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An Intelligent RFID-based Electronic Anti-Counterfeit System (InRECS) for the Manufacturing Industry

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Abstract: Radio Frequency Identification (RFID) is a potent technology that manufacturing enterprises can deploy to enhance supply chain management, inventory control and asset management effectiveness. However, counterfeit prevention is seldom addressed in these RFID applications. The quality image of reputable manufacturers is vulnerable to the damage caused by the expanding flow of counterfeit products in today's global market. To combat the counterfeit problem, this paper proposes an Intelligent RFID-based Electronic Anti-Counterfeit System (InRECS) that will deliver accurate and global supply chain visibility with intelligent feedback into inventory and materials transfer processes. A case study will also be presented to highlight the benefits the proposed system can bring to the supply chain participants.

1. INTRODUCTION

Radio Frequency Identification (RFID) technology has emerged in recent years as the enabling technology of various applications related to supply chain management. For instance, Wal-Mart, the world's largest retailer, announced in June 2003 its plan to employ RFID technology to smoothen its logistics and supply chain processes (Fanberg, 2004; Glabman, 2004). While the potentials of RFID have captured widespread attention across many industries through glowing endorsements of the mainstream press (Pescovitz, 2003; Farber, 2004), the adoption of RFID technology is still an exploratory undertaking. It is considered the next revolution in manufacturing industry. Manufacturing is a dedicated and complicated system which comprises many parts and components in which every component must be in good condition to ensure that the product will meet safety and regulatory requirements. In other words, a seemingly minor malfunction or defective part may lead to serious consequences. To address such issues, current research typically focuses on employing RFID to improve supply chain management (Liu *et al.*, 2006), inventory control (Jarugumilli and Grasman, 2007) and asset management effectiveness (Brewer *et al.*, 2004) as the means to improving product quality.

Manufacturing enterprises face tough competition in an increasingly globalized market with increased regulatory scrutiny and requirements in recent years. To survive, they need to deliver safe products with the right parts in the right place at the right time. Harrison (1992) summarized the concept as 'meet demand instantaneously, with perfect quality and no waste'. To exploit the cost advantage offered by overseas suppliers, many manufacturing enterprises currently source parts from abroad. However, the full benefits of outsourcing cannot be realized if counterfeiting is not under control. According to Carbon (2007), the problem of counterfeit parts is getting worse as more manufacturing and sourcing has moved into low-cost Asian countries; 10 per cent of all car parts sold are counterfeits which is equated to a loss of USD12 billion every year (Mathur, 2005). On the other hand, the quality image of reputable manufacturers is vulnerable to the damage caused by the expanding flow of counterfeit products in today's global market. Thus, manufacturing enterprises have a pressing need for a solution to the counterfeit problem.

In response to the globalization of counterfeiting, a new data sharing approach - an electronic pedigree (ePedigree) - is advocated to provide full supply chain visibility with detailed trace-and-track information in electronic format (Bacheldor, 2006). So far, publications on the topic of employing RFID and ePedigree to deliver accurate and global supply chain visibility with intelligent feedback into inventory and materials transfer processes are rare. An Intelligent RFID-based Electronic Anti-Counterfeit System (InRECS) is proposed in this paper to meet this challenge.

The rest of this paper is organized as follows: Section 2 reviews the RFID and ePedigree technology. The system architecture of the proposed system is presented in Section 3. The case study in Section 4 serves to illustrate the feasibility of system adoption. The conclusion is drawn in Section 5.

2. RFID AND EPEDIGREE

RFID is a wireless data collection technology that uses radio signals for identifying objects, delivering dynamic asset supply chain contents and visualizing the entire asset life-cycle. It has been widely adopted in several applications like animal behavior analysis (Ting *et al.*, 2007) and patient location visualization (Kwok *et al.*, 2007). Moreover, integrating the RFID and Electronic Product Code (EPC) technologies creates an "Internet of things" that enables automatic information acquisition and effective information sharing in a supply chain (ITU, 2005). Theoretically, every tagged item on earth can be tracked.

