# Ultra Wideband Positioning: An Analytical Study of Emerging Technologies

Suheer Alhadhrami, AbdulMalik Al-Salman and Hend S. Al-Khalifa
Computer Science Department, King Saud University, Riyadh, KSA
Email: 430204094@student.ksu.edu.sa
salman@ksu.edu.sa
hendk@ksu.edu.sa

Abdulrahman Alarifi, Ahmad Alnafessah and Mansour Alsaleh
Computer Research Institute, King Abdulaziz City for Science and Technology, Riyadh, KSA
Email: aarifi@kacst.edu.sa
aalnafessah@kacst.edu.sa
maalsaleh@kacst.edu.sa

Mai A. Al-Ammar
Department of Computer Science, Al-Imam Mohammad bin Saud Islamic University, Riyadh, KSA
Email: mai.alammar@ccis.imamu.edu.sa

***Abstract*—In recent years, indoor positioning has emerged as a critical function in many end-user applications; including military, civilian, disaster relief and peacekeeping missions. To cope with this surge of interest, much research effort has focused on meeting the needs of these applications and overcoming their shortcomings. Ultra WideBand (UWB) is an important technology in the field of indoor positioning and has shown great performance compared to others. In this work, we identify and analyze existing ultra wideband positioning technologies and present a detailed comparative survey. We also provide a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, a method generally used in management science to evaluate the strengths, weaknesses, opportunities, and threats involved in a product or technology, to analyze the present state of UWB positioning technologies.**

***Index Terms*—Ultra wideband; localization; positioning; indoor positioning; wireless sensor networks; networking; SWOT**

## I. INTRODUCTION

Positioning is the process of determining a position of people, equipment, and other objects. Recently, it has been an active research area where much of the research focuses on utilizing existing technologies to address the problem of positions' determination. Positioning can be classified, according to the environment where the positioning is conducted, into two types: outdoor positioning and indoor positioning. Outdoor positioning is performed outside buildings and indoor positioning is performed inside buildings such as houses, hospitals, malls and others. Different applications may require different types of positioning technologies that fit their needs and constraints. For example, Global Positioning System (GPS) is a technology that is suitable and efficient for the outdoor rather than the indoors since satellite radio signals cannot penetrate solid walls and obstacles [1][2][3][4].

Indoor Positioning Systems (IPSs) determine the position of something in a physical space continuously and in real-time [5]. IPSs use numerous positioning approaches, which vary greatly in terms of accuracy, cost, precision, technology, scalability, robustness and security [2]. There are five main quality metrics of the indoor positioning systems, which should be considered: (1) accuracy and precision of the system; (2) coverage and resolution of the coverage; (3) latency in producing location updates; (4) impact of a building's infrastructure; and (5) effect of random errors on the system such as errors caused by signal interference and reflection [6]. Indoor positioning has many applications such as indoor navigation systems for blind and visually impaired people, locating devices through buildings, aiding tourists in museums, finding an emergency exit in a smoky environment, tracking kids in crowded places, and tracking expensive equipment. Indoor positioning applications may require different quality attributes and thus IPSs should be carefully selected to meet the requirements of the application.

Indoor location-based services are an important application of indoor ubiquitous computing. Accurate position measurement is a critical requirement for indoor positioning techniques. Given that UWB is one of the key techniques that is proven effective in indoor positioning, a comparative analysis of the state-of-the-art UWB indoor positioning systems is indeed required. Furthermore, due to the U.S. Federal Communications Commission (FCC) recent allowance for the use of unlicensed UWB communications, UWB civilian applications have been studied and explored intensively worldwide. Also, the development of international wireless communication standards that adopts UWB technology has encouraged research and development efforts on UWB. Consequently, developing new algorithms to improve UWB positioning performance is becoming an active research area [7].

This work is motivated by the fact that UWB is the most promising technology for indoor positioning and tracking.

 

Further, to the best of our knowledge, this paper is the first analytical study of the state-of-the-art UWB indoor positioning systems. Our study analyzes a wide range of positioning algorithms that have empowered UWB positioning systems and tackle different aspects of applications needs and requirements. The nature of the application in question plays a major role in determining the appropriate solution for achieving certain quality attributes. Hybrid positioning approaches have future potentials as they combine features of different approaches to improve the performance.

