A Comprehensive Review of RF-Based Localisation Methods and Their Applications in Healthcare

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Abstract: This paper reviews the fundamentals and applications of RF-based localisation techniques, focusing on phase-based methods. RF-based localisation uses radio frequency signals to determine the position and orientation of a target, such as a patient, device, or object, in indoor environments. Phase-based methods exploit the phase difference between the transmitted and received signals to estimate the distance and direction of the target. These methods have advantages such as high accuracy, low cost, and real-time performance but also face challenges such as interference, noise, and phase ambiguity. The paper discusses the physics and properties of RF waves, RF-based localisation systems' main components and algorithms, and the current uses and challenges of RF-based localisation in healthcare settings. The paper also provides a comparative analysis of different RF-based localisation techniques and technologies, such as RFID, Wi-Fi, Bluetooth, and UWB. The paper concludes with future directions and open issues for research and development in this field.

Keywords: RF waves, patient localisation, radio frequency identification, real-time location systems, wireless sensor networks, RF-based localisation, Phase-based methods, RFID systems, RTLS, Healthcare applications, Wireless communication.

1. Introduction

In the ever-advancing domain of medical science, patient localisation emerges as a linchpin for ensuring precision and safety across various clinical procedures. Patient localisation refers to determining a patient's exact position and orientation relative to a designated reference frame. This frame may be a medical device, such as an ultrasound probe, a surgical instrument used in minimally invasive procedures, or an imaging system used for diagnostics [1]. The role of accurate patient localisation extends to a myriad of clinical applications. Robotic surgeries, for example, necessitate precise patient positioning for optimal surgical outcomes. Likewise, radiation therapy and ultrasound imaging rely heavily on accurate patient localisation to focus

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on the target area while minimising surrounding tissue exposure [1]. Even in navigational procedures used in endoscopy, accurate patient localisation is vital [2]. Nevertheless, achieving such precision in patient localisation is complex, mainly due to the patient's body's inherent motion and deformation during a procedure. Even minute changes can severely compromise the localisation system's accuracy and reliability, making the potential for procedural errors or complications a genuine concern [1]. To mitigate these challenges, modern technology offers promising solutions. One such innovation is the Intel RealSense camera, a depth-sensing camera that captures 3D images of the scene, thereby allowing real-time tracking of the patient's surface shape and motion. Interestingly, this camera achieves this level of detail without requiring markers or wires attached to the patient, significantly enhancing its usability in a clinical setting. Furthermore, it can be integrated with other devices, such as robotic surgical systems or ultrasound probes, providing real-time feedback to the operator [1]. A key technological component in these innovative localisation solutions is Radio Frequency (RF) waves. RF waves, a form of electromagnetic radiation, have diverse applications, from wireless communication and radar systems to medical and industrial applications. The behaviour of RF waves, including their energy, bandwidth, strength, and timing, is dictated by their unique properties like wavelength, frequency, amplitude, and phase. RF waves are generated when charged particles, like those in an electric current, experience acceleration. Devices such as antennas can then detect these waves, converting them back into electric currents [3].

RF waves can traverse diverse media, including air, vacuum, water, or metal. Their journey, however, is only sometimes straightforward. Depending on the medium's properties, RF waves can undergo reflection (bouncing back), refraction (change in direction), diffraction (bending around obstacles), scattering (dispersing in multiple directions), absorption (conversion to other forms of energy), or polarisation (vibration in a specific direction) [3]. Different patient localisation methods and algorithms have been developed to harness the potential of RF waves. Techniques such as the angle of arrival (AOA), time of arrival (TOA), and received signal strength (RSS) use RF waves to measure the distance or direction of the patient from the reference frame. For instance, AOA uses the direction of the incoming RF waves, TOA uses the time taken by the RF waves to reach the receiver, and RSS uses the strength of the received signal to estimate the distance [1].

As we delve deeper into this review, we aim to provide a comprehensive understanding of the physics and applications of RF waves in patient localisation. Our exploration will reveal the exciting potential of these technological advancements in transforming the safety, quality, and precision of medical procedures.

2. Literature Review

Over the years, RF-based patient localisation has emerged as a cornerstone in healthcare, demonstrating compelling advantages such as cost-effectiveness, low energy consumption, robustness to multipath and occlusion, and high precision [4]. This technique employs wireless signals to pinpoint a patient's location in indoor settings, such as hospitals and is increasingly recognised and adopted in healthcare settings.