EPC is a collection of interrelated standards for hardware, software, and data interfaces, together with core services operated by the EPCglobal (EPCglobal Inc., 2005). EPCglobal is an organization for promoting worldwide adoption and standardization of EPC technology which is a coding scheme for RFID tags. In other words, EPCglobal has standardized the EPC number stored in individual RFID tags. To check the authenticity of manufactured items, enterprises can simply validate the EPC number from the EPCglobal network. Typically, RFID-based anti-counterfeit measures are widely adopted in the pharmaceutical industry. According to the Food and Drug Administration (FDA) of the US Government, RFID technology, coupled with the EPC and electronic pedigree (ePedigree) are key elements in a multi-layered approach to combat the growing problem of counterfeit drugs that jeopardizes patient safety in the United States (Clara, 2004). By leveraging the EPCglobal network, ePedigree serves as a means for bundling all the EPC events together in a secure and auditable manner and adding up to the audit trail of product movement from source to point of use, thereby ensuring the authenticity of a product (for example, it may raise an alert that the item took four weeks to move from one location to another which normally takes only two days to do so).

This paper presents an attempt to apply the ePedigree technology to strengthen anti-counterfeit measures in the manufacturing industry. Apart from elaborating the use of the proposed system to combat counterfeiting, this paper also discusses the unification of a case-based reasoning algorithm and data mining techniques in a proactive approach to enhance effectiveness of anti-counterfeiting investigations. A case study in a garment manufacturing company will also be presented to illustrate the feasibility of the proposed system.

3. SYSTEM ARCHITECTURE OF INTELLIGENT RFID-BASED ELECTRONIC ANTI-COUNTERFEIT SYSTEM (InRECS)

Figure 1 shows the 4-tier system architecture of InRECS. The system is structured to separate the major activities of the system applications into logical sections of: display (Presentation Tier), processing logic (Inference Tier), data services (Persistence Tier), and provision of industry-driven standards (Global Network Tier).

3.1 Presentation Tier

The Presentation Tier is so designed that users can easily communicate with the system via the software and hardware layer that are compatible with Extensible Markup Language (XML) and the Internet, such as Personnel Digital Assistants (PDA), smart phones, personal computers and special terminals (e.g. kiosks). With the user-friendly and easy-to-use graphical user interface, even casual users can query the system effortlessly by scanning the item's RFID tag which is embedded with the item's unique identification number (e.g. EPC). A user's enquiry initiates processes in the other tiers of the system.

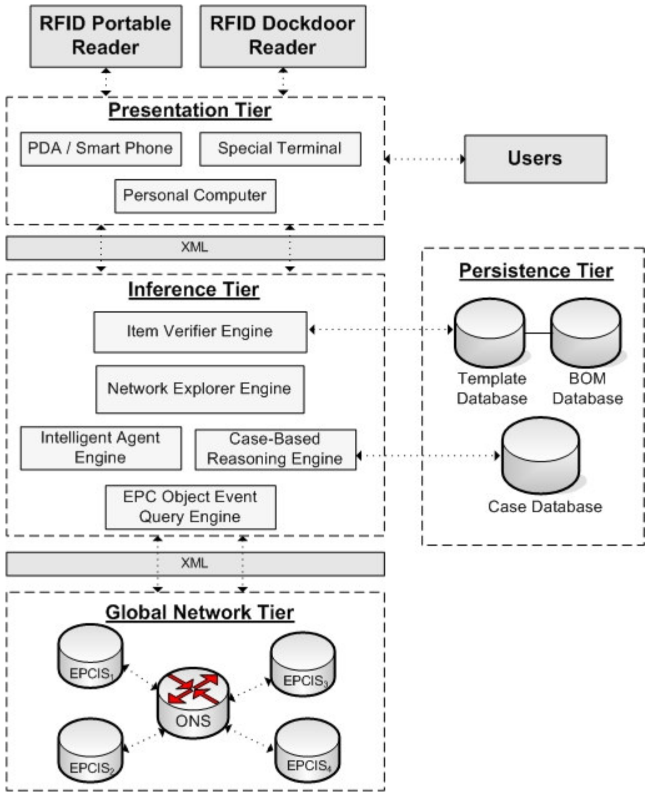


Fig. 1. System Architecture of InRECS

3.2 Inference Tier

The Inference Tier is the brain of the whole system since most of the work is performed here. Table 1 lists the main functions of the core engines embedded in this tier.

