Expert Systems with Applications 42 (2015) 6082–6097

Contents lists available at ScienceDirect

Expert Systems with Applications

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

An intelligent model for logistics management based on geofencing algorithms and RFID technology

Rodrigo R. Oliveira [a,*], Ismael M.G. Cardoso [a], Jorge L.V. Barbosa [a], Cristiano A. da Costa [a], Mario P. Prado [b]

[a] Interdisciplinary Postgraduate Program in Applied Computer Science (PIPCA), University of Vale do Rio dos Sinos (Unisinos), 950, Unisinos Ave., Postal Address:93.022-000, São Leopoldo, Rio Grande do Sul, Brazil

[b] Taggen RFID Solutions Company, Unicamp Technology Center, 100, Bernardo Sayão Street, Barão Geraldo University City, Postal Address:13.083-866, Campinas, São Paulo, Brazil

ARTICLE INFO

Article history:
Available online 7 April 2015

Keywords:
Logistics tracking
Context-aware decision support system
Intelligent tracking system
Geofence
GPS
RFID

ABSTRACT

The cargo transport represents the largest share of logistics costs in most companies. Consequently, companies are investing in tracking and tracing systems aiming to improve services, reduce costs and ensure the safety in cargo transportation. To play a part in this area, we propose in this article SafeTrack, a model for logistics management based on geofencing algorithms and radio-frequency technology. In this approach, the focus is on dealing with delivery management. The main scientific contribution of SafeTrack is automatic delivery management. Besides dealing with deliveries without user interaction, we provide a mechanism to detect inconsistencies at real-time. Furthermore, the model monitors detours in planned routes and deals with alarms notifications using mobile devices. To provide that features, we employed Geofence concept with two solutions that enable to detect, in real-time, the occurrence of detours in planned routes. We also created a component, named SafeDuino, to control loads delivery and pickups. The decision on the occurrence of inconsistencies during the logistics flow is performed through the fusion of context information, obtained from SafeDuino and a mobile device, using radio-frequency technology. We built a complete and functional prototype, which was evaluated in a controlled environment, testing several conditions. The test scenario was executed twenty times, showing that the proposed model is capable to identify all inconsistencies along the travels. We concluded that SafeTrack improves logistics operation, optimizing decision-making, avoiding losses during the logistics flow, and also allowing companies to remain competitive in the market.

1. Introduction

Transport plays a key role in supply chain integration, particularly due to its capacity to control flows of resources, goods and products (Huq, Stafford, Bhutta, & Kanungo, 2010). Furthermore, transport represents most of the logistics costs in almost all companies. To enhance efficiency and flexibility in fleet operation and management, the companies have adopted technologies to obtain real-time information with a high level precision (Ngai et al., 2012). One important piece of information is composed of time and location, which can be acquired through the Global Position System (GPS) (Hofmann-Wellenhof, Lichtenegger, & Collins, 1997), a technology commonly used in location systems (Hightower, LaMarca, & Smith, 2006).

Companies are investing in tracking and tracing systems aiming at improving services, reducing costs and ensuring the safety in cargo transports (Zhang, Zhao, Yi, & Wang, 2011). Bowersox and Closs (1996) highlight the companies need real-time information with high accuracy for efficient logistics management, allowing to know how, when and where resources can be used. According to Shamsuzzoha and Helo (2011), the use of tracking and tracing systems is essential to reduce costs, speeding deliveries and even identifying bottlenecks and operational deficiencies. In Brazil, the main reason for companies to use tracking systems has been to decrease the number of cargo thefts (NTC, 2012). The logistics tracking for delivery networks is an important issue for providing customer service in the transportation business (Shamsuzzoha & Helo, 2011) and the continuous tracking and tracing are required for shipments of high value and important cargo (Yang, Xu, & Li, 2010).

According to Hillbrand and Schoech (2007), tracking systems and logistics monitoring are divided into two categories: discrete and continuous. The discrete monitoring only gets the location of

* Corresponding author. Tel.: +55 (51) 3590 8161; fax: +55 (51) 3590 8162.
E-mail addresses: rodrigo.remor@gmail.com (R.R. Oliveira), ismaelcardoso@yahoo.com.br (I.M.G. Cardoso), jbarbosa@unisinos.br (J.L.V. Barbosa), cac@unisinos.br (C.A. da Costa), mario.prado@taggen.com.br (M.P. Prado).

http://dx.doi.org/10.1016/j.eswa.2015.04.001
0957-4174/

a specific load in predefined spots. On the other hand, continuous monitoring gets the location at real-time, and knows a load's pinpoint in a specific time. In practice, the main technologies that are used for logistics tracking are: barcode, RFID (Radio-Frequency Identification), GPS (Global Positioning System) and GSM (Global System for Mobile Communications). Kandel, Klumpp, and Keusgen (2011) add to the taxonomy of Hillbrand and Schoech (2007) a subcategory called semi-continuous monitoring. This subcategory represents systems that combine both discrete and continuous technologies. This technique uses a continuous technology for the tracking of transportation vehicles, such as GPS, and a discrete technology for monitoring loads delivery. In recent years, we can observe the growth of RTLS (Real Time Locating Systems) use in solutions of logistics tracking and tracing (Ding, Chen, Chen, & Yuan, 2008; Ma & Liu, 2011; Park, Choi, & Nam, 2006; Zang & Wu, 2010). The RTLS are usually employed in order to do the continuous tracking and tracing of loads at indoor environments, through the use of discrete technologies, such as RFID and wireless networks.

