A Data Management System for Identifying the Traceability of Returnable Transit Items Using Radio Frequency Identification Portals

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Abstract. The advancement of paradigms such as Industry 4.0 and cyber physical systems herald increased productivity and efficiency for manufacturing businesses through increased capture and communication of data, information and knowledge. However, interpreting the raw data captured by sensing devices into useful information for decision making can be challenging as it often contains errors and uncertainty. This paper specifically investigates the challenges of analysing and interpreting data recorded using Radio Frequency IDentification (RFID) portals to monitor the movements of Returnable Transit Items (RTI), such as racks and stillage, within an automotive manufacturing environment. Data was collected over a yearlong pilot study using an RFID portal system installed across two automotive facilities to trace the movement of RTIs between the sites. Based upon the results key sources of errors and uncertainty have been identified and a data management framework is proposed to alleviate these errors.

Keywords. RFID Portal System, Returnable transport items, traceability, automotive manufacturing and assembly

1. Introduction

The transportation of parts and products within and between manufacturing facilities in a safe, durable and efficient manner is a vital aspect of any manufacturing supply chain. A cost effective way to achieve this is to use reusable packaging and containers, referred to as Returnable Transit Items (RTIs), which are specifically designed to house the parts and components during transportation between factories. In order for the supply chain to run smoothly, the RTIs must be managed [1] to prevent bottlenecks in the manufacturing process and to ensure they are well maintained so damage or contamination of parts and products is avoided. Developing systems to monitor RTIs to determine locations, status and conditions can therefore be a valuable tool in supply chain management [2].

Radio Frequency IDentification (RFID) is a well-developed technology, which can enable location traceability by uniquely identifying objects through electromagnetic

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radiation. RFID "tags" are placed on the objects of interest, which can then be identified when they pass through RFID portals placed in strategic locations within and around a manufacturing facility. Ultra-High Frequency (UHF) is of particular interest as the RFID tags can be read up to 9m away [3], enabling automatic detection that does not impinge on the business process. While this technology is promising, there are a number of challenges in interpreting the data collected from the RFID portals and assessing its reliability. Previous research has discussed issues with false positive and false negative readings [4]–[6] which add uncertainty and errors to the data. However, most of these issues have been researched in controlled experimental scenarios, with little research conducted in the challenges of implementing full RFID portal systems in real manufacturing settings, which add additional complexity due to the harsh RF environment, such as high metallic content and significant external sources of RF interference (e.g. motors and actuators).

The aim of this research is to identify the challenges in utilising data collected by UHF RFID systems to manage RTI movement within an automotive manufacturing facility. A UHF RFID system was designed and installed in a UK automotive manufacturing business, capturing data for one year. Based upon the findings from this pilot study a number of challenges have been identified and a data management framework presented to help address these issues.

2. RFID Portal System

The RTI traceability system was designed and installed within a UK automotive manufacturing business, with the aim of monitoring the RTI movement between two facilities, allowing the end user to determine (i) the location of RTIs and (ii) when RTI maintenance is required based upon the number of cycles around the manufacturing process have been completed.

A schematic of the layout of the manufacturing facilities and portal locations is given in **Figure 1**. Automotive components are manufactured in Building A. They are then transported to Building B were they are assembled with other components to make the finished product. RTIs are used to transport the components between the buildings. Forklifts move the RTIs within each building, whilst lorries transport RTI between factories. To monitor the movement of RTIs between factories, RFID portals were placed on the entrances (and exits) of each building to detect when forklifts move them to be loaded onto lorries.

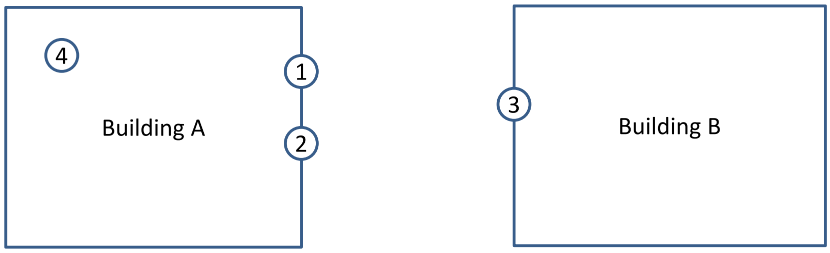

Figure 1 Schematic layout of the manufacturing buildings with portals locations numbered

Four portals were installed across the manufacturing plants, two at the entrances/exit of Building A (1, 2) and one at the entrance/exit of Building B (3) and one at the entrance / exit of a washing process (4) to determine when maintenance has been conducted. UHF Gen2 [7] RFID tags were placed on 10 racks and 100 separators, as shown in **Figure 2**, representing a small sample (i.e. ~ 1%) of racks and separators in use within the facility. A summary of the deployed system is shown in Table 1.

