Component detection with an on-board UHF RFID reader for Industrie 4.0 capable Returnable Transit Items

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Abstract. *Industrie 4.0*, Cyber-Physical Systems and Smart Manufacturing are all terms used to describe a vision of how intelligent products, processes and services can provide connectivity and real time information based technologies to improve manufacturing. This can be realised by embedding intelligence at the product and operational level to provide predictive, risk preventative and high performing manufacturing systems. The work outlined in this paper details how a Returnable Transit Item (RTI) can become an integral part of the Industrie 4.0 vision as an intelligent container that can interact with components, machines and other manufacturing services.

Keywords. Industrie 4.0, Cyber-Physical Systems, RFID, Returnable Transit Items.

1. Introduction

Supply chains can become a complex sequence of processes involving many different entities each with differing processes and technical challenges [1]. Part of this chain often includes the transporting of finished goods and work in progress placed in Returnable Transit Items (RTIs). An RTI, also referred to as a stillage, rack, pallet or case provides the role of aggregating many components into a single entity that improves logistical efficiency and reduces costs [2]. This is achieved through maximising the use of space, more efficient handling and the reduction of one way packaging [3]. RTIs can also provide an effective role in component protection, not least from physical damage but from environmental conditions such as grime, dust and moisture. When RTIs are exposed to the processes of the supply chain, often they become misplaced, damaged and lost [4–6]. To combat these issues Radio Frequency Identification (RFID) tracking systems have been implemented to identify the current and previous locations of the RTIs [7–9]. Many of these systems use an account-based data model [10], where the movement of RTIs is represented as a set of transactions that update the RTI and component quantities in each respective location. These types of models do not traditionally provide the ability for unique component traceability, such as in a product centric data model [10]. *Industrie 4.0* has been proposed as the next industrial revolution [11] where the ubiquitous nature of the internet is utilised to link manufacturing systems, intelligent products and the human workforce providing a new level of product customisation and quality in a competitive fashion [12]. To support the *Industrie 4.0* vision, the development of intelligent products and services

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are a way of distributing the execution of product specific tasks such as determining product context [13], interaction between other smart products, environments and machines [14], as well as being able to store data in a product centric model at all phases of its lifecycle [12]. Within this context, an intelligent product is defined as a physical and information-based representation that possesses a unique identity, communicates with its environment, stores data about itself, utilises an information model of itself and is capable of participating or making decisions [15]. This research is focused on the application of an intelligent RTI or container, which has knowledge of its constituent parts and is able to make decision not only for itself, but on behalf of the products it holds [16]. This paper looks at the performance of passive Ultra High Frequency (UHF) Radio Frequency Identification (RFID) tags with an on-board UHF RFID platform to enable the detection of metallic engine components such as cylinder heads and their corresponding separators. Figure 1 depicts a typical automotive cylinder head RTI, which is focus of this research. Figure 2 shows the fitment of a UHF RFID tag to a cylinder head.

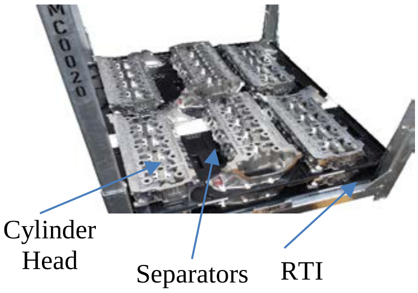

Figure 1. Cylinder Head RTI

Figure 2. Cylinder Head with attached RFID tag

2. The Intelligent RTI

In this paper, it is proposed that by developing a UHF RFID platform that can be embedded into RTIs, a new generation of active RTIs can be achieved with the ability to support Cyber Physical Systems (CPS) services and provide quantitative data about the RTI, its separators and any components it holds, thus acting as an intelligent container. This is to be combined with the embedding of passive RFID tags onto cylinder heads and separators, allowing them to be detected when placed onto an intelligent RTI. The collection of these unique identifiers from the RFID tags, inform the RTI of the exact components it has been loaded with and any corresponding information it may require, for example, assembly due date, processing route and other specific information that may be critical for the movement of the RTI. The UHF RFID hardware positioning in relation to the cylinder heads and components is shown in Figure 3. By removing material from the RTIs base, a UHF RFID antenna can be placed centrally under all of the loaded components (refer to Figure 4).