Significant strides have been made to unravel the capabilities and effectiveness of RF technology in patient localisation. A comprehensive analysis of RF-based localisation for unmanned aerial vehicles (UAVs) reveals the sophisticated methods and challenges of tracking using RF signals [4]. On a more conceptual level, an exploratory paper divulges the unique requirements and obstacles when deploying RF-based technologies to create interconnected healthcare ecosystems involving patients, healthcare professionals, sensors, computers, and medical devices [5, 6].

An exemplary innovation in this field is WiTrack2.0, a system capable of localising multiple individuals based on the reflections of wireless signals from their bodies. Interestingly, it remains effective even when subjects are stationary or involved in minimal movements such as breathing [7].

Moreover, comparative studies examining indoor localisation techniques and wireless technologies have substantially contributed to the growing knowledge of RF-based localisation [1, 8]. Technologies under comparison often include Wi-Fi, Bluetooth, RFID, and ultra-wideband (UWB), all of which have their unique features and benefits.

Ground-breaking studies, such as by Zhao et al., have developed and tested RF-based patient localisation systems using passive UHF RFID tags. This research offered valuable insights into optimising system accuracy by considering factors such as signal interference and tag placement [9]. While Raad's study [10], showed that Wi-Fi signals can be used for patient tracking with decent accuracy using existing equipment and minimal setup effort.

The practical implications of such effort are profound, offering ways to enhance patient safety, optimise patient flow, and improve resource allocation in healthcare settings. Zohaib Iqbal et al.'s research presented an RFID-based patient localisation and tracking system. They argued that the system could monitor patient movements in real-time, improving patient safety and workflow efficiency [11].

Additionally, research by Bharadwaj et al. suggested the significant potential of ultra-wideband (UWB) technology for patient localisation, which can achieve high tracking accuracy [12]. Furthermore, Raad et al.'s exploration of RF-based patient localisation highlighted its benefits in telemedicine services, particularly beneficial for elderly patients and those suffering from chronic diseases [13].

3. Evaluating the Accuracy of RF-based Localisation

The precision of RF-based localisation hinges on many factors, including the type of RF metric used, the quantity and arrangement of RF sources, the prevailing environmental conditions, and the methods deployed in signal processing [14].

For instance, a system utilising the Time of Arrival (TOA) and Angle of Arrival (AOA) of RF signals to localise aerial vehicles attained an accuracy level of 0.5m in three-dimensional space [14]. A separate system, applying Received Signal Strength (RSS) in conjunction with Artificial Neural Networks (ANN), successfully located patients in a hospital environment with a 1.2m accuracy in two-dimensional space [15]. Another system used RSS and Particle Filters (PF) to determine users' location within indoor environments, achieving an accuracy of 1.5m in two dimensions [16]. These examples underscore some of the most promising results, although opportunities for further enhancements exist.

4. RF-based systems find expansive applications in the realm of healthcare

RF-based systems find expansive applications in healthcare, as they enable wireless communication, sensing, monitoring, and tracking of various devices and parameters related to healthcare delivery. RF-based systems can leverage radio frequency signals to perform functions such as identification, localisation, data transmission, and motion detection of medical devices, patients, and staff. RF-based systems can also support remote and intelligent healthcare services like telemedicine, wearable devices, and Internet of Things (IoT) applications. Some examples of RF-based systems in healthcare include RFID tags, Wi-Fi networks, Bluetooth devices, cellular/mobile phones, and wireless medical implants [17].

Real-time tracking of patients, medical equipment, supplies, and staff is possible through RF signals. This tracking capability can enhance operational efficiency, improve safety measures, and ultimately contribute to better quality care by ensuring essential resources are readily available when needed. Healthcare environments can benefit from RF localisation technology, which enables real-time tracking of patients, assets, staff, and medical equipment. This technology can improve patient safety, streamline workflow efficiency, optimise resource utilisation, and reduce operational costs. Different technologies, such as RFID, WLAN, BLE, and UWB, can be used to implement RF localisation. RFID is one of the most widely studied and used solutions in healthcare tracking applications. [18], [19].

Human Activity Monitoring: RF signals can recognise human activities such as walking, sitting, and lying down, in addition to detecting vital signs like breathing and heart rates [18]. This capability facilitates remote and non-invasive health monitoring, providing patients with a less intrusive and more comfortable experience.

