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Real-Time Location Systems Across the Industries - Literature Review and Case Studies

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Abstract: Real-Time Location Systems (RTLS) are pivotal in enabling the instantaneous tracking and monitoring of objects, contextualized within their immediate environment and time frame. The current industry landscape boasts a plethora of technologies and services, showcasing RTLS's expansive potential in the manufacturing, healthcare, and logistics sectors. This article endeavours to elucidate a holistic understanding of RTLS's technical proficiencies while transcending the confines of a myopic view limited to isolated solutions. It posits that RTLS-based infrastructures can be methodically engineered utilizing this technology, fostering advancements in industrial applications. The synthesis presented herein integrates extensive research and practical implementations of RTLS across various industrial sectors, aiming to augment the proposed RTLS framework within warehouse operations.

Keywords: RTLS; industry; monitoring; tracking; warehouse management;

1. Introduction

The growing trend of digitalization in manufacturing, often linked with concepts such as Industry 4.0, smart manufacturing, or the industrial internet, holds significant importance in the industrial sector [1]. This progression is paralleled by the adoption of Internet of Things (IoT) technologies in industrial contexts, an advancement commonly termed the Industrial Internet of Things (IIoT) [2]. IIoT is prominently marked by the seamless integration of industrial devices and the open sharing and accumulation of data throughout various stages and operations within a company [3].

In the IIoT framework, having real-time information on the whereabouts of various objects in a factory is a crucial element that spans numerous application areas. The common method for identifying specific objects within a space involves the use of tracking technologies [4]. Systems that monitor individual (moving) objects in real-time are known as Real-Time Location Systems (RTLS, the term used in this paper) or Indoor Positioning Systems (IPS) [5].

In addition to relaying an item's location (coordinates), it can also transmit additional information like temperature or condition to the system. The foundational principles of RTLS, as well as the relevant technologies and algorithms, are well-documented. Moreover, RTLS has been applied in various fields, as evidenced by numerous case studies in both research and real-world applications, including sports (for tracking athletes), healthcare (for locating beds, patients, or medical staff), and logistics environments like warehouses and manufacturing companies.

Warehouses are becoming more reliant on RTLS to enhance their overall value through the automated tracking of goods and real-time monitoring of interactions. RTLS, as described by [7], refers to wireless networks that accurately pinpoint the location of objects within a certain area, either instantly or with minimal delay. A recent UK study revealed that distribution centres lose approximately 3000 hours

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each year due to inefficient workflows. The survey involved 250 leaders from various industries related to supply chain, warehousing, and distribution. The potential for future production delays can be linked to inaccuracies and inefficiencies in managing pallet inventories within storage facilities. Reports suggest that these delays can last up to three hours, causing substantial financial and operational challenges. With the implementation of RTLS, it will be possible to immediately obtain information on the movement paths and speeds of forklift drivers, as well as the exact positions of pallets and forklifts [8].

This research aims to conduct an in-depth analysis of the practicality of RTLS in different areas. It seeks to ease the adoption of RTLS by offering a structured approach for its application and to contribute as an essential asset for subsequent studies and advancements in this domain. A broad review of literature was carried out to explore future possibilities, utilizing various scholarly web databases including Web of Science, Google Scholar, ACM, IEEE, Gartner, Scopus and Science Direct.

1.1. RTLS Technology

Real-time location systems (RTLS) are wireless systems capable of accurately identifying and tracking items within a designated space, ranging from local areas like campuses to broader regions globally. These systems comply with standards set by the International Organization for Standardization (ISO) and offer low-latency performance, delivering almost instantaneous data on the location of monitored objects. The pinpointing of positions in radio networks is determined by assessing physical parameters [9].

RTLS can be also defined as a method of obtaining location information through radio frequencies. However, some systems utilize different technologies like infrared light (IR) and ultrasonic sound (US), as well as combined solutions that integrate infrared and radio frequency (IR-RF, US-RF, IR-US-RF) [10]. Infrared (IR) and ultrasonic (US) waves can overcome some limitations of radio signal coverage due to their barrier-penetrating capabilities. For instance, "US" can be used to precisely differentiate between closely situated rooms. The characteristics of RTLS depend on the technology employed. Thus, choosing a real-time location system involves a complex decision-making process that requires evaluating various factors, both qualitative and quantitative. Technologies commonly used in real-time location systems include Wi-Fi, radio frequency identification (RFID), ultra-wide band (UWB), ZigBee (based on IEEE802.15.4), Bluetooth (BT), and infrared (IR) [11].

