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Medical Asset Tracking Technologies in Healthcare: A Review

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This study evaluates the literature on the application of barcodes, radio frequency identification (RFID) and ultra-wideband (UWB) for asset tracking in healthcare. These existing tracking technologies in healthcare are reviewed and compared in terms of suitability for asset tracking. The paper provides an overview of the system structure for each technology and their application in various areas within healthcare. Attributes such as working principle, read range and read rate are also compared. Barcode technology exhibits the highest performance for single-tracking medical equipment, while RFID and UWB systems are more effective for real-time equipment tracking. However, these technologies have drawbacks including dependency on power for UWB, line-of-sight operation requirement for barcode technology and less precision in equipment tracking with RFID compared with UWB. Ultimately, the choice of tracking technologies depends strongly on specific organizational goals.

Keywords: healthcare, barcode, RFID, UWB, medical equipment tracking

1. INTRODUCTION

A fully responsive healthcare system requires efficient medical resources and entity management. Implementing such a system is challenging but is essential to safeguard patients' welfare because even the smallest error may result in life and death decisions [1, 2]. Medical assets play significant roles in the quality of healthcare services. Healthcare institutions typically experience shortage and malfunction of medical equipment, and these conditions negatively affects the delivery of healthcare services to patients [3]. In some instances, transportable medical devices, such as intravenous (IV) pumps, heart monitors and other high-value equipment, are prone to be misplaced, lost or stolen in healthcare facilities. As the instruments may have similar physical appearance and operation, they are readily misidentified [4]. When supplies are insufficient, emergency orders must be made. This situation adds to the labor costs, prolongs treatment time and even potentially endangers a patient's life [5]. Hospitals commonly lose 10% of their inventory annually, and medical personnel spend 25% to 33% of their time searching for biomedical equipment [6, 7]. Therefore, a comprehensive overview of the location and availability of all relevant equipment is vital to reduce inventory searching time and increase the quality of healthcare services.

The Internet of Things (IoT) and smart technologies have opened new possibilities

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and opportunities in healthcare by improving patient care and increasing the security of the entire healthcare ecosystem [8]. The integration of IoT and medicine has formed a new paradigm known as the Internet of Medical Things (IoMT) [9]. In the last decade, IoMT applications have increased, including the need for location-tracking services in outdoor and indoor situations [10]. This development ensures that medical equipment cannot be lost and can be located; this feature is advantageous for busy medical facilities, such as general hospitals or clinics [11]. The use of location tracking technology in the healthcare context may elevate new prospects for medical equipment management [12]. With the incorporation of smart technology, such settings are gaining increasing attention among researchers and industrialists to improve existing systems and fit today's digital environment [13].

The review article is driven by the following research question: (1) What are the existing tracking technologies in healthcare; and (2) How do different technologies such as barcodes, radio frequency identification (RFID) and ultra-wideband (UWB) compare in terms of suitability for asset tracking. In this paper, these technologies are comprehensively reviewed. Near-field communication is also a potential technology to be implemented for research purposes, but it was excluded from this work because of lack of related literature. The state-of-the-art for these systems and their applications in the healthcare environment, particularly medical equipment tracking, is presented. The existing technologies are also compared in terms of equipment tracking and performance.

2. OVERVIEW OF EXISTING TRACKING TECHNOLOGIES

In this section, three tracking technologies, namely, barcode, RFID and UWB, were reviewed. Each tracking technology is discussed based on the system's architecture and application in healthcare.

2.1 Barcode

The original concept of barcode was inspired by the Morse code [14, 18], which uses dots that expand into alternating black and white lines [19]. Barcode was developed in the 1970s [20]. It was scanned by combining 500 W light bulbs with a photomultiplier, a technique that is commonly employed in the film industry. This approach increases the light's brightness and facilitates the scanning procedure. With an increasing number of businesses seeking to save expenses and implement an inventory system, better technology was required to make the system more practical. As the history of barcodes progresses, new concepts and advancements began to emerge [21].

