Robotics and Computer-Integrated Manufacturing 29 (2013) 502–512

Contents lists available at SciVerse ScienceDirect

Robotics and Computer-Integrated Manufacturing

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

Evaluating the performance of a discrete manufacturing process using RFID: A case study

Ihsan Arkan*, Hendrik Van Landeghem

Department of Industrial Management, Ghent University, Technologiepark 903, B-9052, Ghent, Belgium

ARTICLE INFO

Article history:
Received 18 February 2013
Received in revised form
21 May 2013
Accepted 23 June 2013
Available online 19 July 2013

Keywords:
RFID
Rapid manufacturing
Material flow
Real-time location system
Workflow layout
Middleware development

ABSTRACT

The material flow is a major focus point in improving productivity in today's product diversified manufacturing organizations. Nevertheless, there is still a lack of efficient methods to control material flow through manufacturing processes in cases where multi-item tracking is difficult to achieve. This paper presents an RFID-based RTLS (Real-Time Location System) solution for obtaining multi-item work-in-process visibility within a manufacturer. It delivers detailed performance metrics through RTLS data analysis in order to evaluate workflow performance and to obtain a lean process. We pre-filter the RTLS data through the development of a middleware data collection method to acquire near real-time performance evaluation. A case study illustrates the complete process including measurements before and after a workflow redesign. The increased level of detail from RFID measurements yields new insights into shop floor actions and the real effects of redesign efforts.

1. Introduction

Radio Frequency Identification (RFID) is an automatic identification technology for tagging objects and receiving object data wirelessly by the signal transmissions between tag and antennas, linked to a central server. Its main function is to register real-time information on the identity and location of the tags. This technology for industrial purposes was first initiated in supply chain operations [1,2]. Up to now, many RFID applications have been discussed for supply chain purposes, but also manufacturing practices have been reported [3]. However, increasingly the shop floor has to be synchronized with the RFID-enabled supply chain [4] and for this RFID technology must be adapted to the manufacturing environment. In order to track tagged products or objects on a shop floor, RFID technology is employed in a Real-Time Location System (RTLS) configuration. RTLS is a system that locates objects automatically within a pre-defined area and is able to monitor them in real-time [5,6]. This system generally utilizes active RFID tags that signal periodically to the RFID reader antennas surrounding an area to precisely track moving targets [7]. This paper explores the potential of RFID technology, as an RTLS solution, for manufacturing implementation.

Companies must constantly control and improve manufacturing performance to remain competitive. The major concern of businesses is to maintain sufficient up-to-date workflow knowledge to be able to effectively advance performance. This workflow knowledge, which contains measures of material flow, worker utilization and many complex events [8], has up to now not been investigated in an automated manner. Time measurements are mostly being performed manually by stopwatches and video analysis. In complex shop floor situations, these tools are not accurate enough, and too time-consuming for regular use. The lack of advanced measurement tools and incomplete shop floor data lead to a decrease in analysis skills within companies, and a further reduction of detailed flow studies [9]. As a result, currently many production companies lack clear visibility into their internal plant logistics, and cannot adequately reconfigure their shop floors, in order to meet the changes in customer demand and product variety.

The purpose of the research is twofold:

- Identify the potential of RFID location tracking in workplace redesign.
- Validate the findings in an industrial setting.

This paper describes a method for beneficial use of RTLS to analyze product flow through performance evaluation within multi-item production process. The method has been tested in the quality control department of a company producing plastic bumpers and spoilers for passenger cars. The trajectories of the

* Corresponding author. Tel.: +32 484 56 7863.
E-mail addresses: ihsan.arkan@ugent.be, ihsan_arkan@yahoo.com (I. Arkan), Hendrik.vanlandeghem@ugent.be (H. Van Landeghem).

0736-5845/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rcim.2013.06.003

products are collected automatically as location data streams. This data collection is improved by developing a middleware which pre-filters redundant data before storing into the database. From the database we calculate productivity and other key performance indicators (KPIs) linked with time and motion analysis, such as cycle time analysis and speed. In a separate study the workflow is redesigned via a simulation model. The redesign step using the simulation model is only described succinctly, since it is not the main focus of the paper, but nevertheless it forms an integral part of the case study. Consequently, the redesign is evaluated with the previous productivity parameter and KPIs recalculated using newly obtained RTLS data. The significant level of detail of productivity and KPIs could not be achieved before RTLS with current measurement tools. This kind of beneficial application of RFID was up to now largely missing in literature.

