RFID Technology: A Review of its Applications

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Abstract—**Radio Frequency Identification (RFID) facilitates automatic identification of items using radio-waves. This technology albeit initially introduced in the 1940s and 1950s, has seen a drastic increase in the number of applications and implementations in the recent years. This work aims to review some of the current developments in this field and to develop a taxonomic framework to classify literature which will facilitate quick content analysis and identify future direction of research.**

Keywords: RFID, framework, organizational challenges, applications

1 Introduction

Radio Frequency Identification (RFID) originated during World War - II [44] when it was imperative to determine whether combatants were "friend or foe". In essence, the system facilitates automatic identification through a combination of *tags* and *readers*. Today, RFID system have been successfully applied to the areas of manufacturing, supply chain, agriculture, transportation, healthcare, and services to name a few. Research in this area has been growing at a rapid pace as is evidenced by the number of articles published in the past couple years.

This work aims to provide a review of the current developments in this field and to develop a taxonomic framework to classify literature which will facilitate quick content analysis and identify future direction of research. Section 2 looks into the basic concepts involved. Section 3 discusses the proposed framework for categorizing literature in the realm of RFID. Section 4 presents the conclusions and possible directions of future work.

2 Background

RFID technology consists of a combination of *tags* and *readers*. The tags store and transmit data to readers using radio waves. The readers garner data from the different tags and relay them back to the server for further analysis and processing. The system serves the purposes [44] of *identification*, *monitoring*, *authentication* and *alerting* through this exchange of data between the tag and the reader. The process is automatic and both the tag and the reader do not need to be in plain sight. In other words, the RFID system facilitates remote and automatic identification. To improve the security tags and readers have a *challenge-response* mechanism [58] which works much like the security question that many websites have the users complete in order to authenticate the user.

Cronin [20] compares RFID with its predecessor technology viz. barcodes. Barcodes require that the barcode and scanner are in direct line of sight for them to be scanned and the items have to be physically moved against the scanner for data collection. RFID tags, on the other hand, automatically transmit data to the reader even without a line of sight. Singh et al. [61] provides a brief overview of the RFID technology and also the recent advances towards standardization of the system. The authors also describe some of the recent applications in the field of apparel, and fresh produce. Ngai et al. [51] summarize the research findings in this area from 1995 up to 2005. Alani et al. [2] summarize the various aspects involved in a RFID system and their classification schemes.

3 Research Framework

In this framework, the existing literature has been categorized into conceptual areas and application. The conceptual areas include *organization*, *privacy and security*, and *technology*. Applications have been categorized into 3 areas viz. *supply chain*, *production*, and *others*. The focus of this work was to identify potential areas for research in the area of manufacturing and supply chain management and hence all other applications have been combined into a single category for purposes of the framework. Table 1 summarizes the findings of this work.

3.1 Organization

Implementing RFID requires a system-wide reorganization and significant infrastructural changes. Attaran [7] identifies the challenges that companies face as they embark upon the journey of implementing a RFID-based system. These include lack of expertise, resistance to change, lack of top management support and lack of system integration. Battini et al. [9] suggest that many companies fail at a successful implementation of RFID systems due to inconsistent and diverse information and the lack of supporting tools. The authors propose a methodological framework for implementing such systems. Chowdhury et al. [18] identify reduction in the

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Table 1: Framework for literature in RFID

Organization	Privacy and Security	Technology
Alani et al. [2], Anagnostopoulos et al. [5], Attaran [7], Battini et al. [9], Chowdhury and D'Souza [18], Floerkemeier and Fleisch [22], Huang and Tang [31, 32], Leimeister et al. [45], Singh et al. [61], Tzeng et al. [68]	Hossain and Prybutok [27], Langheinrich [44], Piramuthu et al. [53], Ryu and Takagi [58], Spiekermann [62], Spiekermann and Evdokimov [63]	Carbunar et al. [13], Catarinucci et al. [14], Chen et al. [16], Thoroe et al. [65]
Applications		
Supply Chain	**Production**	**Others**
Abad et al. [1], Amador et al. [4], Bottani and Rizzi [10], Gandino et al. [23], Geng et al. [24], Hsu et al. [28], Jedermann et al. [34], Kim et al. [39], Kovavisaruch et al. [43], Martinez-Sala et al. [48], Mourtzis et al. [50], Reiners et al. [55], Sawyer [59], Shanahan et al. [60], Torrent and Caldas [66], Wang et al. [69], Yan et al. [71]	Bottani et al. [11], de Kok et al. [21], Guo et al. [26], Hua et al. [30], Liu and Chen [47], Rekik et al. [56, 57], Szmerekovsky and Zhang [64], Xianwen et al. [70], Zhou et al. [72], Zhou [73]	Ali and Hassanein [3], Anonymous [6], Brandl et al. [12], Chattaraj et al. [15], Chen et al. [16], Chen [17], Conneely [19], Gueaieb and Miah [25], Hu et al. [29], Idris et al. [33], Jeong et al. [35], Kathawala and Tueck [36], Khan et al. [37], Kim and Chong [40], Kim et al. [41], Ko [42], Lin et al. [46], Oztaysi et al. [52], Rahman et al. [54], Tu et al. [67]