Barcode technology is employed in various hospital departments, such as laboratory, pharmacy and radiology, and for procedures, such as drug administration. The use of barcodes precludes human error in the inventory of supplies or equipment. This feature allows the healthcare administration to decrease waste, perform frequent inventory inspections and ensure the adequate quantity of medical supplies [22, 23].

2.1.1 System architecture

A barcode is a set of vertical lines with different widths printed onto a strip of paper and attached to items with alphanumeric information. The typical form of a barcode is a basic linear pattern or a more complex 2D structure (Fig. 1) [24, 25]. A barcode can be easily recovered and decoded by a barcode reader according to its width and pattern. A barcode alone is not a system, but it entails an identifying instrument that provides precise, real-time and fast data support for complex management systems [25, 26].

(a) (b)

Fig. 1. (a) Defibrillator machine; (b) QR code example on a nebulizer machine.

In a linear bar code, an identification number is encoded as a string of 12 digits that serve as a link to the system. George Laurer, an IBM consultant, created the 12-digit code known as the Universal Product Code (UPC), which is still relevant today [27]. The first six digits of the UPC barcode represent the manufacturer, and the last six digits indicate the item. Given the international adoption of the UPC, a more extensive code was required. The International Article Number, formerly known as the European Article Number (EAN), has made global usage possible. With the widespread acceptance of EAN/UPC as standards, approximately 5 billion barcodes are scanned daily throughout the globe [21].

Similar to the quick response (QR) code, 2D barcodes include data horizontally and vertically, instead of solely using the horizontal orientation. The Intermec Corporation created the very first 2D barcode and designated it as Code 49 in 1988. In 1994, Denso Wave, a Japanese company, introduced the QR codes that we are currently using. 2D barcodes allow a higher storage capacity with up to 7089 characters and may be accessed when they are linked to mobile devices with cameras [21, 25, 28-30]. According to [31], QR codes can facilitate the ordering, management and tracking of medical offices and hospital equipment, such as air ionizers, nebulizers and patient lifts. Healthcare professionals have a strong inclination towards the utilization of 2D Data Matrix in a significant majority of cases (90%) [32].

2.1.2 Applications in healthcare

Sales team reports of trackable hospital fixed assets, such as medical devices and supplies, are sent monthly to the head office in a project conducted in [21]. The authors measured and analyzed the efficiency of the vaporizer device per hospital by tracking the monthly gas usage through a QR code. The results indicated the generation of accurate information, such as the ownership of the equipment to its respective hospital, details of the supervisor and creation date.

According to [33], the Singapore General Hospital deploys a real-time tracking system for surgical tool processing. Since the implementation of this approach in 2010, the system has saved approximately 2,000 hours of labor every month.

A repair management system for hospital medical equipment utilizes various QR code applications. The primary objective is to enable equipment or facility engineers to quickly collect extensive equipment information and restore the regular operation of medical equipment. The implementation of the system has eliminated waiting time because of insufficient information and increased repair efficiency [34].

2.2 RFID

RFID is a wireless identification system that uses radio waves to identify, track, sort and/or detect a wide range of items in various applications, including product identification, healthcare, supply chain management, access limitation within a facility, location of objects or people determination. In comparison with barcode, RFID does not require line-of-sight (LOS) to identify an object; an RFID reader can scan multiple items at once, indicating its versatility in different fields [35-37]. RFID is positioned as a lucrative new business in the healthcare industry. The RFID tags and systems business model increased rapidly from USD 94.6 million in 2009 to USD 1.43 billion in 2019. This growth is primarily attributed to the development of applications, such as real-time locating system (RTLS) for tracking assets, medical personnel and patients [38, 39].

2.2.1 System architecture

RFID systems primarily include hardware (tags, antenna and readers) and software (Figure 2). Data are encoded in a chip implanted in the tag and communicated between a reader (interrogator) and a tag (transponder). Active (battery powered) or passive (non-battery powered) tags can be integrated with an antenna and packaged into a final label (powered by a reader field).