Our contributions in this paper are twofold.

- We provide an updated literature review for existing and recent research in UWB positioning systems (see Sections II and III).
- We conduct a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis for UWB technology, which provide new directions and deeper insights into the state of this technology beyond its well-known pros and cons (see Section IV).

## II. UWB Positioning

UWB is one of the most recent, accurate, and promising technologies [8]. The precursor technology of UWB is referred to as a base-band, impulse, and carrier-free technology. The US Department of Defense is the first to use the term ultra wideband. At the late of 1990, the UWB was commercially available [8]. UWB radio is a method of spectrum access that can provide high speed data rate communication over the personal area network space. UWB is based on transmitting extremely short pulses and it uses techniques that cause a spreading of the radio energy over a wide frequency band with a very low power spectral density [8]. This high bandwidth offers high data throughput for communication. The low frequency of UWB pulses enables the signal to effectively pass through obstacles such as walls and objects.

There are three main application areas for using UWB, namely (1) communication and sensors; (2) positioning and tracking; and (3) radar [8][9]. UWB positioning techniques can provide real time indoor precision tracking for many applications such as locator beacons for emergency services and mobile inventory, indoor navigation for blind and visually impaired people, people or instruments tracking, and military reconnaissance. The characteristics of UWB signals provide the potential of highly accurate position and location estimation for indoor environments [10][8].

### *A. Why UWB has recently gained attention?*

In general, UWB has different features that are explored in the literature [8][3][11]. The high data rate of UWB can reach 100 Megabits per second (Mbps), which makes it a good solution for near-field data transmission. Also, the high bandwidth helps in reducing the effect of multipath interference, which makes UWB a more desirable solution for indoor positioning than other technologies [12]. In fact, UWB provides a high accuracy rate in which error can be minimized to sub-centimeters. Therefore, UWB is considered to be one of the most suitable choices for critical positioning applications that require highly accurate result.

UWB technology, unlike other positioning technologies such as infra-red and ultrasound sensor, does not require line-of-site and does not get affected by the existence of other communication devices or external noise due to its high bandwidth and signal modulation [13][14]. Furthermore, the UWB equipment cost is low and it consumes less power compared with other competitive solutions.

Many IPSs were implemented commercially using UWB. One of the most known positioning systems that use UWB is Ubisense system. In Ubisense system, a user carries tags that transmit UWB signals to fixed sensors that use the signals to determine the user's positions using Time of Arrival (TOA) method [15].

### *B. Signal Modulation*

Signal modulation is the process of carrying information on the impulse signal (the carrier signal) by modifying one or more of the signal properties. In general, signal modulation can be categorized based on the signal state into three categories; binary modulation, ternary modulation, and M-ary modulation. Also, signal modulation can be categorized based on signal properties that need to be modified into four categories; amplitude modulation, frequency modulation, phase modulation, and hybrid modulation.

Signal modulation is a crucial phase in signal transmission, which can greatly improve the quality of transmitting signals to achieve certain quality criteria. For example, UWB signals are usually transmitted in the existence of other signals in the air as well as reflected signals which may cause multipath interference. Thus, UWB must have high modulation efficiency as signals must be recognized correctly in the presence of noise and interference [9].

There are various signal modulations that are used for UWB, such as Pulse Position Modulation (PPM), On-Off Keying (OOK), Pulse Amplitude Modulation (PAM), and Pulse Width Modulation (PWM) [9][16]. Signal modulation is utilized to enhance the accuracy of UWB localization [9]. In UWB, Time-Hopping Spread Spectrum (TH-SS) impulse radio could be used to solve multipath problems and generate UWB signals with relatively computational cost. There are other modulations that are used by UWB such as Pseudo Random (PR) time-modulation, Binary Phase Shift Keying (BPSK), Time-Hopping Binary Phase Shift Keying (TH-BPSK), Time-Hopping Pulse Position Modulation (TH-PPM), and Minimum-Shift Keying (MSK) [6][17]. Further details about using these modulation technologies in positioning are presented in the next sections.