The remainder of the paper is organized as follows; in Section 2, the background for this study is provided, mainly focusing on positioning technologies and previous work on asset tracking; in Section 3, the shop floor case with the RTLS implementation is described; in Section 4, the developed middleware is explained; in Section 5, the research steps that follow data mining and then to obtain the KPIs are stated; in Section 6, the results are presented and discussed, and in the last section, the conclusions and future research are summarized.

2. Literature study

2.1. Technical background

An RFID system consists of fixed readers and mobile tags that communicate by messages, sent by the tag's transponder to antennas of the readers within the work space boundary [10]. RFID functions as an indoor wireless positioning technology that determines tag positions with a timestamp. The position is represented in terms of a set of coordinates [11] and it is basically estimated by triangulation algorithms that also yield the accuracy of the measurements.

RFID technology has been mostly used in supply chain settings [1] (such as warehousing or transport yards) and only recently emerged for use on the shop floor. The dense plant environments with the dynamic production flow need accurate measurements with high update rates. At the same time it presents a difficult and challenging environment for electromagnetic waves. Few RFID systems are built up on low-frequency wave spectrum solutions [12]. The low-frequency systems provide accurate data, but require many readers throughout the shop floor to track sequenced operations, since the reader-tag proximity is important for the data update rate [13] and this need for proximity decreases the usefulness of the wireless feature of the system. Therefore, many RFID systems are built up on the UHF (Ultra High Frequency) wave spectrum and WLAN (Wireless Local Area Network) solutions [13], but they do not provide location accuracy of centimeters which is required for this case. In this case study, Ultra Wide Band (UWB) is used to track shop floor operations, which delivers enhanced RTLS performance in terms of location accuracy, throughput and environmental robustness [14,15]. Ubisense UWB technology was selected for this study [13]. It provides the appropriate accuracy, precision and wireless technology solution.

RFID tags are divided into three main categories: passive, semi-passive and active. The differences between these types are found in their frequency limits, detection range, memory space and battery specifications [10]. In this case, active tags were used, as they constantly broadcast strong signals and can communicate with readers over long ranges of 20 to 100 m [8]. Also, active RFID yields enhanced communication performance [16].

2.2. Existing work and methodological background

RFID systems are used in many fields such as supply chain, manufacturing, business processes and warehouse operations [17–19]. In manufacturing applications, companies have been using this system mostly for access control [8], inventory management [3], product quality improvement [20], but rarely for shop floor process control in real-time [21]. The manufacturing application which addresses in-plant logistics is the case discussed in this empirical study.

Recently RFID technology applications in manufacturing are focusing on asset tracking in real-time [14,22,21]. We are interested in using trajectories of goods and handling equipment to optimize asset flows and work organization. The facility layout has a significant impact on shop floor productivity [21]. Some optimization studies using indoor positioning technologies are discussed conceptually [23,24], but practically, data streams are not processed or analyzed.

The articles about RFID data acquisition are mostly based on generating time series of position data [25,26] and the data is usually analyzed through data cleansing methods [27], adjusting the monitoring frequency [28] and event extraction [29]. Specifically, in this research, product workflow measurements are converted by RFID middleware into node-arc data [23], and this type of data is then processed by time analysis and material flow visualization.

3. An industrial case study

As part of a collaborative research project on RFID in-plant logistics, an RTLS object tracking system was used in the QC (Quality Control) department of a plastic bumper/spoiler manufacturing company in order to evaluate the performance of workflow, before and after a redesign. Next, the shop floor overview, the RTLS deployment and the simulation model are discussed.

3.1. Shop floor overview

The characteristics of the QC department and the workflow, before and after the redesign are described in this section.

The department forms a small cell with an area of 375 m^2 between a paint shop and the warehouse for final part assembly, with the purpose of assessing the quality of products. The products are plastic bumpers and spoilers for passenger cars, and there are 32 types of items. The dimension of a bumper is about 1.5 m in length and 0.5 m in width, and 1.5 m by 0.2 m for a spoiler. Each product requires one to five process steps. The process is a low automated craft job. The workers carry and process unfixed, lightweight and fragile items between work islands. Fig. 1 shows a cross-section of the QC department. The work units are located 1–2 m from each other. The environment is highly metallic because of the infrastructure consisting of multi-item carrier skids, process tables, WIP (work-in-process) conveyor buffers and storing units. The shop floor can hold up to 52 items as WIP. The incoming skids carry 3, 4, 5, 6, 8 or 12 pieces depending on the item type.

The workflow follows the process steps shown in Fig. 2. Items arrive into this department from the paint floor according to a production schedule and they are carried by skids which are moving on a rail. The process is divided into two steps named QC1 (Quality Control 1) and QC2 (Quality Control 2) respectively.

The process before redesign goes as follows:

1. The pieces on incoming skids are removed by two operators to conduct a first visual quality control. This is carried out either