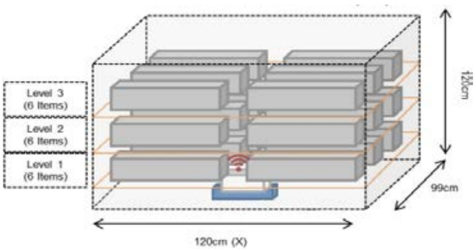

Figure 3. Intelligent RTI Layout

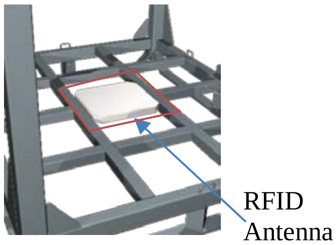

Figure 4. Antenna location

UHF RFID tags, such as the Alien® ALN-9640 tag, can be interrogated at around 9m away in an ideal environment [17]. However, significant performance degradation (e.g. a 57% reduction in signal strength when 150mm from metal) is observed when deploying RFID technology into harsh RF environments, such as near the presence of metal or water [18]. With the RTI being filled with aluminium cylinder heads the likeliness of RFID interference is high, especially when interrogating cylinder heads on layers above the bottom, as any RF signal propagation is influenced by additional layers of aluminium components. This means that there are significant technical challenges in the application, fitment and detection of components that must be addressed through experimentation and modelling [19].

3. Hardware

For this project, a UHF RFID hardware platform, known as smaRTI, has been developed for experimentation and research into intelligent containers. The hardware platform has an on-board ThingMagic® Nano UHF RFID module with a single antenna port and low power consumption (3.6W at full output power, +27dBm and 0.00025W in shutdown mode), ideal for battery powered devices. An ESP-12E Wi-Fi module from Espressif provides wireless communications (802.11 b/g/n) with an on-board PCB antenna. An integrated 32-bit microcontroller (160MHz) and 4MB flash storage device, provides the basis for on-board processing and storage capabilities with application software being developed under the Arduino IDE 1.6.8 [20] and the open source ESP8266 core for Arduino [21]. Embedded sensors such as 3 axis accelerometers & gyroscopes, compass, temperature, humidity and pressure, provide the RTI with the ability to monitor environmental conditions and utilise these data to determine further context information for the RTIs immediate environment. Events such as temperature or humidity excursions and physical collisions provide valuable information on the handling, transport and storage of RTIs and its constituent components. For experimentation, the cylinder head RTI was modified to fit an antenna (i.e. Alien® Technology ALR-8696-C right hand circularly polarised antenna). For component RFID tagging, off-the-shelf UHF RFID tags were used. The tags that were used in the experimentations are listed in Table 1. In particular, two types of tags were used, general-purpose RFID tags for the fitment to separators and *on-metal RFID tags* for the fitment to cylinder heads. *On-metal* RFID tags are optimised for placement on metal objects. In comparison, general-purpose RFID tags will be detuned by close proximity to metal and may cease being detected.

Table 1. Off-the-shelf UHF RFID tags for component and separator tagging

Manufacturer	Model	Type	Dimensions (mm) (WxHxD)
Alien	ALN-9640	Off Metal	94.8 x 8.15 x 0.25
Xerafy	Pico X II	On Metal	17.7 x 10.9 x 5
Xerafy	Nano X II	On Metal	31.7 x 12.8 x 4.8

Note: All tags use an Alien Higgs 3 RFID Chip.

4. Experimentation and Results

For experimentation, RFID tags were affixed in each of the identified potential tag locations. The tags were read 30 times and performance data (Received Signal Strength Indicator (RSSI), where larger values indicate higher performance) from the RFID hardware was recorded. Additionally, the Read Success Rate (RSR) was determined from the RSSI (0 is a no read) and was also used as an indicator of RFID performance.

Cylinder head separators are made of moulded ABS plastic with geometric features designed to locate the cylinder heads in a regular and controlled fashion. The component locations have a slight relief (5mm) that ensures heads remain in position. Eighteen (18) tag locations (see Figure 6) were identified where there was sufficient space for fitment of an Alien ALN-9640 (Squiggle) RFID tag. These locations include the external edges and in between cylinder head resting locations. Experimentation was carried out at full RF output power (+27dBm) and also at a reduced power (+18dBm), with all cylinder heads present. By reducing the output power of the RFID interrogator, energy savings can be made giving greater time between potential recharges or a reduction in required battery capacity. Figure 6 and Figure 7 represent the experimental results for +18dBm and +27dBm respectively. At full output power (+27dBm, Figure 7), all tag locations were successfully detected (all tags responded to a read command) at each separator layer, except positions 6 and 12 that failed on layer 2 and layer 1 respectively. Positions 1, 3, 4, 5, 7, 9 and 13 managed 100% RSR on each layer making them the most viable tag locations. It can be seen that at the lowest power setting (+18dBm) only tag position 7 continues to offer total visibility of each separator layer, with an RSSI value between 14,292 at 100% RSR (layer 2) and 5969 at 100% RSR (layer 3). Position 7 also achieves a 100% RSR with an RSSI range of 6357 to 49147 once all cylinder heads were removed (representing an empty RTI state). This makes position 7 the best location to fit an Alien ALN-9640 for the detection of component separators on this particular RTI layout and type.