## III. UWB Positioning Algorithms

UWB technology is well-suited for indoor positioning applications. In order to employ this technology, different

 ISBN: 978-1-61208-374-2 

TABLE I. COMPARISON OF UWB SYSTEMS

| No. | Authors | Year | Accombined Technology | Algorithm | Environment |
|---|---|---|---|---|---|
| 1 | Ch'oliz et al.[26] | 2011 | | TOA | LOS/NLOS |
| 2 | Guangliang Cheng[10] | 2012 | | TOA | LOS/NLOS |
| 3 | Gunter et al.[27] | 2010 | | TOA | LOS/NLOS |
| 4 | Sivanand et al.[14] | 2007 | | TDOA | NLOS |
| 5 | Rowe et al.[29] | 2013 | | TOA | LOS |
| 6 | Jiang et al.[34] | 2010 | GPS | AOA, TDOA | NLOS |
| 7 | Jiang et al.[34] | 2010 | | TDOA, TDMA | LOS |
| 8 | Pittet et al.[31] | 2008 | MEMS | AOA, TDOA | |
| 9 | Shahi et al.[11] | 2012 | | AOA, TDOA | LOS/NLOS |
| 10 | Segura et al.[12] | 2012 | | TOA, TDOA and TDMA | LOS/NLOS |
| 11 | Cao and Li[47] | 2012 | | ROA, TDOA and DOA | |
| 12 | Mucchi et al.[37] | 2010 | | AOA, TOA | LOS |
| 13 | Liu et al.[48] | 2012 | GPS | TDOA, RSS | NLOS |
| 14 | Kuhn et al.[17] | 2011 | GPS, RFID and WLAN | | |
| 15 | Zhang et al.[49] | 2010 | | TDOA | |
| 16 | Deissler et al.[38] | 2012 | | TOA | |
| 17 | Tuchler et al.[50] | 2005 | | TOA | LOS |
| 18 | Digel et al.[39] | 2013 | | | LOS/NLOS |
| 19 | Jiang et al.[40] | 2012 | | TOA,RSS | LOS/NLOS |
| 20 | Tome et al.[28] | 2010 | | TOA | LOS |
| 21 | Arias-de-Reyna and Mengali[13] | 2013 | | TOA | LOS |
| 22 | Kilic et al.[51] | 2013 | | TOF | LOS |
| 23 | Mahfouz et al.[52] | 2011 | | TDOA | LOS |
| 24 | McCracken et al.[53] | 2013 | RSS Sensor | RSST | |
| 25 | Jiang et al.[54] | 2013 | | TOA, TDOA | |
| 26 | Yang et al.[55] | 2013 | | STBCS-TDOA | LOS/NLOS |
| 27 | Mirza et al.[56] | 2012 | Ultrasound sensor and compass | AOA,TDOA | |
| 28 | Ubisense[57] | 2010 | | AOA,TDOA | LOS/NLOS |
| 29 | Ubisense[58] | 2011 | | TOA,TDOA | LOS/NLOS |
| 30 | Ubisense[59] | 2010 | | TOA,TDOA | LOS/NLOS |
| 31 | Ubisense[60] | 2010 | | TOA/TDOA | LOS/NLOS |

positioning algorithms have been developed in which position information is extracted from radio signals traveling between the target node and the reference nodes as well as position information of the reference nodes. There are many positioning algorithms that can be classified into five main categories based on estimating measurements: (1) Angle of Arrival (AOA); (2) Time of Arrival (TOA); (3) Time Difference of Arrival (TDOA); (4) Received Signal Strength (RSS); and (5) hybrid algorithm. In this section, we give a detailed review of these algorithms for UWB indoor positioning. Also, we compare the algorithms in different aspects such as accuracy, environment, estimation technique, range, purpose of use and others. A summary and comparison of UWB positioning algorithms is presented in Table I.

### A. AOA-based Algorithms

In AOA technique, the estimation of the signal reception angles from at least two sources are compared either with signal amplitude or carrier-phase across multiple antennas. From the intersection of the angle line for each signal source, the location can be found. AOA estimation algorithms are very sensitive to many factors, which may cause errors in their estimation of target position. Furthermore, AOA estimation algorithms have a higher complexity compared to other methods. For instance, the antenna array geometry has an important role in the estimation algorithm [18]. Increasing the distance between the sender and receiver may decrease the accuracy [19]. AOA technique can be used with other techniques to increase the accuracy [20].