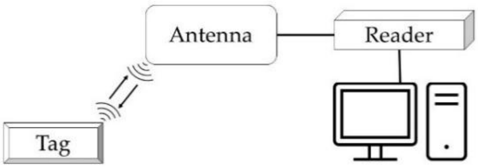

Fig. 2. Overview of RFID system.

2.2.1.1 Tag

An RFID tag consists of two parts: an antenna for sending and receiving signals and an RFID chip, which is also known as an integrated circuit (IC). The chip holds the tag's ID as well as other information known as entities. An RFID reader and antenna are used in conjunction with RFID tags that are attached to the tracked items [7, 40, 41]. Depending on how they are powered, RFID tags may be categorized as passive or active. Passive RFID tags can only communicate with the reader when they are within the reader's electromagnetic field; meanwhile, active RFID tags can power the ICs and transmit the response signal to the reader [7, 42].

Active tags are powered independently [43] and possess a built-in battery to supply power to the tag [44]. These tags have a larger data capacity than passive tags. An active RFID tag can cost from USD 15 and higher [45, 46]. An active RFID tracking system is an excellent option for tracking patients or valuable equipment [47].

Passive tags are energy-independent tags [48]. They utilize the reader's energy to power the microchip by altering the input impedance [49]. The tag used in a previous experiment [50] costs approximately USD 0.25. A passive RFID tag with a range of less than

3 ft can be purchased for approximately USD 0.10 to USD 1.50 [51]. Passive RFID tags are inexpensive and have low maintenance and are therefore suitable for small, low-cost object access control, theft prevention and inventory tracking [52].

2.2.1.2 Antenna

An antenna is an essential component of an RFID system [53] because it simultaneously transforms the signal from the RFID reader into radio frequency waves. RFID antennas are positioned around the objects of interest, such as beds in hospital rooms, to create a coverage area for desired wireless applications [54, 55]. Most RFID antennas range in price from USD 50 to USD 300 [40] and EUR 20 to EUR 200 [54] depending on their specifications and requirements.

An antenna gain plays a significant role because it translates the strength of the antenna to generate a range of waves in a specific direction [56]. A higher antenna gain indicates more powerful antenna with further reach [40]. Antennas are categorized into directional and omni-directional types. A directional antenna, also known as a beam antenna, sends or acquires more power in one direction [57]. An omni-directional antenna sends radio waves in all directions within 360°, and any tags within the range will be able to pick them up [58]. According to [59], directional antennas performed significantly better than omnidirectional antennas; they can pick signals up from farther distances by reducing their capability to pull signals from other directions

2.2.1.3 Reader

An RFID reader, as described by [40], is the brain of the RFID system, and it is essential to the operation of any system. This device can broadcast and receive radio waves by continuously transmitting a signal to connect to RFID tags [60]. The reader can only detect tags within the interrogation region. The tag uses the electromagnetic signal emitted by the reader to activate its components, access the stored data and transmit it back to the reader. This phenomenon is referred to as ‘backscattering’. Typically, the reader is linked up to a host computer, which performs further signal processing and displays the information of the tags [61, 62]. The RFID reader can range in price from USD 400 to as much as USD 3,000 [40]. Many UHF readers cost between USD 500 and $2,000, based on the device’s characteristics [63].

2.2.1.4 Host computer

RFID software on the host analyses data and conducts various filtering operations to minimize the duplicative reads of identical tags to a manageable and relevant data set [64]. An RFID system has two components. The first component is responsible for handling RFID tag readings within the range of the antennas, storing data and updating the database. The second one has a graphical user interface, wherein data from the database are kept [54]. The data are utilized to manage communications between the RFID network and various intra- and inter-organizational systems [7]. [65] used Midmark Asset Tracking and Management software to store the location transmitted from the asset tags located on an IV pump; they also used periodic automatic replenishment technique to manage the inventory. The average cost of RFID software is USD 200,000 [66].

2.2.2 Applications in healthcare

Based on previous articles [7, 54, 65, 67], the RFID technology was adopted in hospitals in three (3) areas. Namely trauma centres, emergency department and hospital rooms.

Table 1. Examples of RFID utilization in the healthcare.