Wireless Communication: Wireless communication using RF signals can offer several advantages for healthcare environments, such as mobility, flexibility, scalability, and cost-effectiveness. RF signals can enable various devices and systems to integrate into a wireless network supporting different healthcare applications, such as patient monitoring, diagnosis, treatment, and management. RF signals can also facilitate the exchange of data and information among different stakeholders, such as healthcare providers, patients, and caregivers, enhancing the quality and accessibility of healthcare services.

Despite the extensive benefits of RF-based localisation, it presents some challenges and limitations in healthcare environments, such as interference, security, privacy, and health effects. Therefore, wireless communication using RF signals requires careful design, implementation, and evaluation to ensure efficiency, reliability, and safety in healthcare settings [20] [5].

5. Physics of Radio Frequency Waves

Radio Frequency (RF) waves, positioned distinctly within the electromagnetic spectrum, have become indispensable in contemporary technological evolution, attributed to their unique characteristics. Their multifaceted nature is exemplified across various domains: they power wireless communication networks that weave the global tapestry, underpin innovative medical treatments, revolutionise patient outcomes, and drive industrial processes to unprecedented efficiencies. In essence, RF waves are the unsung linchpins of our technologically driven existence.
Essential attributes are central to understanding RF waves: wavelength, frequency, amplitude, and phase. The frequency, articulated in hertz (Hz), governs the wave's energy and bandwidth,

reflecting the number of oscillations it undergoes per second. The wavelength, meanwhile, describes the distance between consecutive peaks or troughs and intriguingly exhibits an inverse relationship with frequency. Consequently, higher frequencies correspond to shorter wavelengths and vice versa. The amplitude indicates a signal's intensity or power, with a larger amplitude signifying a more potent signal. The phrase, pivotal for numerous applications, is particularly vital in communication systems, shedding light on a wave's position relative to a reference at any given moment, thereby ensuring the optimal synchronisation and coherence of signals [21], [22].

Electromagnetic waves, categorised as RF waves, emerge when charged particles, predominantly within time-varying electric currents, experience acceleration. As these waves journey through space, they manifest oscillating electric and magnetic fields, which remain orthogonal. Devices such as antennas are instrumental in capturing these waves, adeptly transforming them back into electric currents, fuelling processes ranging from communication to intricate data transmission. This phenomenon underpins contemporary technological marvels, encompassing wireless communication modalities and radar applications [21], [22].

Travelling through diverse media, RF waves might undergo transformations like reflection, refraction, diffraction, scattering, and absorption, contingent on the medium's intrinsic properties. Nevertheless, RF waves offer distinct advantages: they can traverse significant distances, permeate obstructions, transmit vast data quantities, cater to multiple users simultaneously, and are amenable to modulation and demodulation. The mechanisms behind their generation and detection employ relatively simple and cost-effective devices, making them both accessible and efficient [21], [22].

Harnessing the potential of RF waves in diverse applications is challenging. Foremost among these is interference from other electronic devices and environmental noise, which can compromise transmission quality. Obstructions like architectural structures, flora, and atmospheric elements can induce attenuation and fading, diluting the signal's potency and clarity. Security remains paramount, as the possibility of illicit access or unsanctioned eavesdropping looms large, especially in wireless communication. Furthermore, the deployment of RF waves is meticulously regulated by authoritative bodies to circumvent spectrum congestion and uphold safety norms. Adherence to these regulations introduces an additional dimension to the complexities inherent in RF utilisation [21], [22].

RF waves underpin modern telecommunication infrastructure, from mobile communication and Wi-Fi to satellite transmissions, ensuring instantaneous global connectivity.

In radar applications, they provide pivotal information for navigation, aviation management, and climatic predictions by interacting with objects or atmospheric anomalies, subsequently relaying positional or meteorological data. In the medical landscape, RF energy is harnessed in varied capacities, from facilitating MRI scans for intricate body imaging and employing radiofrequency ablation in cardiac arrhythmia treatments to inducing hyperthermia in tumour management.

The industrial sector, too, capitalises on RF waves, especially in RF heating techniques, bolstering processes like plastic welding, food desiccation, and chemical production [1], [23-27].

When harnessed for patient localisation, RF waves exhibit nuanced properties, encompassing wavelength, power, phase, and polarisation. The wavelength critically influences the accuracy and resolution of localisation systems while determining wave interaction with diverse materials and settings [1], [23-27].