AOA based algorithms have been used in many literatures. Xu et al. presented a new cooperative positioning method based on the AOAs, which utilizes pairwise AOAs information among all the sensor nodes rather than relying only on anchor nodes [21]. Lee proposed the using of signal model and weighted-average to estimate AOA parameters for Low data Rate UWB (LR-UWB) [22]. A Kalman filter based AOA estimation algorithm was introduced by Subramanian, which rely on a new linear quadratic frequency domain frequency invariant beamforming strategy [23].

Furthermore, many studies have been conducted to evaluate the performance of AOA for different applications, environments, hardware, and configurations. Mok et al. studied the feasibility and performance of AOA for UWB in Ubisense Real-Time Location System (RTLS) when integrated with GPS to facilitate resource management in underground railway construction sites [24]. The influence of UWB directional antennas on the performance of AOA estimation was presented in detail by Gerok et al. [25]. Gerok et al. presented a corrected AOA estimation algorithm, which mitigates the error resulting from the UWB directional antenna.

### B. TOA-based Algorithms

TOA is based on the intersection of circles for multiple transmitters. The radius of those circles is the distance between the transmitter and receiver. This distance is calculated by finding one-way propagation time between them [19]. The time synchronization of all transmitters is required while the receiver synchronization is unnecessary so that any possibility of significant delays must be accounted for during calculation of the correct distances.

Choliz et al. identified a realistic indoor scenario, defined by a layout of walls and corridors, and a specific indoor UWB ranging model to evaluate different kinds of TOA based algorithms for UWB such as Trilateration, Weighted Least Square with Multidimensional Scaling (WLS-MDS), Least Square with Distance Contraction (LS-DC), Extended Kalman Filter (EKF) and Particle Filter (PF) [26].

TOA based algorithms have been used to locate targeted objects for various applications and environments. Cheng et al. designed TOA-based personnel localization system for coal mine using UWB technology, which can be very helpful to locate workers effectively in case of accidents [10]. For mobile robot tracking, Segura et al. proposed a novel UWB navigation system for indoor environment, which employ a TOA based estimation algorithm to accurately locate mobile robot [12]. Fischer et al. designed a monolithic integrated transceiver chipset for UWB to use them in indoor localization systems where TOA techniques have been used for position estimation [27]. The system was implemented for Line-of-Sight environment and its accuracy was estimated to be 8.3 cm. On the other hand, Tom'e et al. designed and built a large-scale deployable UWB-based Local Positioning System (LPS) in which TOA is used for position estimation [28].

### C. TDOA-based Algorithms

TODA is based on measuring the time difference of arrival of a signal sent by an object and receive by three or more receivers. In this manner, the location of the object (transmitter) will be determined. Also, the scenario can be flipped where a single receiver can determine the target location by measuring the difference in arrival times of two transmitted signals [19].

Typically, only one transmitter is available that requires the multiple receivers to share the data and cooperate to determine the location of the transmitter. This cooperation requires significant bandwidth in comparison with other algorithms.

Krishnan et al. have used TDOA for UWB indoor positioning system where the site has been divided into cells and each cell has four UWB readers mounted on the top corners to have line-of-sight with user tag. In this manner, the readers will be able to receive the signals from the user tag then send the time of arrival to a central processing unit to determine TDOA and find user location [14]. Rowe et al. designed one dimensional system with two sensors and one tag using TDOA based algorithm to determine the tag location [29]. On-Off Keying (OOK) modulation was used to overcome the collision deduced by synchronous tag transmission, increase the performance, and decrease the cost and power at the same time.

### D. RSS-based Algorithms

In RSS-based algorithms, the tracked target measures the signal strength for received signals from multiple transmitters in order to use signal strength as an estimator of the distance between the transmitters and receiver. This way, the receiver will be able to estimate its position relative to the transmitter nodes. Although RSS is sensitive to multipath interference and small scale channel effect, which cause a random deviation from mean received signal strength, it is used frequently with unrealistic assumptions such as transmitted power and path loss exponent are known, and transmitter antennas are isotropic [19][30]. According to Pittet et al., the accuracy of RSS for Non-Line-Of-Sight (NLOS) and multipath environment is low, which shows clearly that RSS is not the right estimation method for indoor positioning systems [31]. Gigl et al. explored the performance of RSS algorithms for positioning using UWB technology [32]. They also studied the effect of small scale fading on the system accuracy; however, a simulator based on the UWB channel model 802.15.4a was used to evaluate the algorithms rather than relying on real scenarios for indoor environments.