Studies	Year	Hospital Area	System	Result
Shokouhifar [7]	2021	Trauma centers	swarm intelligence RFID network planning model with multi-antenna readers (RNP-MAR)	The proposed method achieves an average cost reduction of 39.57% in the total expenses of the RFID network by effectively utilizing multi-antenna RFID readers.
Álvarez López *et al.* [54]	2018	Hospital Room	implementation of an ultra-high frequency (UHF) RFID system	The UHF RFID technology is capable of efficiently tracking medical asset and can be seamlessly integrated into medical information systems.
Angeles [65]	2021	Emergency Department	RFID-based RTLS system to track IV pumps by using the Tornatzky's technology-organization-environment framework	The implementation of RFID technology leads to advantages such as increased job satisfaction among medical staff, improved workflow efficiencies through the use of tracking technologies, and enhanced patient care.
Adame *et al.* [67]	2018	Rehabilitation Area	combination of RFID and Wireless Sensor Network (WSN) technologies	The real-time tracking system can precisely identify the position of assets at both the zone and room level.

(A) Trauma Centers

The Sacred Heart Medical Centre Oregon implemented an RFID-based RTLS system to track IV pumps. The researchers the researchers interpreted and comprehended this RFID implementation by using the Tornatzky's technology-organization-environment framework [65].

(B) Emergency Department

Shokouhifar [7] introduced the swarm intelligence RFID network planning model with multi-antenna readers (RNP-MAR) to efficiently track medical assets in the Emergency Department of Iran's Parsian Hospital, Tehran. RFID network planning (RNP) is crucial for effectively monitoring assets with considerations for higher economic efficiency and optimal placement to achieve the best coverage of readers. The overall expense of an RFID system is primarily determined by the quantity of readers deployed inside the network. The primary advantage of the RNP-MAR model is that it employs multi-antenna RFID readers, thereby reducing the total cost of the RFID network and enabling it to successfully increase the network coverage with fewer readers and antennas.

(C) Hospital Room

Álvarez López *et al.* [54] investigated the implementation of an ultra-high frequency (UHF) RFID system in Rooms 312 and 314 of the Central Hospital of Asturias, Spain. Their work presented a proof-of-concept based on UHF-RFID technology. The system provides a basic architecture for tracking medical items and drugs and can be easily integrated into medical information systems and network infrastructures in most hospitals.

(D) Rehabilitation Area

Adame *et al.* [67] implemented the combination of RFID and Wireless Sensor Network (WSN) technologies to track wheelchairs near the warehouse of the rehabilitation department of the Hospital Asepeyo Sant Cugat del Vallès (Barcelona). The integration of both technologies provides a centralised and autonomous performance, without the need for human intervention. At the same time, the system was able to locate all the wheelchairs and activate an alarm if a wheelchair left the rehabilitation area, preventing it from being lost.

2.3 UWB

UWB can identify an individual or item with centimeter-level precision. In contrast to conventional RFID systems, which utilize a single radio spectrum band, UWB transmits a signal over multiple channels and frequencies. UWB uses nanosecond-scale time-compressed ultrashort pulses with a low duty cycle. Mobile nodes tagged to target individuals or assets can be precisely discovered and monitored using a network of fixed-position UWB wireless local area network node [70-72].

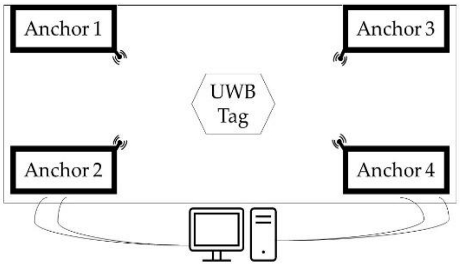

Fig. 3. Overview of UWB system.

2.3.1 System architecture

The UWB system consists of tags attached to assets, a UWB reader to detect pulses transmitted by tags and a system/software for coordination, information storage and full control of the tracking assets. Fig. 3 illustrates the system architecture of UWB.