The variety of locations and communication technologies supporting Real-Time Location Systems (RTLS) is growing. The choice of technology is influenced by various factors, such as the environment of installation and use, specific use cases, regulatory compliance, and existing infrastructure. These factors collectively determine how the technologies are utilized. Often, businesses opt for technologies like Wi-Fi or active RFID that they already use, aiming to make processes more efficient and reduce expenses [12]. The RTLS infrastructure is composed of four primary elements. Tags are attached to objects that need to be tracked for identification purposes. Fixed-position devices communicate wirelessly with these tags and a location engine. The location engine is a software application that processes data from the locating

Table 1. Main RTLS technologies comparison [13]

	Active RFID	*Bluetooth*	*WiFi*	*UWB*
Range	Up to 100 m	Up to 100 m	Up to 50 m	Up to 100 m
Accuracy	2 m	1-2 m	10-15 m	0.3 m
Tag price (€)	~20-30	~20	~50-100	~15-70
Anchor price (€)	~500-5000	~25	Uses existing access points	~100-200
Battery life	2-3 years	5+ years	1-2 months	2-5 years
Security	Medium	High	High	High
Other characteristics	Prone to signal interference	Latent; prone to signal interference	Uses existing networks; requires dense reader coverage	Least prone to signal interference; works best in line-of-sight scenarios

devices to determine the exact locations of the tags. User interfaces and applications are essential for integrating RTLS with backend systems.

According to [13], the wireless technologies that facilitate communication between tags and readers encompass WiFi, GPS, infrared, Bluetooth, and both active and passive RFID systems. Table 1 provides a detailed comparison of these technologies, highlighting their unique features and the performance metrics that determine their appropriateness for various applications.

Passive RFID tags, which require activation by a radio frequency signal from a scanner and lack the capability for real-time tracking, are not suitable for use with Real-Time Location Systems (RTLS). Therefore, we pay attention only to active RFID tags. These tags are commonly used for indoor asset tracking and for monitoring containers or pallets at the shipment level in warehouses due to their long-read range of up to 100 meters and their location precision of 2-3 meters.

2. Utilization of RTLS

The applications for real-time location systems (RTLS) are vast and varied. Such technology could offer a practical answer for businesses struggling with the lack of immediate data regarding the location of their resources. There's a significant amount of research on RTLS within the manufacturing, construction, warehousing, and healthcare sectors. A study referenced as [14] details the deployment of an RTLS in an elderly care facility in Antwerp, which successfully tracks the real-time positions of both staff and patients and archives this information for subsequent analysis. During emergencies, patients can alert others through the system. Staff can then quickly and precisely identify and locate the patient who triggered the alarm. Another study utilized RTLS to evaluate patient movement within a hospital [15].

To summarize, the healthcare industry has utilized RTLS to track the movement and status of items, staff, and patients. The system was notably adopted by Singapore during the COVID-19 pandemic to monitor medical staff movements, as detailed by [16], authors confirmed RTLS's effectiveness in identifying potential staff-patient interactions. The research suggests that BLE/WiFi-based asset tracking systems are critical for healthcare facilities, offering benefits to nursing operations. However, to fully leverage these systems' capabilities and improve user satisfaction, certain technical and managerial challenges must be addressed.

Figure 1: Example of RTLS utilization in healthcare industry [15].

RTLS technologies are implemented in warehouse operations to boost efficiency and customer satisfaction. They autonomously manage tasks such as inventory audits, storage organization, and quality checks [7]. Additionally, RTLS ensures the continuous monitoring of product stocks [17]. In manufacturing, RTLS advancements aim to streamline production by offering real-time material tracking [3, 6, 12]. Recognizing the high accident risk in construction, RTLS is employed at some sites to actively monitor both personnel and materials to enhance safety management [13].

2.1. RTLS in Warehouse

Warehouses are intricate environments where numerous processes such as picking, storage, planning, and routing occur, and where safety and operational efficiency are critical markers of effective management. A common issue in warehouses is when pickers cannot accurately locate an item destined for a customer. Similarly, a problem occurs when a forklift operator loses track of a pallet after scanning it. To solve these challenges, RTLS has been implemented in warehouses [7].