3.3 Persistence Tier

The Persistence Tier maintains all the information of the Inference Tier in the system databases. Users can retrieve specified data from the system databases and turn it into useful information. In order to help the user to gain access to a wide variety of data in an investigation, two databases, namely the Template Database and the Case Database, are used. The Template Database stores all the items' pre-defined flows for detecting irregular activities, while the Case Database gathers all the identified irregular cases to enable trend analysis and to inform decisions on precautionary actions. Furthermore, a Bill of Material (BOM) Database is maintained with information obtained from the Template Database to identify the parts (in terms of EPC number) needed to complete a specified end product.

3.4 Global Network Tier

Figure 2 illustrates the interactions between the major components in the EPC-based Global Network Tier for the exchange of information about items. The two types of main components in the network are described below.

Table 1. Functions of the Core Engines in the Inference Tier

Core Engine	Main Function
EPC Object Event Query Engine	To provide services for other engines to query the specified EPC's object events from the EPCglobal Network
Network Explorer Engine	To explore, explode and integrate related object events from the EPC Object Event Query Engine
Item Verifier Engine	To verify the item's pedigree by comparing the captured EPC information with the data in the Template database and the BOM database
Case-based Reasoning (CBR) Engine	To store all the problematic cases from the Item Verifier Engine; and to acquire similar cases and send them to the Data Mining Engine
Intelligent Agent Engine	To provide users with services to investigate suspected items

EPC Information Services (EPCIS). The EPCIS is the primary vehicle for data exchange between supply chain parties in the EPC network. It functions as the data repository that provides standardized interfaces for handling queries and returning results, and it is also responsible for authenticating the parties involved in the data exchange to ensure security.

Object Naming Service (ONS). Similar to the mechanism for locating resources in the Internet by domain name service (DNS), the ONS server returns a list of network addresses and redirects queries to different parties containing the actual data associated with a given EPC.

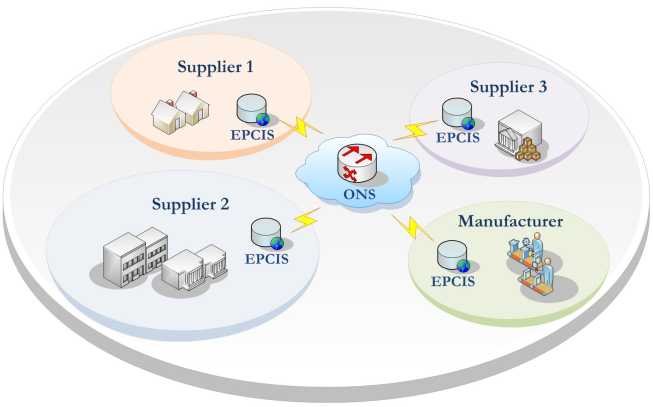


Fig. 2. Architecture of the EPC-based Global Network

3.5 ePedigree

Since the logistics flows taken by an item may vary from one supplier to another, a reliable and secure data collection process is required. InRECS is offers a solution that operates with a high degree of security. Figure 3 depicts integration of the ePedigree approach with InRECS. By encrypting and locking the data that moves from one party to another in the entire supply chain (until reaching the final point of use), only authorized partners can unlock and decrypt the data, providing restricted access to such data. As a result, such a universal pedigree approach can accommodate all items manufacturing enterprises receive, which may come from or pass through any supplier.