2.3.1.1 Tag

The UWB location tag consists of several components: a microcontroller unit, battery, audio-visual alarm module, wireless transceiver chip, programming interface, antenna and crystal oscillator [73]. A tag is affixed to the device to monitor its location. The medical device must remain within the proximity of the anchor for effective tracking. Communication between tags and anchors is facilitated by the UWB network [74]. According to [75], the estimated price for a UWB tag is USD 15 depending on the specification needed.

2.3.1.2 Antenna

The UWB antenna transmits and receives electromagnetic energy in small intervals [76]. UWB has a bandwidth above 500 MHz as classified by Federal Communications Commission [77, 78]. It has a high data transmission rate, low spectral power density and few interferences. As a result, the UWB radio communication technology is applied to high-speed communication (more than 100 Mbps). The two common UWB antenna patterns are directional and omni-directional. In directional UWB antennas, transmission and reception of high-powered signals are restricted to specified directions. The emission pattern improves the antenna's performance and decreases interference. The Vivaldi antenna is an example of a co-planar UWB antenna with a directional radiation pattern. Omni-directional UWB antennas provide effective communication at all angles between a transmitter and a receiver. Researchers have developed other UWB antenna patterns, including rectangle, ellipse, octagonal, planner UWB and binomial curve, rhombus and bow-tie antennas to increase the bandwidth, improve the performance and achieve a low profile while maintaining small dimensions that are available for the antenna [79-81].

2.3.1.3 Receiver (Anchor)

An anchor is an electronic device that identifies the UWB signals emitted by mobile UWB tags [82]. A localization method decodes the location-dependent properties of signals passed between the tags and anchor nodes to determine the location of an object [83]. Two common localization techniques for UWB are Time of Flight (TOF) and Time Difference of Arrival (TDOA) [84]. Overall, TOA is more accurate than TDOA because it uses two way ranging (TWR) approach [85], in which tags and anchors broadcast and receive signals in turn [86]. TDOA is based on the calculation of the difference in signal arrival times between the synchronized anchors and tags [87]. The vast majority of current UWB systems rely on multi-anchor configurations [88], and users can select the best combination of anchors according to the requirements needed.

2.3.1.4 System

Localisation systems based on UWB (summarized in Table 2) include, but are not limited, to the following.

(A) Ubisense

Ubisense is a pioneer company that introduced the UWB localization technology to the commercial sector. The Ubisense positioning system comprises a network of sensors that are strategically placed in fixed locations, along with UWB tags that have predetermined positions. The sensors are equipped with a UWB radio receiver that is connected to an array of antennas. The sensors determine the positions of the Ubisense tags by analyzing the UWB signals received from the tags. Each individual sensor autonomously calculates the azimuth and elevation angles of arrival of the UWB signal, thereby supplying each tag with a bearing. The computation of TDoA involves the utilization of information obtained from sensor pairs that are connected by a timing cable [89].

Table 2. Comparison between UWB commercialized system.

Attributes	Ubisense	Bespoon	Decawave
UWB implementation	Fixed network of sensors and UWB tags	UWB integrated with smartphone	UWB fully integrated with CMOS chips
Localization technique	Combination of Time difference of arrival & Angle of arrival	Time of arrival	Either Time-of-flight or Time difference of arrival
UWB RF channel	6 – 8 GHz	Channel 2 3.99GHz	Channel 2 & 5 3.99 GHz & 6.48 GHz
Range	Greater than 160m	Up to 880m	Up to 300m
Price	€26 900	€1699	€853

(B) Bespoon

Bespoon is a French startup enterprise that specializes in the development of IR-UWB technology for practical applications. The group successfully integrated the UWB technology into a smartphone and, consequently, set a significant standard. The company's products are marketed and supplied as modular kits under the brand UM100, which can be exploited for developing customized solutions. The modules provide high levels of precision, with a resolution of 0.1 m. They also offer an extensive range of up to 880 m under LOS conditions. Furthermore, these modules exhibit a receiver sensitivity of 168-118 dB [89].