incidence of errors, improved asset management, and reduction in time lost to locate resources as some of the benefits of implementing RFID in the health-care industry. However, the authors conclude that this also poses a unique set of challenges too. Kim et al. [38] propose a cost of ownership model that computes expected profit from RFID-related infrastructure investment based on various parameters to help with the decision-making.

Floerkemeier et al. [22] look into the challenges and issues involved in integration of RFID systems with the existing systems. The authors contend that proliferation of RFID applications and the abundance of reader technology has compounded the problem of integration. Achilleas et al. [5] propose a lightweight middleware for collecting and filtering data in RFID systems that is programmable thus making it easily customizable which facilitates easier implementation of RFID systems. Huang et al. [31, 32] also conclude that implementation of RFID systems has its pitfalls and propose a business strategy for implementing such a system organization-wide. Leimeister et al. [45] state that although the reasons for implementing RFID system might differ based on cultural differences, companies in general are in favor of implementing RFID systems. The authors base their conclusion on the survey of Chief Information Officers (CIO) from Germany and Italy.

It is also imperative to analyze if RFID systems will be beneficial before jumping onto the bandwagon of implementers. Tzeng et al. [68] propose a framework to evaluate the business value involved in implementing RFID-based systems thus enabling companies to determine its economic viability before embarking upon the implementation. Rekik et al. [56] propose an analytical model to determine when it is cost effective to implement RFID tags in order to improve inventory accuracies in a retail store. The authors conclude that if the error is minimal and can be estimated, implementing RFID does not yield benefits. However, authors conclude that RFID does help in controlling errors due to theft. de Kok et al. [21] carry out a break-even analysis to determine when it is cost effective to implement RFID tags to control pilferage. The authors conclude that this depends on the cost of the item being pilfered, extend of pilferage, and decrease in pilferage after implementing RFID-based control system.

3.2 Technology

Besides the organizational challenges, researchers have also focused on making technological improvements to the RFID system. Carbunar et al. [13] categorize the inaccuracies in the system into three main groups viz. tag detection, tag coverage and reader collision. The authors propose algorithms to handle these issues which improves the performance and accuracy of the system. Catarinucci et al. [14] develop a cost-effective general-purpose RFID tag that can be connected to generic sensors and can be read by standard readers. Chen et al. [16] develop a dual-function metallic RFID tag with barcodes for use

in the steel industry. These tags prove cost effective and improve readability. Thoroe et al. [65] look into the environmental implications of replacing barcodes with RFID tags.

3.3 Privacy and Security

With the plethora of RFID applications prevalent today, it is imperative to analyze the factors that influence the acceptance or rejection of a new technology. Muazzem et al. [27] apply the Technology Acceptance Model (TAM) concept to RFID technology and determine that the ease of use works in favor of its acceptance. However, the issues of security and privacy act as deterrents to the increased acceptance. Piramuthu et al. [53] investigate the vulnerabilities in the existing authentication protocols used for communication between the tag and the reader and propose modifications that secure the data from unauthorized access.

Langheinrich et al. [44] look into the various challenges involved in protecting the privacy and maintaining security for adopters of RFID technology. The authors state that due to the low computational powers available within the tags, the system to prevent tampering with data to protect privacy must be simple. The authors also suggest that it is important to prevent unauthorized readers from accessing tag data. It is also imperative to continuously change the authentication process. The authors classify the methods to protect privacy and improve security based on the above requirements into two main categories viz. *hiding and blocking* and *encrypting and rewriting*.

Ryu et al. [58] combine the challenge-response mechanism with a *one-time pad* system which improves the efficiency of the process of authentication. Spiekermann et al. [62, 63] analyze 218 papers found on the Gildas Avoine's [8] repository of research papers in the area of privacy and security related to RFID systems. The authors identify five different schemes prevalent in the literature. One scheme involves "killing" the RFID tag such that it does not transmit any information once it leaves the point of sale. Another scheme uses the popular *challenge-response* system or *on-tag* scheme we have already seen earlier. The communication between the tag and the reader can also be off-loaded to an external agent with customizable privacy preferences that serves as a "privacy guardian". This scheme is also known as *off-tag* scheme.

