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RFID and the Internet of Things: Technology, Applications, and Security Challenges

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Abstract

Radio Frequency Identification (RFID) has started to exert a major influence on modern supply chain management. In manufacturing, RFID changes the way objects are tracked on the shop floor and how manufactured goods interact with the production environment. In logistics, RFID is used to track and trace pallets or individual objects on a global scale. In retail, RFID is used to identify objects, retrieve related information, and prevent theft. Sometimes the tags remain attached

to the objects post-sale, thus facilitating additional services. Overall, enterprises have much more detailed information about the objects: the use and produce, their location, their trajectories, and their physical state.

In this survey paper, we show how RFID has transformed the supply chain over the past decade, discussing manufacturing, logistics, and retail and related cost/benefit considerations. We also describe the vision of an "Internet of Things," where each participating object has a digital shadow with related information stored in cyberspace. We conclude with an extensive discussion of related privacy and security risks, including some of our own proposals to mitigate them.

Contents

1

Introduction

Radio Frequency Identification (RFID) is likely to join the ranks of those information technologies that are called disruptive. Its adoption by an enterprise and subsequent integration into the local IT infrastructure typically triggers considerable changes to existing architectures and business processes. The cost of the following reengineering tasks may well exceed the cost of the required hardware and software.

On the other hand, RFID and related sensor technologies have the potential to change the way we control business processes in a fundamental manner. RFID allows us to track objects throughout their production and subsequent life cycle, spanning enterprise boundaries as well as spatial and temporal limits. A consequent application of the technology leads to a detailed and accurate digital shadow of the objects and processes being surveyed. Using appropriate aggregation and reporting techniques, this information can be used by decision makers at different layers of the organizational hierarchy. This may lead to considerable operational and strategic benefits. Prototypical installations confirm this positive outlook; some of them already led to impressive productivity gains throughout the various functional areas of an enterprise.

We believe that RFID is likely to have a significant impact on a broad variety of business functions, in particular manufacturing, logistics, and marketing and sales. In this survey paper, we present some insights how the technology can be applied in a variety of industries. We also offer operational and strategic guidelines for organizations to improve their expected return on investment.

By now there are a great number of applications and industries using RFID in an effective manner. We will not be able to cover all of those in this paper and therefore refer the reader to some related work. The growing importance of RFID is reflected by its inclusion into the main categories of e-business as presented by Gupta et al. [55]. A general meta study and framework for RFID-related research issues is presented by Irani et al. [59]. Identification and tracking of people have been covered in [2, 40, 41, 45]. General tracking in operations management is covered by Holmstrom et al. [58], whereas Camdereli and Swaminathan [18] focus on the tracing of inventory. Applications in healthcare have been analyzed in [4, 65, 75, 82, 102, 111]. Ngai et al. [83] give a framework and guidelines for RFID systems implementation. Ferrer et al. [39] study RFID applications in service delivery and operations.

Our own practical insights are based on a number of case studies, focusing on the concrete benefits of RFID technology in manufacturing. All of the companies we surveyed see considerable potential for RFID. RFID is expected to lead to increased automation, especially in data capture, and therefore to a reduction in labor costs. Improved tracking and tracing may lead to a more stable manufacturing process with interruptions in the production process becoming less frequent. This should help to reduce downtimes, to lower error rates, and to cut down on production waste. Tracing faulty parts and processes in the wake of a complaint or an accident is becoming much easier. Given the increasing demands on product liability, this is likely to create major competitive advantages for early adopters. In container management, RFID can optimize the scheduling and help to reduce shrinkage. Using RFID for the uniform labeling of shipments may lead to considerable savings in labor and hardware. RFID on the shop floor will help to cut down theft and allow more sophisticated presentations of the merchandise to the customer.

In order for these positive potentials to come true, it is crucial that RFID does not form a technology island but is tightly integrated into existing IT infrastructures. Enterprise software systems need to be adapted to take advantage of the richness of data becoming available through RFID. Appropriate filtering techniques need to be put into place to make sure that other system components receive the relevant information in the appropriate granularity. Moreover, companies must consider carefully how to distribute storage and processing in the resulting multi-tier IT architecture that ranges from RFID tags and sensors, on the one hand, to data warehouses and business intelligence tools, on the other hand.

During our case studies, we found that most of today's RFID applications focus on issues that are operational and local, i.e., intra-enterprise. In many cases, this is most likely to guarantee a short-term return of the required investment. Use cases where RFID is used as a strategic enabler, on the other hand, are found much less frequently. The same holds for inter-enterprise applications, where supply chain partners cooperate to maximize the positive impact of the new technology. This may be done, for example, by leaving RFID tags on the objects being produced as they move through the supply chain and by integrating the related business processes. Cooperating partners can use the technology to provide fine-grained product traceability and quality assurances across the whole supply chain. This may translate into significant and tangible competitive advantages.

The paper is structured as follows. We first introduce the reader to the relevant hardware and software as well as to standards and architectures. We then present several case studies and use cases how RFID can be used in manufacturing and retail. Here, the focus is on intra-enterprise applications and local benefits. Subsequently, we move further down the supply chain, discussing RFID applications in logistics and the perspectives for an Internet of Things. This is followed by a discussion of cost/benefit analyses of RFID implementations. The paper then discusses possible security and privacy risks of RFID and presents several architecture proposals for a less centralized Internet of Things. We conclude with a summary and outlook.

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