Computers in Industry 60 (2009) 149–160

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

An active product state tracking architecture in logistics sensor networks

Sang Hoon Woo, Ja Young Choi, Choonjong Kwak, Chang Ouk Kim *

Department of Information and Industrial Engineering, Yonsei University, Seoul 120-749, Republic of Korea

ARTICLE INFO

Article history:
Available online 22 January 2009

Keywords:
Logistics sensor network
Product tracking
State transition diagram
Temporal data modeling
Publish/Subscribe model

ABSTRACT

Sensor technologies are being introduced as a means to collect the accurate and online information of products in logistics networks. Products with RFID (Radio Frequency Identification) tags can guarantee timely product location visibility. Also, additional sensors can measure location dependent attributes such as temperature and humidity. Representative product centric approaches such as EPC Network and the Dialog system make it possible to secure the item level product information automatically and fast. However, they leave room for more advanced services, especially for active product state tracking service that monitors the locations and attributes of products in a timely manner and triggers exception handling when the constraints associated with the product states are violated. Using state transition model, temporal data model, and publish/subscribe model, this paper proposes an active product state tracking system architecture which is able to track products even when they are enclosed in a box, a pallet, or a container. A simulation based experiment is provided to evaluate the performance of the proposed system.

1. Introduction

Traditional supply chain management (SCM) has much focused on optimal resource planning such as collaborative forecasting, production/inventory coordination among multiple sites, vehicle routing, etc. However, thanks to the rapid development of information technology, the efficient management of location dependent product information generated in logistics networks across suppliers, distributors, retailers, and end-customers has surfaced as an important factor in SCM. Through the logistics services of SCM such as product status monitoring and exception handling, delay notification and proof of delivery in a just-in-time mode, corporations are able to supply products of good quality to the end-customers in an efficient and timely manner.

1.1. The need for product centric data management in logistics network

The location dependent product information means time variant logistics data such as changes in the inclusion relationship of product, product location, and product attribute values such as temperature and humidity. In general, logistics networks are large-scale and handle a huge amount of products. As a result, some portion of products is often delivered to unplanned sites, which usually accompanies additional logistics costs for processing customers' claims. This situation occurs especially in air cargo transportation environment. According to Fleisch et al. [1], the costs for claims as a consequence of product routing errors approximately equal 2% of turnover in logistics. Also, since the sites of a logistics network are under different environmental conditions, it is necessary to manage the attributes of the products in transit or in storage, in order to minimize returned goods due to product deterioration or environmental damages. The management of product attributes is especially important in the high-tech manufacturing industry that requires product protection and in the food industry where deterioration in quality is crucial [2]. With problems in product quality, furthermore, the management of location dependent attributes can be useful in identifying legal responsibilities among different departments or companies on a supply chain.

The complete visibility of products on a logistics network can be secured only by tracking such information in a timely manner. In existing supply chains, however, even basic product information is not maintained well [3,4]. For example, approximate 30% of tracking and tracing data in logistics networks is incorrect and the reliability of data is dependent on subcontractors [1]. As a result, logistics networks frequently fail to deliver products on time to the right customers and need significant amount of human effort to correct the delivery error. The problem not only incurs monetary loss to the corporation but also lowers customer confidence, resulting in fall in corporate competitiveness.

* Corresponding author. Tel.: +82 2 2123 2711; fax: +82 2 364 7807.
E-mail address: kimco@yonsei.ac.kr (C.O. Kim).

0166-3615/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.compind.2008.12.001

1.2. Recent sensor-based logistics network management systems

Sensor technologies are being introduced as a means to collect the accurate and online information of products in logistics networks. Sensors are devices that measure the physical attributes of an object and their common examples are object identification, temperature, and weight sensors. A logistics sensor network is composed of numerous sensor nodes. A sensor node has one or more sensors to detect product location and to measure product attributes. Sensor nodes may be deployed at the entrance, exit, and storage areas of each logistics network site. With sensors at the strategic sites of a logistics network, product location and attribute information can be collected online, guaranteeing more timely visibility. As a result, the management of product location and attributes is improved and the logistics costs are reduced by minimizing the inspection time and misdelivery [5–7].

RFID (Radio Frequency Identification) is a representative object identification sensor technology for detecting moving object autonomously using wireless radio frequency. The basic components of the RFID technology are RFID tags and readers. Typically, an RFID tag is attached to a moving object and communicates wirelessly with a reader when the object comes into the range of the radio frequency field of the reader. Also, sensor-based RFID tags can be used to monitor product attributes. Infineon conducted a pilot study for cool chain management [9].