Table 1 Summary of the physical system elements

Number of Portals	Buildings	Objects tagged	Portal Design	Tags	Data Storage
4*	2	10 Racks, 100 Separators	1 Alien 9900 reader, 4 antennas, 2 light gates, cellular data SIM	Passive UHF	MySQL database hosted on a remote LINUX Server

*Portal 1 at manufacturing, Portal 2 and 3 at assembly, portal 4 at washing.

Each portal contains a single Gen2 Alien UHF reader [8] connected to four antennas with locations shown in **Figure 3**. Additionally, light gates placed at the entrance and exit of the portal to determine the direction and speed a forklift carrying RTIs is travelling. Data captured from the portal are then sent wirelessly using cellular networks to a central MySQL database located on a remote server. A Programmable Logic Controller (PLC) is used to control the reader, manage communications with the cellular network and to act as a local storage buffer to minimise data loss in the event of communication errors.

Figure 2 RTIs comprising of a rack and separators with RFID tags attached

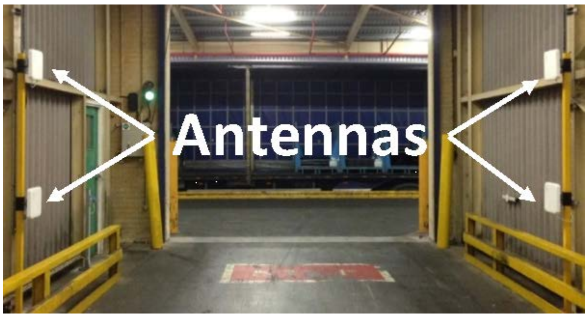

Figure 3 Installed Portal with 4 antennas visible

3. Findings and Challenges

Data from the described system were recorded for a year, creating over 31,000 data points. However, a number of challenges exist to extract meaning and context from the raw data and support the end user requirements. Each of the challenges are explained below.

3.1. False Positives

A false positive occurs when a tag is detected by a RFID reader in a situation that was not intended by the system. This can occur when tags are read on the periphery of the intended “read zone” rather than when it is passing through the portal. External factors can affect the probability of a false positive occurring, such as surrounding metallic material can cause reflections of RF signal increasing the range of RF signal, RTIs passing near but not through portals, and the proximity of parked RTIs. Within the pilot study, false positives occurred far more frequently at Portal 1 due to the proximity of RTIs left near the portal during the loading and unloading process. Examples of this can be seen in **Figure 4** on tags EPC number ending *0001* and *0080*, whilst an RTI (rack and 7 tagged separators) appears to be waiting transport from Building A to Building B. The additional data generated by false positive reads increase the complexity of calculating user defined metrics, particularly when detecting completed cycles as sequences in the data.

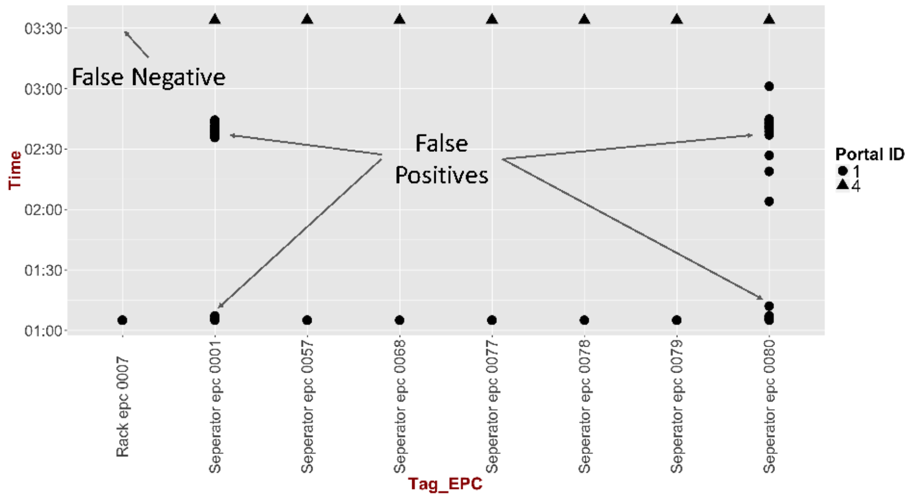

Figure 4 System data showing an RTI moving from Building A to Building B, with false positives and false negatives

3.2. False Negatives

False negatives are missing data points caused by RFID tags not being detected as they pass through a portal. This can occur when a tag is not energised by the RF field created by the portal as an external object may obscure it.