A conventional RTLS utilized in warehousing environments is comprised of four principal elements: identification tags, signal receivers or anchors, a middleware platform for data storage and processing, and an enterprise application. One may opt for an integrated solution provided by a single vendor, which includes system configuration and customization tailored to specific operational needs or procure each component independently and subsequently integrate them into a cohesive system (Fig. 2) [18].

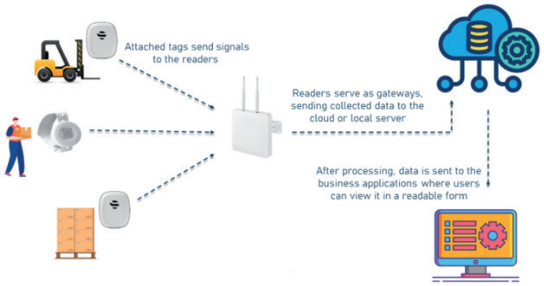

Figure 2: Typical RTLS infrastructure [18].

Tags are affixed to assets or individuals and are programmed to broadcast information encompassing identification, location, and temporal data at specified intervals (ranging from every second to several minutes, contingent upon system configuration). These tags may be augmented with sensors for the collection of ancillary data, Light Emitting Diodes (LEDs) for visual signalling to facilitate prompt recognition, and an emergency button feature to initiate urgent notifications (Fig. 3) [19].

Figure 3: UWB tags for indoor location tracking from Sewio company [19].

Anchors, which are reading devices installed throughout the warehouse, create an interlinked mesh network that captures signals emitted by tags. Their role is comparable to satellites in a GPS, which may help clarify their purpose. Depending on the supplier's specifications and the site of installation, these anchors may be connected to a power supply or operate on batteries. The requisite quantity of anchors is determined by the characteristics of the warehousing environment and operational requirements, such as the dimensions of the area, the feasibility of maintaining unobstructed sightlines, and the preference for two-dimensional or three-dimensional tracking capabilities. For instance, four Ultra-Wideband (UWB) anchors can encompass an area up to 50 by 50 meters with a clear line of sight to ensure precise tracking. In scenarios where the environment presents complexities, consultation with an RTLS specialist is advisable to strategically plan anchor placements. Alternatively, one may elect to design the RTLS framework independently using specialized software tools like the Sewio RTLS planner (Fig. 4).

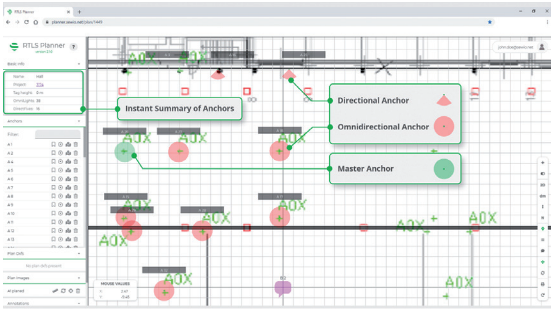

Figure 4: Sewio RTLS Planner [19].

Storage/processing middleware serves as the central repository and computational hub for data, incorporating a location engine to pinpoint the positions of monitored items. It can be hosted on cloud services or locally, with the former offering greater scalability and power, while the latter is favoured by some organizations for enhanced data security. Servers transform raw data into actionable insights, which are then relayed to enterprise management systems through application programming interfaces (APIs), enabling user interaction and utilization (Fig. 5) [19].

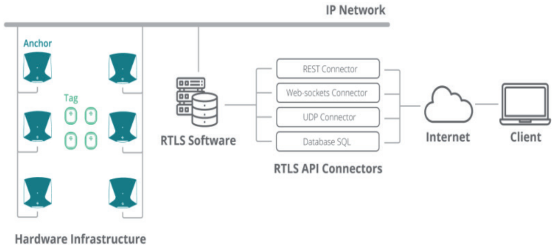

Figure 5: API documentation from Sewio [19].

A warehouse management system (WMS) application orchestrates the selection and distribution of items based on the production department's schedule, facilitating data interchange between warehouse and production operations. In the event of a component shortfall, an immediate order signal is dispatched to the warehouse sector. Upon receiving detailed component requirements from the production department, the warehouse expedites the retrieval and delivery of components to the production line. The warehouse can strategically schedule the receipt and assembly of components at staggered intervals to avoid concurrent loading and unloading activities. This approach is anticipated to yield cost savings in transportation and labor, as well as enhance equipment efficiency [20].