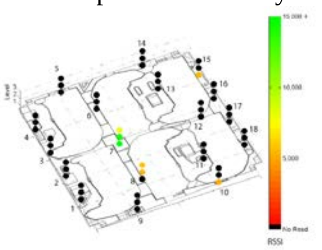

Figure 6. Separator testing at +18dBm output power with cylinder heads

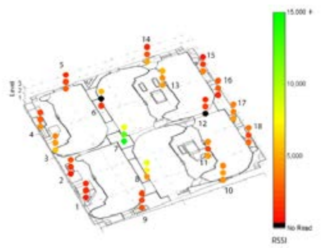

Figure 7. Separator testing at +27dBm output power with cylinder heads

The aluminium cylinder heads present a challenge as they are of all metal construction and thus cause detuning to general-purpose passive RFID tags. For experimentation a series of on-metal RFID tags were selected and tested when attached to various positions on the cylinder head. Results highlight two main contenders for the tracking of cylinder heads, the Xerafy Pico X II and Xerafy Nano X II. Both of these tags are an *on-metal* construction rather than *in-metal* and make use of adhesives for affixing to the cylinder head. In a simple range detection experiment, the Nano X II outperformed the Pico X II by 1.5m, a 60% increase (Nano X II read at 4m) and could be written to at up to 3m. Therefore, the Nano X II was placed onto the cylinder heads and measured when loaded into the RTI. Figure 8 and Figure 9 show the RSSI performance of cylinder heads on each layer with output power set at +18dBm and +27dBm respectively. It can be seen that at +18dBm only position 4 on the first layer can be detected (100% RSR). By contrast, at +27dBm the entire first layer of cylinder heads can be detected with RSRs of 100%, except position 5 with a 0% RSR. However, it should be noted that positions 2, 1 and 3 had cylinder heads that could not be detected on other layers, resulting in a total head detection rate of 69% which, despite not achieving the desired 100% detection rate, enables the majority of cylinder heads to be detected after they have been loaded onto the stillage. In terms of contextual information, the intelligent RTI can determine valuable information such as the presence of cylinder heads, and thus it's able to monitor and communicate this information to manufacturing activities or CPS services subscribed to this information.

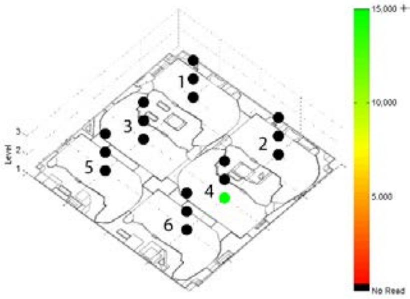

Figure 8. RSSI results for cylinder heads on 3 layers at +18dBm output power

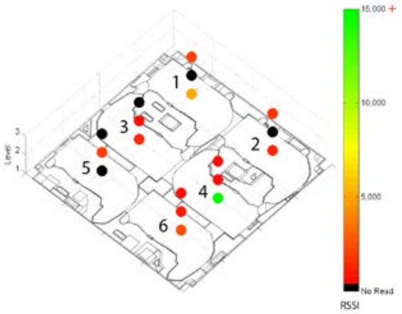

Figure 9. RSSI results for cylinder heads on 3 layers at +27dBm output power

Conclusions and Future Work

The challenges in embedding passive UHF RFID tags into cylinder heads and their separators has been investigated in the research outlined in this paper in order to enable the next generation of intelligent RTI containers. Despite difficulties with tagging metallic objects in harsh metallic environments that are characteristic of manufacturing plants, it has been shown that it is possible to achieve a 69% detection rate of cylinder heads and 100% of separators after they have been loaded onto the stillage. Despite not detecting each unique component, it is still possible for the RTI to infer the presence or absence of components using contextual data. Future work is required to develop the CPS services that can be deployed to take advantage of the increased information that an intelligent container can offer and to determine the effect of relocating antennas to the loading actuators and stations where each part can be interrogated individually. Additional work will also include determining how embedded sensors such as temperature, humidity and accelerometers, gyroscopes and compass can be reliably used to provide further information about the tagged components and RTIs, such as detecting collisions, humidity excursions and determining location.

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