transporting object has to be monitored and controlled precisely. Although the RFID technology still has limitations such as tag readability, due to physical constraints enterprises are increasingly using RFID to assist their business operation because of the advantages it brings.

Because of the emerging RFID technology and the diversity of identification devices, challenges exist as implementing an AIDC infrastructure. The challenges are: The performance of data capture and processing; the manageability and extensibility of heterogeneous devices; scalability and performance of the AIDC infrastructure; Discoverability and availability of resources; the integration of various identification resources with the diverse EIS. The extensibility, scalability, resources usability and discoverability, RFID system performance, device manageability, and system integration ability of AIDC infrastructure are important topics of current AIDC research.

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