The RF wave's power directly influences the reliability and reach of localisation systems and necessitates an evaluation of its impact on human health [28]. The phase provides invaluable insights for gauging the distance and orientation of transmitters or receivers, rendering it indispensable for localisation frameworks [29] [30]. Polarisation, meanwhile, can significantly sway localisation systems' performance, influencing aspects like interference and signal path diversities [29].

RF waves are an essential part of modern society, with their complex applications and numerous advantages. As technology advances, it becomes increasingly evident that RF waves are a cornerstone of this progress. Their impact on communication, medicine, and industry highlights their crucial role in shaping our current civilisation. Researchers and practitioners continuously work to refine and enhance the capabilities of RF waves, leading to ground-breaking innovations that improve our daily lives and open new scientific realms for exploration [31].

6. RF waves: A versatile technology

In the pulsating heart of our modern era, Radio Frequency (RF) waves stand as an unparalleled testament to the marvels of human ingenuity. Let's embark on a journey through their myriad applications:

Wireless Communication: Imagine a world interconnected, not through roads or cables, but through invisible waves pulsating with data. RF waves have rendered this dream a vivid reality. Radios that narrate stories, televisions that portray distant realities, mobile phones that close global distances, Wi-Fi that invisibly tethers us to the vast cosmos of the internet and satellites that whisper celestial secrets; they all owe their magic to the modulation of RF waves. This unseen amplitude, frequency, and phase choreography enable the seamless transmission of sound, data, and visuals, holding the world in a harmonious dance of information [32].

Radar: As vigilant eyes in the sky, radars harness RF waves to map our world in motion. These high-frequency waves embark on a mission with each pulse, only to return with tales of distant objects' position, speed, and direction. Whether guiding aircraft through the vast blue, forecasting nature's temperament, or aiding military endeavours, radar's insights have sculpted our understanding and manoeuvring through the world around us [33].

Medical: Medicine, a field dedicated to the sanctity of life, finds in RF waves a profound ally. Beyond the conventional use in sealing IV bags, RF energy's capability to pierce deep, devoid of the scalding touch of heat, has revolutionised surgical realms. Surgeons, wielding this potent tool, can now sculpt and mend with unprecedented precision, especially the delicate tapestries of our connective tissues. Beyond the theatre, the silent vigour of RF sensing - encapsulated in Wi-Fi, radar, and RFID technologies - monitors heartbeats, guards against falls, lulls us into sleep, and even ensures that assets find their rightful place in vast medical mazes [18].

Industrial: In the grand theatre of industries, RF waves don the cloak of a versatile performer. They breathe warmth into the wood, grant resilience to rubber, meld plastics with a whisper, and sculpt metals with finesse. Each wave, a symphony of energy, transforms raw potential into tangible marvels [34].

7. Phase-Based RF Localisation

The rapid development and widespread use of wireless technology have sparked significant interest in RF localisation techniques, particularly those that rely on phase-based measurements. Phase-based RF localisation leverages the phase difference between the transmitted and received signals to estimate a target's distance and direction. This phase difference depends on the signal's wavelength and the receiver's arrival angle. One can triangulate the target's location by recording the phase difference across multiple receivers [35].

RF localisation techniques have been extensively used in various applications, each with specific requirements and challenges. Among the notable uses, acoustic source localisation finds its place. This technique determines the location and characteristics of sound sources, such as a ship, speaker, or gunshot, and finds utility in navigation, surveillance, communication, and sound field analysis [36].

Another application lies in indoor localisation, where RF localisation can determine a person or object's location within a mall, museum, or office, aiding in navigation, tracking, security, and context-aware services [32].

Furthermore, RF localisation is integral in RFID localisation, which determines the location of RFID tags or readers, enabling inventory management, asset tracking, supply chain optimisation, and authentication [37], [38].

When evaluated against other techniques, phase-based localisation reveals its strengths and weaknesses based on accuracy, complexity, robustness, and applicability. Studies have indicated that phase-based RF localisation is more accurate than methods relying on signal strength or distance measurements. These include RSSI, with phase-based RF localisation capable of achieving sub-meter or even centimetre-level accuracy depending on the frequency and antenna array configuration [39],[37]. Moreover, it is cost-efficient and power-conserving since it utilises passive tags, eliminating the need for batteries or active transmitters. Phase-based RF localisation can also employ analogue beamforming, which reduces the need for additional RF equipment and signal processing [40]. Furthermore, it demonstrates swift recognition speed and real-time performance by simultaneously processing backscattered signals from multiple tags using simple algorithms, such as beamforming or MUSIC [39],[37].