RSS based algorithms can be classified into two main types: trilateration and fingerprinting [33]. Trilateration algorithms use RSS measurements to estimate the distances to three different reference node and hence estimate the current location. On the other hand, fingerprinting requires collecting a dataset of RSS fingerprints of a scene, which is later used to match on-line measurements with the closest fingerprint in the dataset in order to estimate the location.

### E. Hybrid-based Algorithms

When multiple positioning techniques are used, they can complement each other or target different parts of the site that fit with their strengths. Overall accuracy will increase and the complexity and cost will increase, too. Jiang et al. presented a tracking system for staff, patients, and instruments in a hospital environment [34]. They used GPS for outdoor tracking and UWB for indoor tracking. Furthermore, the site was divided into cells where each cell has at least 4 UWB readers and GBS repeater. They used PDA, which has built-in GPS receiver and it was connected to UWB tag in order to work with both GPS and UWB at the same time. The UWB subsystem uses both AOA and TDOA received by UWB readers to estimate the user position. Similarly, Kuhn et al. designed a multi-tag access scheme for UWB localization system, in which Minimum-Shift Keying (MSK) modulation was used with 2.40-2.48, 5.40-10.6 Gigahertz (GHz) frequency and refresh rate of 1-20 Hz in the range of 1m-100m [17]. Also, they have used Time Division Multiple Access (TDMA) for channel access control. TDOA was used to discover new tags and identify its position in 3D. Experimentally, it uses two tags and switches between them 20 times per second.

A new pedestrian navigation solution has been introduced by Pittet et al., which combines UWB localization system and Micro Electro Mechanical Sensors (MEMS) to improve the performance of pedestrian positioning [31]. AOA and TDOA were used to know the presence of multipath and position estimation. Furthermore, they used an Extended Kalman Filter (EKF) based algorithms to couple the measurement of these two subsystems in order to combine the complementary advantages of UWB and MEMS. Another system has been introduced by Shahi et al., which consists of a network of tags and receivers communicating over 68 GHz signals [11]. The path from transmitter to receiver is measured to locate the tag. The true location is determined by the direct path signals; however, the error was produced by reflections of the signals. The direct path signal can be distinguished from reflection using UWB, so the accuracy increases. The computation is calculated in one master server, which uses AOA and TDOA for estimation. Also, FuCheng and MingJing designed UWB localization and tracking system based on Kalman, linear H and extended H filters to accurately estimate the target position using DOA and TOA [35]. Their system was implemented in 30x30 meter cell with one access point, which is equipped with 4 elements array and noise statistics.

Several other systems have been developed for critical missions to help in tracking people and object. An UWB indoor/outdoor NLOS localization system has been implemented for disaster aid, in which GPS is used for outdoor localization while UWB is used for indoor localization [36]. TDOA and RSS are used to improve localization performance. Another UWB tracking system for athlete has been presented by Mucchi et al. in order to determine the athlete's speed and acceleration and analyze his/her performance after medical surgery [37]. They have implemented their system for outdoor environments with different cell sizes and for indoor environments using 4 sensors. The system was implemented for Line-Of-Sight (LOS) environment setup and uses TOA and AOA for positions' estimation with good accuracy. Another system was designed by DeiBler et al., which tackles the problem of simultaneous localization and mapping in an emergency like an earthquake, fire, or terrorist attacks [38]. The system was designed to perform UWB indoor mapping using a mobile antenna array with two receiver antennas and one transmitter between them. DeiBler et al. used Kalman filter for position estimation and Rao-Blackwellized particle filter for data association and initialization of new objects.

Furthermore, a new UWB indoor navigation system was proposed by Segura et al., which includes two sub-systems: the location system and Mobile Robot (MR) control system [12]. They detect the first arrival of signal by designing a novel dynamic threshold crossing algorithm and using TOA/TDOA for estimation. Time Division Multiple Access (TDMA) is used to avoid multi-users interference.