EPC Network [10] is an industry driven, product centric data management architecture to provide product location visibility based on the RFID technology. EPC Network consists of EPC, RFID Middleware, ONS (Object Naming Service), and EPC-IS (EPC Information Service). As an item level coding scheme, Electronic Product Code (EPC) was developed. EPC describes individual product identification data such as manufacturer, product type, and serial number [8]. EPC for a product is usually implanted in an RFID tag.

EPC Network is a distributed architecture proposed to conveniently query and collect product information on a huge logistics network. An RFID reader submits data consisting of (EPC, Reader_ID, Time_stamp) to an RFID Middleware every time a product with an RFID tag passes through. An EPC-IS stores information from an RFID Middleware in a database. Generally, more than one RFID Middleware submits the RFID data to a single EPC-IS that exists on each site or a group of sites. Therefore, several companies (or sites) on the same logistics network operate mutually independent EPC-ISs and keep the movement history of products that have passed through their areas in the logistics network.

An ONS works as a broker that integrates the independent EPC-ISs. A user sends a query to the Root ONS to find out the address of supplier's local ONS, whenever static information such as a list of product specifications is needed. The user needs to find the address of supplier's EPC-IS through its local ONS and then send a query to the EPC-IS for product information [8]. However, ONS and EPC-IS that reflect their architectural specifications completely have not been operated yet [11].

In the current version of the EPC Network architecture, it takes much more time and efforts to receive dynamic information such as product movement history, because a query should be sent to every EPC-IS over a logistics network. Discovery Service [12] is a future component proposed to provide a solution to this problem. Since the Discovery Service keeps the addresses of all sites through which a product with an RFID tag passed, it is possible to query product movement history. However, the movement information of every product on a logistics network should be submitted from EPC-ISs to the Discovery Service, causing high data transaction loads.

A pioneer work on the product visibility in the related academic fields is product centric approach [13]. The most unique feature of the approach compared with EPC Network is the method of item coding. Instead of the EPC coding scheme, the product centric approach uses the item code of the format ID@URI. The URI (Universal Resource Identifier) which is uniquely managed by the Domain Name System (DNS) on the Internet is an Internet address of the server of a manufacturing company and the ID is a unique product identifier. The clients who desire to retrieve or update product information can connect the server using the URI part, and a product agent inside the server provides the clients with information of the product identified by the ID part.

The Dialog system [13,14], software that implemented the idea of the product centric approach, is a fully distributed, object-oriented architecture where the product agents are distributed at the servers of supply chain members. The Dialog system offers functionality more than a query processing for product information. Using the composite design pattern [15], information on product containment hierarchy such as assembly structure and inclusion relationship for transportation can be efficiently maintained. In addition, using the observer design pattern [15], information update of a composite product, e.g. location update and part replacement, can be automatically propagated, through the containment hierarchy of the composite product, to the agents responsible for managing the data of the assembled parts.

Besides the two product visibility approaches described above, the following are other recent approaches that applied the RFID technology to supply chain management. RFArch [16] is a product history management architecture for a product recall process. RFArch is based on a predecessor of the EPC Network architecture that was proposed by MIT Auto-ID center. RFArch traces the movement history of defective products by using the Trie data structure [17]. Han et al. [18] focused on reducing the size of a large-scale RFID data stream through cleansing and transformation operations and saved it in a data warehouse for hierarchical analysis of product movement history.

Another kind of research is related to the processing of RFID data streams into useful data for business application software in supply chain management. Wang and Liu [19] and Wang et al. [20] developed temporal entity-relationship models of business data that can be transformed from RFID data stream and worked for rule-based systems to extract the business data. Other approaches with RFID data include manufacturing job flow monitoring [21], dynamic job shop scheduling by using an auction based bidding protocol [22], inventory control in a supply chain [23], and case-based warehouse management [24].

1.3. Features in the proposed logistics tracking system

Representative product centric information management approaches such as EPC Network and the Dialog system make it possible to secure the item level product information automatically and fast. However, they leave room for more advanced services, especially for active product state tracking service that monitors the locations and attributes of products in a timely manner and triggers exception handling when the constraints associated with the product states are violated. This study proposes an active product state tracking method that places constraints on movement plans and attributes of mobile products and tracks their locations and attributes using state transition diagram and temporal data model.

Today's logistics networks potentially spread all over the world with diverse and heterogeneous information systems. In such distributed environments, a more flexible communication model is necessary for efficient communications among the systems. EPC Network uses a passive communication model to obtain product