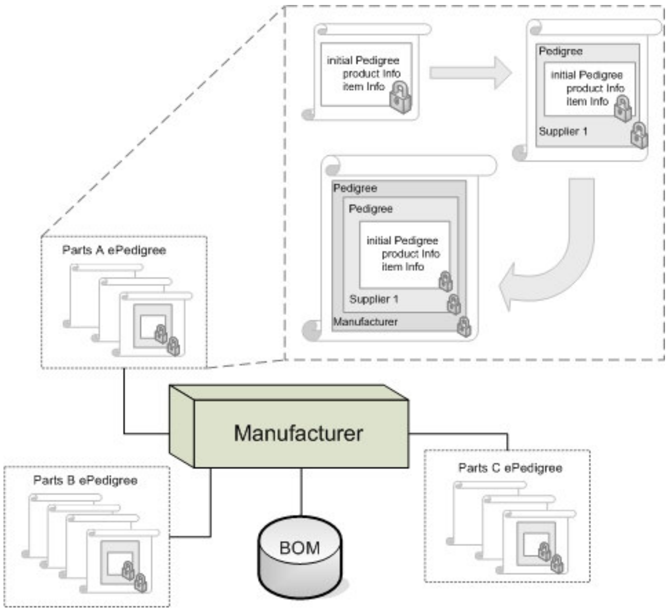


Fig. 3. Integration of ePedigree approach with InRECS

3.6 Proactive Anti-counterfeit Measure by Case-based Reasoning Algorithm

InRECS retrieves real time object events from the EPCglobal Network to present a proactive anti-counterfeit measures to the enterprises. A case-based retrieval technique is then applied to analyze and identify pedigrees to detect irregular logistics flow. In order to find out the degree of similarity (of cases), nearest-neighbour retrieval (NNR) technique is used to compute the stored cases and new input case based on weight features as shown in (1).

$$similarity(Case^I, Case^R) = \frac{\sum_{i=1}^{n} w_i \times sim(f_i^I, f_i^R)}{\sum_{i=1}^{n} w_i} \qquad (1)$$

where w_i = importance weighting of the a feature

sim = similarity function of features (e.g. source characteristics, time)

f_i^I, f_i^R = values for feature i in the input and retrieved cases, respectively (e.g. summation of all interval time between each parties)

To support case-based reasoning, all the cases with their characteristics and features are stored in the Case Database for case retrieval (i.e., pedigree matching) purposes. The importance of each feature used for case ranking is assigned by human experts. In the context of a manufacturing company, the features will include type of product, delivery time, means of transport, duration of stay in each supply chain party, relationships with each supply chain party and paths of the logistics flow. Upon identifying all these specifications, the case retrieval (i.e. NNR) technique is applied. Figure 5 depicts the process flow of the case-based reasoning algorithm. First, the scope of investigation (such as type of product, location, and time) is defined. The use of a filtering system with pre-set rules helps to reduce the amount of process data to be analyzed. This way, all the irrelevant cases are removed. The similarity index of each filtered case is computed using equation (1) to identify all the similar cases stored in the Case Database. Cases are retrieved by comparing a collection of weighted features in the scope of investigation to cases stored in the Case Database. If the degree of similarity - $similarity(Case^I, Case^R)$ (in the range of 0 to 1) of a case is high (such as over 90% similar), it is classifed as a high risk item (i.e., it is very likely to be a counterfeit part). On detection of such cases, InRECS will automatically generate a message to alert the user.