Several other efforts have been done to improve positioning in UWB using hybrid based algorithms. Digel et al. designed and improved a digitizer of no-coherent Impulse Radio Ultra WideBand (IR-UWB) [39]. Jiang et al. designed a technique to mitigate NLOS error by using Biased Kalman Filtering (BKF) and Maximum Likelihood Estimation (MLE) where both AOA and RSS were used [40]. Srimathi and Kannan made a comparison between Time-Hopping Spread-Spectrum (TH-SS), Time-Hopping Binary Phase-Shift Keying (TH-BPSK), and TH-SS coded and un-coded scheme UWB systems [41]. Zebra is a commercial UWB positioning system, that offers a UWB Real-Time Location System (RTLS) integrated with other RTLS, which can use technologies, such as GPS, Radio Frequency Identification (RFID) and Wireless Local Area Network (WLAN) [17].

## IV. SWOT Analysis

SWOT analysis is a useful analysis tool to understand and evaluate a technology, solution or business. SWOT analysis aims to identify the key internal (strengths and weaknesses) and external (opportunities and threats) factors that may affect the success of an analyzed target. SWOT analysis has been applied in many areas such as; industry, management and engineering. Here, we apply the SWOT analysis to evaluate UWB in terms of strength, weakness, opportunities and threats

TABLE II. SUMMARY OF SWOT ANALYSIS FOR UWB TECHNOLOGY

| Internal | |
|---|---|
| **Strengths** | **Weaknesses** |
| • License free<br>• Low power consumption<br>• Does not interfere with most of the existing radio systems<br>• High level of multipath resolution<br>• Large bandwidth<br>• High data rate communication<br>• High processing gain in communication system<br>• Involve very short pulses<br>• Carrierless transmission property offers the advantage of hardware simplicity.<br>• Work well with low SNR<br>• Low Probability of Intercept and Detection<br>• Resistance to jamming<br>• Penetration through different kinds of material | • Potential interference to the existing systems ( ex Wimax in USA)<br>• Affect GPS and aircraft navigation radio equipment.<br>• Potential interference to the existing systems<br>• Very short pulses in UWB may take long time for synchronization |
| **External** | |
| **Opportunities** | **Threats** |
| • Robot guidance<br>• Tracking systems<br>• Medical and surgeries that require sub-millimeters of accuracy<br>• Indoor localization systems<br>• UWB short pulses. This short pulses signals can be utilized in non-communication purposes<br>• Sensor, positioning, and identification network (SPIN)<br>• Industrial warehouses applications<br>• Shipboard environment application<br>• Military applications.<br>• Application for noisy environments<br>• Video streaming | • Commercially expensive compared to other technologies<br>• They are in some cases not totally immune to multipath effects<br>• Design and implementation of UWB antennas can be more challenging |

to have a deep understating of UWB. A summary of SWOT analysis is shown in Table II.

### A. Strength

One advantage of using UWB is being licensed free because of its low power. UWB is not classified as a radio equipment as its low power signal does not interfere with most of the existing radio systems [42]. In addition, UWB has a very high level of multipath resolution because of its large bandwidth. Large bandwidth provides frequency diversity that makes Time Modulated Ultra WideBand (TM-UWB) signal resistant to the multipath problems and interference [42]. Time Modulated UWB has a low probability of interception and detection, which it is used in some applications, particularly in the military.

The large bandwidth is the main feature of the UWB wireless systems. This feature offers an improved channel capacity and high data rate communication in digital communication systems [43]. The channel capacity is defined by Shannons law, where is the channel capacity is proportional to the bandwidth $(B)$ and the log of Signal to noise ratio $\frac{S}{N}$ plus one.

$$C = B\, log_2 \left(1 + \frac{S}{N}\right) \quad (1)$$

In addition to the advantage of large bandwidth, it is potential for high processing gain in communication systems. Processing gain for real Direct-Sequence of UWB (DS-UWB) modulation systems is defined as two times ratio of noise bandwidth at the front end of the receiver to the noise bandwidth of symbol rate. Here is the formula of DS-UWB processing gain [43]:

$$PG = 2 \times \frac{\text{Noise Bandwidth}}{\text{Symbol Rate}} \quad (2)$$

The large processing gain offers a greater immunity distortion and noise. It allows negative Signal to Interference and Noise Ratio (SINR) to be recovered [43].