The insecurity of public roads and the growth of load's thefts are making companies to look for systems able to detect when a vehicle leaves its planned route. Thus, most of the existent tracking systems use techniques of virtual fence known as Geofence (Reclus & Drouard, 2009), which checks if the entity is inside or outside an area. Furthermore, there are techniques (Oliveira, Noguez, Costa, Barbosa, & Prado, 2013) which enable continuous monitoring of travels, obtaining information of probable deviations or even emergency situations. These techniques allow the identification of potential vehicle thefts, but they do not identify inconsistencies during logistics flow, for example when the cargo is removed from vehicles. Therefore, we developed a model capable of identifying both cargo and vehicles thefts, among other load's inconsistencies in logistics.

Considering this, the main motivation for this work is two folded: we aim at reducing the high cost of logistics and, at the same time, better manage deliveries, trying to decrease the possibilities of cargo's thefts. Indirect motivations, derived from those two, are the optimization of the supply chain monitoring, and possible increase in companies profits, maintaining their competitiveness in the market.

With these motivations in mind, we propose a merging of the information technologies and geofencing algorithms to design and develop the SafeTrack, an intelligent model for logistics management. This work continues the research started in SWTrack (Oliveira et al., 2013), which presented an intelligent model that allows companies to track their vehicles and have control over the traveled routes. In this new approach, SafeTrack integrates off-the-shelf mobile devices and open source hardware to acquire information such as vehicle positioning and input/output cargo on the vehicle.

The main scientific contribution of this work is the automatic delivery management of loads, without any user interaction. The main strengths of this solution are time optimization and also minimizing human mistakes. Furthermore, the cargo control is able to identify several inconsistencies in the logistics flow, for example mistaken deliveries and pickups, and also potential cargo thefts. With that, the logistics' costs decrease and cargo's safety is increased, helping companies in competitive markets. On the other hand, the main weakness of the proposed research is related to information interoperability. We focused on the distribution stage, so critical information is not propagated throughout the supply chain. However, in Section 2, we discuss the work of Geerts and O'Leary (2014) that proposes a solution specifically targeted at this issue.

The decision on the occurrence of inconsistencies during the logistics flow is performed through the fusion of context information, obtained from a mobile device, and a hardware component especially developed for this project, named SafeDuino. This component is attached at the back door of the truck with an RFID shield, which detects when a cargo passes over the RFID reader. Another feature of the proposed model is that devices can send alarms notification whenever predefined situations occur. These features speed up decision making, reducing losses and costs for the logistics flow.

The remainder of this article will first introduce related works in Section 2. In Section 3 we introduce the SafeTrack model. We describe the prototype model in Section 4. Section 5 discusses and presents the prototype evaluation in a controlled environment. Finally, in Section 6, we present some conclusions and direction for future work.

2. Related works

He, Tan, Lee, and Li (2009) proposed a system for continuous tracking in supply chain. The model used technologies such as web services, RFID and GPS to integrate RFID events with geolocation information and associated them to the load, so it can easily be tracked. The GPS information is gathered by a mobile device application. This application sends information about the location to a central server named *EPCIS Gateway*. The authors presented a scenario in which a vehicle is equipped with a mobile device that has GPRS and GPS receivers. Thus, the mobile application can communicate with the *EPCIS Gateway* to transmit location data and business context information. This information was stored in the database by *EPCIS Gateway* and available through web services so that other applications can access and use this information for various purposes.

The system proposed by Yang et al. (2010) presented a hybrid cargo model for tracking and tracing. This system used GPS and wireless sensor networks to obtain the vehicle and cargo positions. The authors analyzed, discussed and identified the main logistics tracking systems, also they proposed a low-cost model able to perform the cargo tracking in a continuous way. The system architecture was divided in three components: a *Hybrid Network Infrastructure*, an *Intelligent Monitoring Devices* and a *Central Server*. The *Hybrid Network Infrastructure* integrated technologies GPS, Wi-Fi, RFID and ZigBee to perform the entities tracking, while GSM/3G, Wi-Fi and ZigBee were used for communication between the components. The *Intelligent Monitoring Devices* were embedded devices, that had modules for motion detection, RFIDs and communication through ZigBee networks. Furthermore, these devices had a micro-controller and a battery. The *Central Server* provided services so that different logistics applications are developed. According to the authors, the proposed system achieves higher availability, accuracy and lower cost than existing systems. However, the work did not present how the location information was modeled. So it is not possible to know how the information was represented to perform a continuous tracking.

Papatheocharous and Gouvas (2011) presented a cargo tracking system, named eTracer. The work also proposed to manage the loading and unloading of products in an automated way. The system architecture was divided in four components: *Mobile Logistics Stations Network*, *Fixed Logistics Stations Network*, *Communication Server* and *Web Application Server*. *Mobile Logistics Stations Network* were vehicles used to cargo transport. The Mobile Station had RFID readers that identified the entry and exit of all objects that had RFID tags. Each vehicle also had GPS receivers and GPRS transmitters to provide the location of objects at any time. *The Fixed Logistics Stations Networks* were depot stations that had distributed RFID readers in their inputs and internal divisions. Thus, the fixed stations detected and identified the cargo