3.4 Supply Chain Applications

Although RFID systems have been around since WW-II, implementations specific for supply chain management are a recent development. Bottani et al. [10] conclude, based on survey and analysis of fast moving consumer goods (FMCG) companies with 3-tier supply chain with a manufacturer, distributors and retailers, that a pallet-level identification using RFID tags is beneficial to all parties. Kim et al. [39] propose a RFID-based location identification system to facilitate easy and quick localization of vehicles on a shipping yard of a automotive assembly plant. This improves the delivery performance through better informed decision-making. Cost of tires is a significant portion of the operating expenses incurred by a cargo transportation company after fuel costs. Kovavisaruch et al. [43] look at using a RFID system for effective tire management with the objective of reducing operating costs.

Mourtzis et al. [50] utilize an Internet-based communication system enhanced with real-time information from RFID sensors to determine the availability of parts at any of its suppliers for an automotive plant that provides highly customizable products. Sawyer [59] develops a web-based information system that provides real-time data about the progress of construction and the exact location of its components for a design-building team engaged in construction of a football stadium. Each component used in the project is assigned unique ID using RFID tags the data from which is integrated into the web-based system.

Wang et al. [69] reduce the inventory holding costs and improve the inventory turnover at a LCD manufacturing company by using a RFID-based system for automatic replenishment of inventory in its supply chain. RFID systems have also found applications in the agri-food sector especially with fresh-produce [4, 23, 34, 48] and meat processing [1, 24, 28, 55, 60, 71] companies.

3.5 Production Applications

Production and manufacturing also stands to reap benefits from this technology in terms of improving throughputs, reducing lead times and reducing inventory holding costs [56, 57, 64, 73]. Liu et al. [47] employ RFID to improve production efficiencies in a integrate circuit packaging house. The RFID system when integrated with the Enterprise Resource Planning (ERP) software allows the company to keep track of each of its wafers as it travels through the packing process.

Zhou et al. [72] develop a RFID-based manufacturing data tracking system that facilitates rapid data collection on a real-time basis in a manufacturing plant. Xianwen et al. [70] develop a real-time management system for containers using RFID and electronic data interchange (EDI) thus reducing data entry times and improving container utilizations. Bottani et al.[11] show through analytical models that a RFID-based system does have the potential to reduce losses due to unavailability of fast moving consumer goods.

Guo et al. [26] develop a decision support system for

flexible assembly lines with flexible operator assignments using RFID tags for data capture. Hua et al. [30] propose a real-time manufacturing execution system for a textile company that provides real-time information about production thus transferring the decision-making to the shop floor.

3.6 Other Applications

RFID technology has not been restricted to the manufacturing realm alone. It has found application in the healthcare, construction, hospitality [52], parking management [33, 54], transportation [3] sectors to name a few. Researchers [15, 36, 37] have also focused on improving the traffic control systems using this technology. RFID sensors help in monitoring the health and performance of systems such as power facilities [17, 41] and buildings [42]. This enables early identification of potential problems and thus helping in preventing them from escalating into bigger problems.

Health-care is another area where RFID sensors have found application. RFID sensors have been used to monitor through wireless communication the heart-rates of cardiac patients [29], to identify patients for surgery [35], to help locate embedded devices (pervasive healthcare) [67] and to monitor the life of dental retainers [12]. Mobile robots need information about the surroundings to help them with navigation and RFID sensors help provide the necessary information through wireless communication networks. Kim et al. [40] develop a direction sensing RFID sensor to assist mobile robots in an indoor environment. Lin et al. [46] propose a RFID-based information management system for wirelessly monitoring the missile assembly process. Other applications in improving the navigation systems for mobile robots include [25, 40]

Torrent et al. [66] use a combination of global positioning systems and RFID-tags to monitor the components arriving at a construction site. Since components like structural steel and pipe stools account for a significant share of the expenses in a construction project, the proposed inexpensive data collection system speeds up the process of monitoring the movement of components and also helps quickly locate components at a construction site. Other applications include an efficient paper roll management system [6] and improved asset management and accountability [19].

4 Conclusions and Future Work

RFID has been hailed as one of twenty-first century's greatest contributions [49]. RFID implementations are increasing at an unbelievable rate with it making inroads into areas as diverse as supply chain, health-care, transportation and even bike rentals [32]. However, from the above literature review, it can be concluded that standardization of hardware, software, network protocols and reading devices is important. Moreover, RFID is not necessarily the silver-bullet that solves all issues. It is imperative for companies to analyze its feasibility in each case before hopping on to the "RFID-bandwagon".

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