However, despite its many advantages, phase-based RF localisation has challenges. The uncontrolled radiation of RF waves can affect the health and safety of humans, animals, plants, and insects, particularly near RF cellular towers or high-power transmitters [41]. Another challenge is phase ambiguity and phase wrapping. This can occur when the phase difference between the transmitted signal and the received tag response exceeds 2π radians, resulting in errors and uncertainties in localisation estimates [37].

Noise and multipath effects can also degrade the phase measurements' quality and reliability, especially in complex indoor environments [37],[42].

Lastly, scalability and collaboration issues might arise with increasing tags or readers, complicating the localisation algorithms and protocols [43].

Other techniques offer alternatives for different application scenarios besides phase-based RF localisation. One such method is device-free localisation, which does not require subjects to carry any radio device but determines their location by observing their disruption of radio propagation patterns [45]. Similarly, inertial navigation systems utilise sensors like accelerometers and gyroscopes to measure motion and orientation, estimating position and velocity over time [42]. Alternatively, optical-based technologies use cameras or lasers to capture subjects' images or reflections, with computer vision or triangulation techniques determining their location [42].

8. Current Uses of RF Waves in Patient Localization

Radio Frequency (RF) waves, a type of electromagnetic radiation, have become an important tool for locating patients in medical technology. These waves have introduced new methods for determining a patient's position, including active localisation, which calculates the patient's location based on the time it takes for RF waves to reach a sensor, and passive localisation, which triangulates signals from several sensors to determine the patient's position. Hybrid localisation combines these techniques to achieve even greater accuracy.

RF waves are highly valued due to their non-invasive, safe, cost-effective, and tissue-penetrating nature. This benefits them in surgical procedures, such as tumour localisation or guidance during minimally invasive surgeries. In rehabilitation, they are used to monitor patients' limb movements or head positions, which helps in improving therapeutic plans. Additionally, in the expanding field of telemedicine, RF waves help monitor patients' vital signs or movements, ensuring efficient remote care.

One notable application of RF waves in patient localisation is using RFID (Radio Frequency Identification) systems. This technology employs RF waves to store and retrieve data remotely, making it instrumental in tracking and managing patients in healthcare settings.

8.1 RFID (Radio Frequency Identification) Systems in Healthcare

Radio Frequency Identification (RFID) Systems have made significant strides in healthcare, especially in patient tracking and operational efficiency [46]. These systems are distinguished by their ability to relay patient location information quickly and accurately, which is indispensable for modern healthcare facilities [47]. A complete RFID system consists of three essential components: tags, readers, and antennas. Tags are devices that can be active, passive, or semi-active and are responsible for storing and transmitting data. Readers, which can be either fixed or mobile, interact with the tags to collect data. Antennas play a crucial role in transmitting data between the tags and readers.

Within the healthcare sphere, RFID serves several crucial purposes. It's instrumental in-patient tracking, which helps monitor patients' locations, identities, and medical statuses—this approach ensures heightened safety and reduces potential medical errors [48]. Moreover, RFID plays a pivotal role in inventory management by effectively tracking medical supplies and equipment, thus guaranteeing optimal stock levels and curbing waste [49]. Furthermore, to maintain the gold standard in healthcare, RFID oversees staff adherence to safety and hygiene standards [50]. When it comes to remote patient monitoring, RFID technology stands out. It provides a range of benefits by allowing for the collection and transmission of patient data to centralised systems or mobile applications. Chief among these is enhanced patient care; the continuous monitoring of patient’s vital stats offers timely alerts to healthcare providers about potential risks [49]. There's also the perk of fewer hospital visits; with persistent at-home monitoring, patients can significantly cut down on their trips to the hospital, which translates to lower costs [51]. To cap it off, having access to their health data empowers patients to adopt a more proactive approach to their well-being [46]. Some notable RFID implementations in healthcare include glucose meters for diabetics, wearable devices that monitor heart rate and blood pressure, and surveillance monitors tailored for patients with specific physical or mental impairments [52], [53], [54]. It's worth noting, however, that despite its vast benefits, RFID does pose challenges, including concerns of interference, privacy, security, and substantial initial setup costs, especially on a larger scale [55].