UWB signals have greater penetration of obstacles (such as walls) than conventional signals, and they achieve same data rate [44]. Furthermore, UWB transmissions involve very short pulses, which have recently received significant interest. Very short pulses offer an advantage in terms of resolvability of multipath components [44]. Many received signals in an environment that are characterized by multipath is a superposition of the delayed replicas of the signal. This has been avoided in UWB because the reflection from objects and surfaces near the path between transmitter and receiver tend to not overlap in time because of the very short pulses of UWB. This means UWB has a desirable direct resolvability of direct multipath components.

UWB technologys carrierless transmission property offers the advantage of hardware simplicity and small hardware. UWB transceivers can be built with much simpler radio frequency architecture than narrowband systems with fewer components. Also, there is no need for power amplifier because of its low power consumption [44]. In general, UWB hardware is considered to be simple and the hardware simplicity depends on the application and operational scenario. For example, the transmitter does not need Analog to Digital (A/D) converter, digital pulse shaping filter, or equalizer to correct carrier phase distortion [44].

### B. Weakness

Although UWB has many strengths for different applications, it has some weakness. One of these weaknesses is the possibility of interference with nearby systems [43]. In the United States, the UWB frequency range for communication applications is 3.1 to 10.6 GHz, which is operating in the same frequencies as popular communication products such as Worldwide Interoperability for Microwave Access (WiMAX) and digital TV. In some countries, it may also interfere with some systems such as third-generation 3G wireless systems [43]. There are some concerns that several UWB devices may cause harmful interference to GPS and aircraft navigation radio equipment [44]. To overcome those concerns, different techniques have been developed to eliminate harmful interference with other sensitive services, such as Detection and Avoidance (DAA) [43].

Also interference may happen from the existing system to the UWB system. The UWB systems signals may spread over other bandwidths that contain existing frequency of narrowband systems [44]. This interference can be elevated by using Minimum Mean-Square Error (MMSE) multiuser detection schemes to reject strong narrowband interference.

Although using very short pulses in UWB has many advantages, the UWB receiver requires signal acquisition, synchronization and tracking to be done with very high precision in time relative to the pulse rate. These steps of processes are time-consuming and take a long time to be performed [44]. There are some techniques for reducing this time such as using preamble sequence for rapid acquisition.

### C. Opportunities

UWB becomes a choice for many systems that require high accuracy such in building robot guidance and tracking systems to utilize its advantages. Furthermore, UWB is used for medical applications that require sub-millimeters of accuracy [15]. In addition, UWB is used in radars in order to improve their high performance [45].

For indoor localization systems, there are multipath reflections from objects inside rooms, which negatively impact radio signals. However UWB signals have time resolution, which offers a high resolution positioning applications to solve the multipath problems [43].

As mentioned before, UWB communication signals have short pulses. Those short pulse signals can be utilized in non-communication purposes [44]. For instance, the low power UWB RFID tag transmitters have been used to locate objects with an accuracy proportional to the inverse of the signal bandwidth.

UWB could be beneficial for industry and service providers in many applications such as Sensor, Positioning, and Identification Network (SPIN) systems [46]. These systems need a large number of devices (sensors and tags) in industrial warehouses to transmit low-rate data combined with position information. This allows the devices to operate over long distance (around 100m) between mobile tags and sensors of UWB.

There are some challenges for using Radio Frequency (RF) operation for the shipboard environment. Using UWB and network analyzer measurements offers good opportunities for NLOS communication for indoor and on ships [44]. It allows signals to propagate well aboard ships and around objects, which provide reasonable accuracy to determine positions. UWB is used in radar in order to improve its high performance [45].

### D. Threats

UWB usually does not have a negative impact on the neighbor's devices because there are some techniques that are used to avoid the interference with other devices [15]. However, UWB is still commercially expensive compared to other technologies (see [9] for further limitations).

While UWB systems are known to be robust against multipath reflection issues, they are not totally immune to multipath effects [46]. One of these cases is when there is an extreme ratio of link distance to antenna height. This may result in signal losses and propagation delay that lasts to tens or even hundreds of nanoseconds.

The design and implementation of antennas for UWB systems can be more challenging than the bandwidth and variable conditions of operation [46]. This may add some limitations to UWB systems in comparison with conventional RF.