2.2. RTLS use cases

As stated by [15], logistics expenses, such as time spent driving trucks and fuel consumption, can be minimized through real-time management of the locations of stored goods using specialized systems. Effective management of item locations is pivotal for reducing logistical operation costs. Consequently, their warehouse construction incorporated the use of RFID ceiling tags, which are affixed to the upper structure of the facility.

According to a study conducted by [21], researchers found out that the most time-consuming and expensive part of warehouse operations is the item retrieval process. The study showed that using iBeacon (RTLS provider) for indoor positioning significantly reduced the time taken to gather orders. Specifically, it decreased picking times from 17.2 to 3.1 minutes, achieving a 91.2% efficiency increase in the finished goods warehouse, and from 6.2 to 1.9 minutes, marking a 96.8% improvement in the raw goods storage area.

Another case study by a company specializing in RTLS technologies, it was reported that the implementation of RTLS at HANGCHA, a prominent Chinese handling equipment manufacturer, resulted in a significant reduction in search time. The time required to locate items decreased from 10-15 minutes to merely 1 minute, thereby markedly enhancing productivity [22].

Table 2 presents a summary of case studies and practical applications related to certain areas of RTLS utilization.

Deployment of RTLS across various sectors - ranging from warehouse logistics to healthcare, manufacturing, and construction - has markedly revolutionized operational efficiency. The utilization of RFID, iBeacon, and other RTLS technologies has not only optimized inventory management but also led to significant reductions in time and costs associated with locating and retrieving items. The compelling outcomes highlighted in case studies demonstrate the transformative impact of RTLS, affirming its critical role in enhancing productivity and competitiveness in diverse industries.

Table 2. RTLS implementation – case studies

Area	*Application*	*RTLS type*	*Source*
Healthcare	COVID Tracking	RFID	[16]
Healthcare	Asset tracking system	BT/WiFi	[23] [24]
Healthcare	Staff tracking	WiFi	[25]
Warehouse	Automation in warehouse	RFID/ WiFi	[26]
Warehouse	Warehouse and operational safety	UWB/ RFID	[7]
Warehouse	Trajectory prediction	UWB	[11]
Warehouse	Order picking	UWB	[27]
Manufacturing	Production process	RFID/ UWB	[28]
Manufacturing	Asset tracking	UWB	[29]
Construction	Safety tracking	RFID	[30]
Construction	Safety tracking	RFID	[31]
Construction	Material and staff tracking B	BT	[21]

3. Discussion

To fulfil the aims of this research, an extensive review of the literature was conducted, encompassing selected scholarly papers, articles, discussion boards, and credible digital platforms. The intent behind this comprehensive survey was to acquire a deeper understanding of RTLS applications in practice, especially within the realm of industrial activities centred around warehousing. A multitude of scholarly databases such as ACM, IEEE, Scopus, Google Scholar, Science Direct, Gartner, and Web of Science were explored for the period between 2006 and 2024 to identify relevant academic works. A collection of terms and keywords was curated, encompassing "Real-Time Location System," "Warehouse," "Manufacturing," "Healthcare," and "Construction." The selection methodology involved a thorough review of titles, abstracts, and keywords within the search findings to pinpoint articles, papers, discussion forums, and websites relevant to the subject at hand.

This exploration has revealed the multifaceted nature of RTLS, highlighting its significance in enhancing operational efficiency, accuracy, and safety in warehousing environments. The findings underscore the technology's evolution and its growing integration with other cutting-edge technologies such as IoT, AI, and machine learning, suggesting a trend towards increasingly sophisticated and interconnected industrial systems.

4. Conclusions

This literature review aimed to conduct an in-depth analysis of how RTLS can be applied in warehousing and other industries. The analysis scrutinized the value of location data and pinpointed the most effective traceability technologies for real-time location tracking in various scenarios, thereby ensuring effective traceability. The summary of this paper has proven to be highly valuable for further exploration into RTLS implementation in warehouses. Future research could focus on refining the RTLS framework proposed, to better suit the operational needs of warehouse management.

Adding to this, it may also be beneficial to investigate the integration of RTLS with other digital transformation initiatives within warehouses, such as automation and data analytics, to further enhance efficiency and productivity.

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