8.2 Real-Time Location Systems (RTLS) in Healthcare

Real-Time Location Systems (RTLS), capitalising on advanced wireless technologies including RFID, Bluetooth, Wi-Fi, ultrasound, and infrared, have witnessed increasing adoption within contained spaces, especially in healthcare settings [56]. While these systems find relevance in domains such as manufacturing [57] and logistics [58], the healthcare industry offers a distinct landscape for its applications.

8.3 Broad Healthcare Implications

Within healthcare, the role of RTLS is multifaceted. It aims at enhancing patient safety, satisfaction, and the holistic experience. The system tracks and monitors patients', staff, and medical assets' location, identity, condition, and status [56]. The resultant insights provide a nuanced understanding of patient waiting times, treatment trajectories, potential infection risks, and behaviours such as wandering [59],[74].

An intricate component of RTLS's application in healthcare is its room monitoring capability. By offering data about the occupancy, availability, and utilisation of rooms – from operating theatres to patient wards and storage areas – RTLS assists in streamlining room allocation, ensuring optimal utilisation, and reinforcing infection control protocols [59] [60] [61]. Concurrently, RTLS-driven equipment monitoring has ushered in an era of efficiency. Through vigilant oversight of the location and utility of crucial equipment such as medical devices and wheelchairs, the system minimises equipment losses and fosters a culture of preventive maintenance [59] [60] [62].

8.4 RTLS in Patient Localisation

Deep diving into the patient localisation facet, the granularity with which RTLS operates stands out [62]. The system provides real-time patient locational data within healthcare facilities, ensuring that room and bed allocations are efficient, thereby drastically reducing patient wait times [62] [56]. Significant value addition is security enhancements, especially for patients susceptible to wandering or other associated risks [59]. The overarching benefit is a noticeable improvement in coordination and communication among healthcare professionals [62].

8.5 Case Studies and Practical Applications

Consider healthcare settings where professionals are equipped with RTLS tags to elucidate the practical implications. This arrangement facilitates a data-driven approach to understanding patient-clinician interactions, measuring quality and duration. For example, if a nurse carries a tag, the RTLS can report how much time the nurse has spent in each patient's bedside or cubicle [62]. Furthermore, RTLS aids in refining operations – be it expediting patient transfers or swiftly locating requisite medical equipment. For example, an RTLS can help quickly locate staff or equipment, such as a wheelchair, to transport the patient. It can also help synchronise housekeeping and disinfection tasks to prepare rooms and beds for new patients [62] [61]. The system's inherent capability to demarcate virtual boundaries enhances patient safety, as immediate alerts are dispatched when patients inadvertently access restricted zones [59]. Particularly in scenarios that demand disease contact tracing, RTLS emerges as an indispensable tool, swiftly identifying potential exposure risks. These benefits culminate in enhanced communication, with RTLS platforms providing real-time patient location updates, ensuring harmonised care delivery [62] [63].

9. Future directions

- Improving the accuracy and robustness of phase-based localisation in complex and dynamic indoor environments, such as hospitals, where multipath effects, interference, noise, and human movement can affect the quality and reliability of phase measurements.
- Developing novel algorithms and protocols for phase-based localisation that can handle phase ambiguity, phase wrapping, and scalability issues, especially when dealing with multiple tags or readers.
- Exploring the trade-offs between performance, cost, power consumption, and safety of phase-based localisation systems and finding optimal solutions to balance these factors according to different application scenarios and requirements.
- Integrating phase-based localisation with other technologies, such as device-free localisation, inertial navigation systems, or optical-based technologies, to achieve complementary or hybrid solutions that can enhance patient localisation's accuracy, reliability, and functionality.
- Evaluating the impact of phase-based localisation on human health and privacy and developing ethical standards and regulations to ensure the safety and security of patients and staff exposed to RF waves or tracked by RF devices.

10. Conclusion

Phase-based RF localisation has emerged as a pivotal solution in wireless technology, influencing diverse sectors from acoustic source localisation to the complexities of healthcare. As illustrated, its integration into patient localisation through RF waves has introduced a new paradigm in patient management and care, specifically with RFID systems and RTLS in healthcare. While this technique boasts notable advantages, such as high accuracy, cost-efficiency, and real-time performance, addressing its challenges to harness its full potential is essential. As technology evolves, ensuring these systems' safety, scalability, and efficiency will be paramount, demanding continual research and innovation. Future endeavours in this domain promise enhanced applications and the potential to overcome existing limitations, heralding an era of more precise, efficient, and patient-centric solutions in healthcare and beyond.

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