The SpoonPhone, a prototype designed for study and review, has been sent to developers specializing in hardware and software. The UWB radio of the SpoonPhone can be activated in a manner analogous to the activation of a phone’s Wi-Fi/Bluetooth low-energy radio through menu selection. It utilises the two-way TOA ranging. The UWB antenna is employed for Wi-Fi connectivity and is displayed in the upper-left corner of the screen. Software developers are provided with a software development kit (SDK) application programming interface (API), which facilitates immediate access to data from mobile devices and various small tags [89].

(C) Decawave

Decawave DW1000 modules are fully integrated low-power complementary metal-oxide-semiconductor device. TWR ToF measurements are used to provide range readings with a precision of 0.1 m. By employing either TWR ToF or one-way TDOA approach, the manufacturer expects to attain a real-time location precision of approximately 0.3 m in the X and Y axes for a mobile tag. A maximum detectable range of 300 m can be achieved under ideal circumstances [89].

The results of the comparative analysis undertaken by Ruiz and Granja [89] indicate that DecaWave exhibits superior performance compared to BeSpoon, and both demonstrate superior performance in contrast to Ubisense equipment. The Ubisense system was introduced in 2009, followed by BeSpoon in 2015 and DecaWave in 2016. The DecaWave device utilizes a more sophisticated antenna system compared to the BeSpoon equipment. The BeSpoon equipment is a compact implementation housed within a small tag, where a segment of the ultra-wideband (UWB) system is integrated with the phone's electronic components. The expensive Ubisense technology, characterized by the utilization of large array antennas and the need for synchronization and powering connections, does not yield enhanced precision.

2.3.2 Applications in Healthcare

Romme *et al.* [90] performed UWB channel measurements in a newly built hospital made of lightweight construction materials. The tests were performed on the second floor of the Médecins Sans Frontières, Belgium to determine the suitability of UWB for indoor localization in a hospital setting. Anchors were positioned at service terminals or emergency lights in a realistic scenario, such that future anchors can be readily integrated into the current infrastructure. The radio channel was tested between 5 and 10 GHz with a 120 dB link budget to evaluate system parameters on localization accuracy, such as bandwidth scaling and link budget reduction.

A previous study [91] was based on a measurement campaign in an actual hospital setting at Oulu University Hospital, Finland. The UWB simulations employed the IEEE 802.15.4a standard for low-rate wireless personal area networks. The experiment explored and evaluated the effect of different hospital surroundings on the performance of UWB WBAN receivers. Three distinct types of receivers were examined: a coherent receiver representing the best-performing reference receiver, a binary orthogonal non-coherent receiver that includes and excludes convolutional channel coding and an energy detector as the final receiver.

3. COMPARISON OF EXISTING TRACKING TECHNOLOGIES

Table 2 illustrates the comparison of barcode, RFID and UWB tracking technologies in terms of suitability to specific situation, working principles, read range, read rate and durability.

Barcodes possess an inherent disadvantage of being scannable only once, hence restricting their usage solely to one-time tracking purposes. Barcodes cannot be read in situations when walls or obstructions block the direct LOS between the barcode and the scanner. Barcode scanners typically possess a reading range of 2-10 cm. The tracking capability of barcodes is restricted to only one item at a time. Additionally, barcodes are not durable and are susceptible to damage caused by regular usage and physical deterioration.

The utilization of RFID technology allows for the continuous monitoring of asset locations in real time. Once RFID readers identify tags that correspond to their interrogation region, the location of the asset can be tracked. Passive RFID tags demonstrate efficient functionality over short distances and achieve a maximum range of 30 m. Active RFID tags surpass this range by utilizing internal power sources, which enable them to operate within distances ranging from 30 m to 100 m [40, 44]. The system's ability to concurrently track numerous tags enables efficient and comprehensive asset monitoring. Moreover, the robustness of RFID tags guarantees their capacity to endure demanding environmental circumstances, thereby establishing them as a dependable option for asset management.

Table 3. Comparison between state-of-the-art tracking technologies.