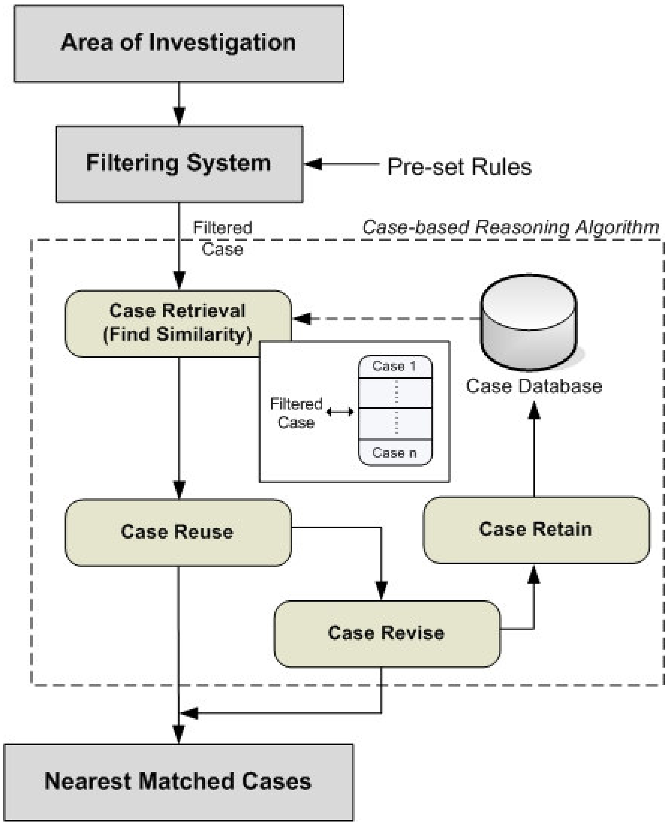


Fig. 5. Process Flow of the Case-based Reasoning Algorithm

4. A CASE STUDY

In order to assess the feasibility of the proposed approach, a practical example is taken from. To enhance its competitive advantage (i.e., to achieve high productivity at low cost) in the market, an aircraft maintenance engineering company in Hong Kong needs to source materials globally. Sometimes, counterfeit components are received from the global suppliers. InRECS was developed to help the company to address the anti-counterfeit issue.

Figure 6 shows the captured screen of the ePedigree Verifier which is a function for item verification. With the help of BOM information and ePedigree chains, users can effortlessly view the actual and pre-defined pedigree of items in the supply chain. While the pre-defined ePedigree is the proper path of the item flow, the actual ePedigree is the path in the supply chain through which the item passed and it is captured by the EPCglobal network. As a result, any problem (i.e., anomalies in the logistics flow) will be highlighted in different colors and indicated in the message box located in the top right hand corner of the display.

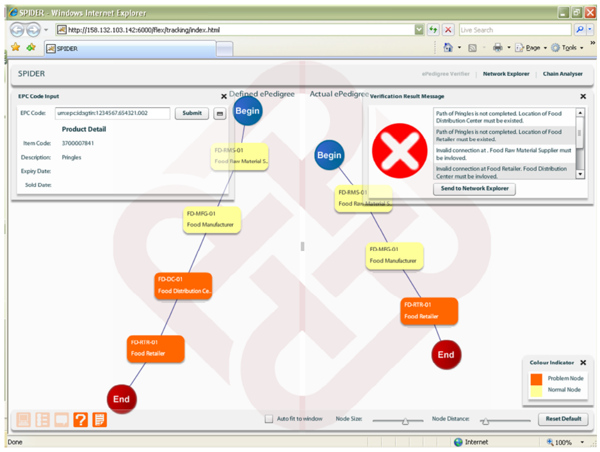
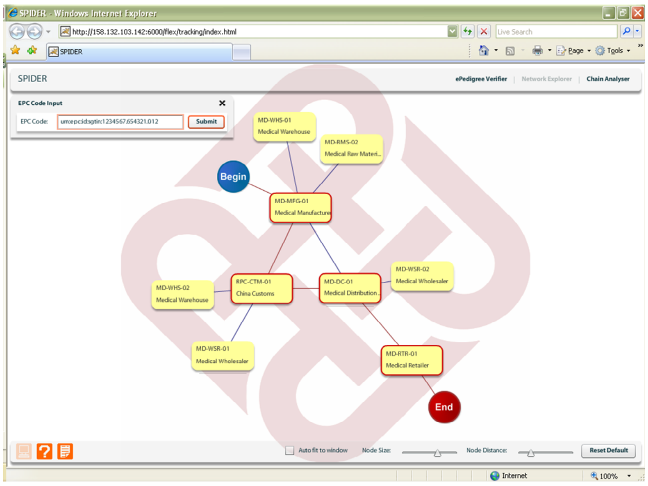