False negatives are particularly challenging to detect as they are absent from the data rather than false positives where there is an excess of data. Identification relies on the knowledge and assumption of expected system behavior from which it can be inferred that a false negative is likely to have occurred. For example within **Figure 4** a false positive can be inferred for tag ending 0007 at just after 3:30, as it passes through Portal 1 at the same time as the other tags, but is not then seen later at Portal 4.

False negatives will cause issues for RTI management systems since the location status will not be up to date and cycle detection algorithms will need to be more advanced (i.e. infer location from predictions of state sequences based upon historic data) due to non-simple sequences.

3.3. Sensor Failure

Physical sensors and equipment used by the system may become uncalibrated or fail completely, leading to unreliable and misleading data. Within the pilot study particular problems were found with directional sensors data from Portal 1, mainly due to misalignments between the optical sensors. This proved to be a significant problem for the system as it was no longer possible to determine an RTIs direction of travel through a particular portal in real time.

Systems should be designed so that the health of individual sensors can be monitored, so that issues can be diagnosed and addressed quickly. Knowledge of the system needs to be embedded into the system so that suspect data can be identified. Additionally, algorithms should be able to adapt to uncertain data, so that less significance is placed upon them when determining user defined metrics.

3.4. Business Process Understanding

Uncertainty about data captured by the system can occur when business processes differ from what is expected. Examples of this include RTIs bypassing portals due to unexpected routes, and unforeseen business processes such as factory shut downs. This can be caused due to a multitude of reasons including operators not following the correct business process, management not fully understanding the requirements, and system designers not fully capturing business process requirements.

Examples of this from the pilot study include the fact that Portal 4 occasionally appears to be missed from the sequence, indicating that alternative route is sometimes used to transport the RTIs which deviates from the expected business process.

4. Data Management Framework

Based upon the findings from this pilot study, it is clear that data management is required to alleviate errors and uncertainty to enable user metrics to be determined. A framework to manage these data consisting of three areas: *information models, data management and feature extraction* and *user services* is presented in this section, as shown in **Figure 5**.

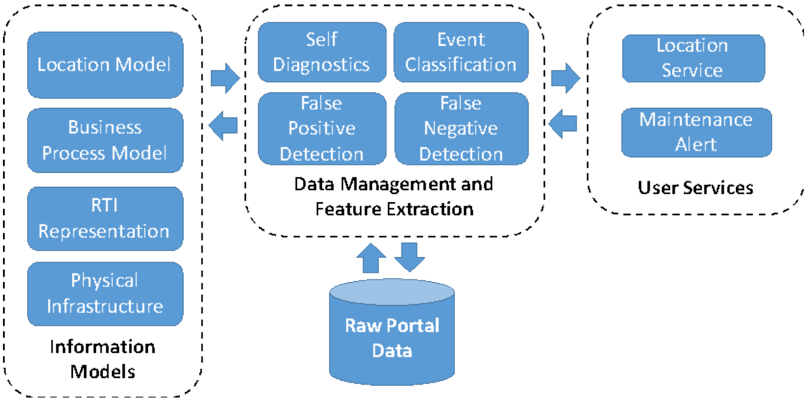

Figure 5 Proposed data management framework for RTI traceability system

Information Models are used to impart knowledge into the system by describing elements and real world relationships, such as the location and type of physical hardware, key features of the tagged objects and the business processes which are monitored. By encapsulating this information into software and model structures that can be simply and quickly modified, such as object oriented class and ontologies, the data management framework can enable reusability and scalability of algorithms.

The *Data Management and Feature Extraction* layer cleans and sorts the raw data captured by the RFID system to filter errors and uncertainty, which were highlighted within the previous section. The algorithms use the knowledge contained within the information models, whilst a self-maintenance layer assesses the health of the system and adapt and notify users of potential system faults.

The *User Service* layer enables the high level management KPIs to be calculated. Once calculated, this information is sent to the presentation layer to be displayed to the user.

5. Conclusion

This research has investigated the challenges in implementing an automotive RTI monitoring system using UHF RFID portals based upon findings from a year long pilot study. False positive, false negative, sensor failure and business process understanding were identified as key challenges to overcome when interpreting the meaning from raw sensor data. A data management framework has been presented to tackle these issues by embedding knowledge into the system, which can help identify sources of uncertainty. Future work is required to develop and test this framework and to assess the benefits of such a system to end-users.

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