Attributes	Barcode	RFID	UWB
Applications	One-time tracking	Real-time asset	Very precise real-time asset location tracking
Working Principle	Requires direct LOS between barcode and scanner	RFID readers trigger matched tags that are within the interrogation area	Send short impulse waves
Read Range	2 – 10 cm	Passive RFID Close contact – 30 m Active RFID 30 – 100 m	Above 100 m
Read Rate	Single barcode	Multiple tags simultaneously	Multiple tags simultaneously
Durability	Not durable	Durable	Medium Durable
Security Level	Low	Average	High
Energy Consumption	Low	Passive RFID Low Active RFID High	Low
Level of Accuracy	High	Moderate	High

UWB operates by transmitting brief impulse waves, and this feature enables the precise positioning of assets. UWB can operate at distances longer than 100 m [10], unlike certain RFID solutions. This characteristic makes UWB well-suited for large-scale applications. In addition, UWB can track multiple identifiers simultaneously, thereby facilitating the effective monitoring of assets on multiple fronts. Although not as durable as certain RFID tags, UWB tags have a sufficient level of durability, making them reliable in various tracking situations. UWB is regarded as cutting-edge technology for asset tracking due to its remarkable precision, extended range and capacity to manage multiple assets.

Wireless networks commonly employ robust cyphers to encrypt information at the digital layer. RFID lacks the requisite security attributes due to the impracticality of implementing robust encryption techniques On the other hand, ultra-wideband (UWB) systems have received significant attention due to their low-power design, which effectively mitigates interference at traditional receivers, as well as their capacity for robust physical layer security [92]. The security level of barcode is inferior to that of RFID and UWB. The production of RFID identifiers is uniformly regulated, making it reasonably easy to recognize a duplicated RFID identifier. The current state of barcode technology lacks a universally applicable mechanism for effectively coordinating the generation of barcode identifiers [93].

A high level of precision in range is an indication of a robust capability for multi-path resolution. Traditional wireless technology employs continuous wave propagation, resulting in a significantly longer standing time compared to multi-path transmission. The ultra-wideband (UWB) pulse is significantly shorter, resulting in a high level of temporal and spatial resolution. For a single nanosecond pulse, the multi-path resolving power is equivalent to 30cm. This makes it well-suited for localization and detection in medical applications [94]. RFID will experience a multi-path phenomenon in a vast area. The precision of RFID localization will significantly decrease due to its susceptibility to environmental effects, such as the reflection, refraction, and scattering of radio signals by objects within a room [95].

4. DISCUSSION OF EXISTING TRACKING TECHNOLOGIES

Barcodes are primarily utilized to monitor assets that demand singular tracking. This system cannot fulfil the requirement for instantaneous tracking because it only allows scanning one barcode at a time. RFID and UWB can be used for location tracking, and the latter exhibits superior precision.

The process of scanning and recognizing barcodes requires a straight LOS between the barcode and the reader. The utilization of barcodes is limited due to their dependence on either a scanner or human interpretation for reading purposes. The user is obligated to direct the scanner towards the barcode. By contrast, the detection of RFID and UWB tags does not necessitate a LOS. RFID and UWB technologies employ radio waves to establish communication between the reader or anchor device and the tags. The RFID reader initiates the activation of any tags detected within its designated region of coverage, which is commonly referred to as the interrogation zone. In contrast to traditional RFID systems that function within a single radio spectrum band, the UWB technology utilizes many channels to send signals, resulting in enhanced precision in RTLS [96]. Furthermore, the UWB technology has reduced power consumption and enhanced precision than RFID.

Barcodes typically range from 2 cm to 10 cm in length [25]. The scanner must have a direct LOS to the barcode for reading, and only one barcode can be read at a time. By contrast, RFID and UWB can handle multiple tags simultaneously. The RFID read range depends on the technical abilities between passive and active tags and is also influenced by the antenna's operational power. Passive RFID tags can be read at distances of up to 30 m, but active tags may reach 100 m [25, 40, 97]. The read range for UWB exceeds 100 m and varies according to the specification of commercialized systems, such as Ubisense, Decawave and Bespoon.