Fig. 6. A Captured Screen of the ePedigree Verifier

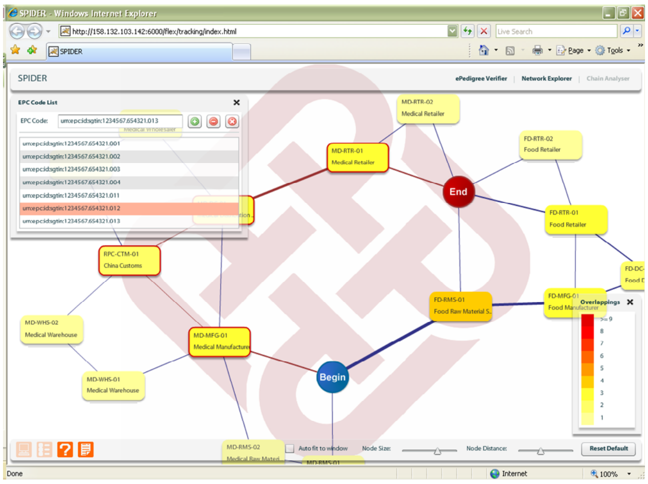
InRECS provides an interactive toolkit with rich media for enterprises to better monitor and analyze the logistics flows of items in their supply chain network. Figure 7 is a captured screen of the inspection toolkit that supports functions such as Network Explorer (Figure 7a) and Chain Analyzer (Figure 7b). The Network Explorer is used for detailed study of the path taken by a particular item in the supply chain. It identifies the parties that supplied the rogue items and the source (such as manufacturer) that produced them. Whereas the Chain Analyzer is a tool for aggregating multi-ePedigree diagrams into a single diagram to inspect the flow of an item in the supply chain. This way, the source of rogue (counterfeit) items can be located with relative ease.

For an aircraft maintenance engineering company, it is important to ensure that the aircraft parts are not changed during the process (i.e., the RFID tag cannot be easily removed and attached to another part). This can be achieved by printing the serial number of the aircraft part on the RFID tag which is permanently attached to the part. The tag will be killed once it is removed from the part.

InRECS can enrich, enliven and add capabilities to traditional anti-counterfeit approaches by leveraging the potentials of RFID and EPCglobal Network. Two of the major benefits of implementing InRECS as demonstrated in the case study organization are:



(a)



(b)

Fig. 7. Captured Screens of (a) Network Explorer, and (b) Chain Analyzer

(i) Effectiveness of detecting rogue parts is enhanced
By using InRECS, manufacturing enterprises can detect rogue parts with a high degree of confidence. Furthermore, inspectors can review the comprehensive information presented by the system's visualization tools to locate the source (i.e., from where the parts came) and study the route taken by the rogue parts on the fly.

(ii) Continuous tracking of products to assure quality
Normally, tightened inspection is triggered by customer complaints. This is too reactive. The artificial intelligence (AI) capability embedded in InRECS enables automatic detection of irregularities in the logistic flow of items in a complex supply chain network to prevent rogue items from reaching the customer.

5. CONCLUSIONS

An effective anti-counterfeit approach is essential to enable a manufacturing company to succeed in assuring quality of the parts and components used in its products, as well as to minimize the risk and costs of product recalls. Formulating a good anti-counterfeit approach used to be a challenge to manufacturing enterprises as they often do not have the needed information available in a timely manner from trusted sources. This paper presents an intelligent system, incorporating CBR and data mining techniques with RFID technologies, that can be used by manufacturing enterprises to combat counterfeiting in supply chains with multiple materials/parts suppliers. In addition, the proactive approach facilitated by the proposed system would demonstrate the enterprise's commitment to continuous improvement on quality of its manufacturing services. In conclusion, by visualizing accurate and global parts supply chain information, manufacturing enterprises can detect transactions involving counterfeit parts, investigate irregularities in transactions, and locate the source of rogue items cost effectively. All these will contribute to enhancing customer satisfaction.

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