Finally, barcodes are commonly imprinted on paper, which is susceptible to moisture, tearing and wrinkles that could lead to potential loss of legibility. RFID tags exhibit enhanced durability and can be covered in robust plastic materials, which allow them to function in the presence of moisture and have reduced susceptibility to routine deterioration. The endurance of a tag allows it to maintain functionality even under adverse conditions or when subjected to rigorous handling. UWB tags have comparable resilience to RFID [98, 99] and are similarly priced. UWB tags operate on battery power, necessitating periodic monitoring of the battery status to ensure optimal performance for asset tracking. A defective battery can impede the effectiveness of the tracking system.

RFID, UWB and Barcode technology enhances hospital efficiency, asset administration, cost effectiveness and financial outcomes. Additionally, it offers time-saving benefits for employees, mitigates instances of stock shortages, minimizes inventory losses, enhances operational efficiency and optimize inventory and equipment procedures [100, 101]. Jiang et. al [102] developed a UWB system for handheld mobile devices that works alongside GPS. This method decreases the time required to identify the position of a tracked asset by displaying all of the tracked item's information on the mobile device and providing users with excellent simplicity of use. The system developed by Kazuhiko *et al.*[103] can precisely identify surgical items using RFID tags, allowing for verification by both the system and humans. This enables the staff to allocate more attention to examining the instruments for flaws and monitoring the patients. Therefore, the system has the potential to enhance the quality of operations.

To ensure the successful use of tracking technology, it is crucial to involve stakeholders. The integration of RFID, UWB and barcode technologies for tracking medical equipment in hospital settings can be significantly enhanced with the active involvement of stakeholders. The active involvement of stakeholders in the planning and decision-making stages can contribute to the successful adoption of these technologies. It is imperative for stakeholders to have a comprehensive understanding of the problems, prerequisites, and user-friendliness associated with current solutions for indoor location-based services. This knowledge is essential for making informed decisions and providing valuable input throughout the implementation phases. Bacon and Hoffman [104] emphasized the significance of adequate infrastructure and resources in healthcare settings when implementing innovative technology, as it directly impacts personnel's readiness to embrace the change and their view of its value. Project managers should acquire the necessary resources, such as IT specialists and infrastructure, to support the installation of tracking technologies both before and after the project.

In conclusion, the utilization of tracking technologies within healthcare facilities may not be obligatory for monitoring all medical equipment but is adequate for precisely locating vital medical equipment and for smooth equipment movement as desired. The utilization of technologies depends on the specific goals and objectives of a business. Barcodes are most suitable for individual tracking purposes, whereas RFID and UWB technologies are preferred for tracking the precise position of medical equipment. In the context of hospital operations, barcodes can be effectively utilized to fulfil specific criteria, such as verifying the status of equipment, rather than only determining the precise position of the tagged equipment. The UWB technology is the most precise technology available. However, it is accompanied by a few limitations, including high costs, lack of self-sufficiency in terms of power and reliance on external power sources. RFID can be used for several decades and is anticipated to continue to meet necessary requirements. Furthermore, the RFID technology represents an advancement over traditional barcodes due to its ability to operate without LOS requirements. However, RFID exhibits low levels of precision.

5. CONCLUSIONS

This paper provides an overview of existing technologies employed in hospitals to track the locations of medical equipment. The recent epidemic has affirmed the significance of medical equipment management in enhancing healthcare service quality and reducing inventory search duration. RFID offers a dependable tracking method inside medical settings and exhibits several advantages, such as repeated tag readings, autonomous function without reliance on a power supply and a high accuracy level. The UWB technology is a nascent and rapidly developing field that exhibits notable advancements in terms of the accuracy of real-time localization of medical assets and energy efficiency when compared with RFID technology. Nevertheless, UWB tags are powered by batteries and are associated with high costs. By contrast, barcodes are designed for single use tracking only. The implementation of any of these technologies and the establishment of standardized practices across healthcare institutions pose significant challenges due to the varying tracking requirements of each facility. Further studies should integrate multiple tracking technologies to enhance the effectiveness of medical resource management.

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