## V. Concluding Remarks

Positioning is one of the most important and challenging phases in navigation systems where different technologies have been developed to improve performance. In this paper, we presented an analytic study of UWB positioning, in which a detailed and updated overview of UWB indoor positioning techniques has been presented. Furthermore, we presented a SWOT analysis of UWB technology, focusing mainly on positioning applications, in which internal factors (strengths and weaknesses) as well as external factors (opportunities and threats) have been identified and analyzed. UWB systems have emerged as one of the leading technologies for indoor positioning and have been used in many more applications than before.

## Acknowledgment

This project was supported by NSTIP strategic technologies program number (11- INF1855-02) in the Kingdom of Saudi Arabia.

## References


[1] J. Hightower and G. Borriello, "Location systems for ubiquitous computing," *IEEE computer*, vol. 34, no. 8, pp. 57–66, 2001, ISSN: 0018-9162.

[2] H. Huang and G. Gartner, *A survey of mobile indoor navigation systems*. Springer, October 2010, chapter 20, pp. 305–319, ISBN: 978-3-642-03293-6.

[3] H. Liu, H. Darabi, P. Banerjee, and J. Liu, "Survey of wireless indoor positioning techniques and systems," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 37, no. 6, pp. 1067–1080, 2007, ISSN: 1094-6977.

[4] S. Ram and J. Sharf, "The people sensor: a mobility aid for the visually impaired," in *Second International Symposium on Wearable Computers*. IEEE Society, October 1998, pp. 166–167.

[5] Y. Gu, A. Lo, and I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," *Communications Surveys & Tutorials, IEEE*, vol. 11, no. 1, pp. 13–32, 2009, ISSN: 1553-877X.

[6] H. Wu, A. Marshall, and W. Yu, "Path planning and following algorithms in an indoor navigation model for visually impaired," in *Internet Monitoring and Protection, 2007. ICIMP 2007. Second International Conference on*. IEEE Society, July 2007, pp. 38–38.

[7] M. Al-Ammar *et al.*, "Comparative Survey of Indoor Positioning Technologies, Techniques, and Algorithms," in *Cyberworlds (CW), 2014 International Conference on*. IEEE Computer Society, October 2014, pp. 1–8.

[8] M. Ghavami, L. B. Michael, and R. Kohno, Eds., *Front MatterUltra Wideband Signals and Systems in Communication Engineering*. John Wiley & Sons, Ltd, February 2006, ISBN: 9780470867532.

[9] K. Siwiak and D. McKeown, Eds., *Ultra-Wideband Radio Technology*. John Wiley & Sons, Ltd, 2005, ISBN: 978-04-70-85-93-39.

[10] G. Cheng, "Accurate toa-based uwb localization system in coal mine based on wsn," *Physics Procedia*, vol. 24, pp. 534–540, 2012, ISSN: 1875-3892.

[11] A. Shahi, A. Aryan, J. West, C. Haas, and R. Haas, "Deterioration of UWB positioning during construction," *Automation in Construction*, vol. 24, pp. 72–80, 2012, ISSN: 0926-5805.

[12] M. Segura, V. Mut, and C. Sisterna, "Ultra wideband indoor navigation system," *IET Radar, Sonar & Navigation*, vol. 6, no. 5, pp. 402–411, 2012, ISSN: 1751-8792.

[13] E. Arias-de Reyna and U. Mengali, "A maximum likelihood UWB localization algorithm exploiting knowledge of the service area layout," *Wireless personal communications*, vol. 69, no. 4, pp. 1413–1426, 2013, ISSN: 0929-6212.

[14] S. Krishnan, P. Sharma, Z. Guoping, and O. Woon, "A uwb based localization system for indoor robot navigation," in *Ultra-Wideband, 2007. ICUWB 2007. IEEE International Conference on*. IEEE Society, September 2007, pp. 77–82.

[15] U. Company, "Ubisense website," 2009, URL: http://www.ubisense.net/en/ [accessed: 2014-04-01].

[16] S. Cui, "Modulation and multiple access techniques for ultra-wideband communication systems," Ph.D. dissertation, Cleveland State University, 2011.

[17] M. Kuhn, M. Mahfouz, J. Turnmire, Y. Wang, and A. Fathy, "A multi-tag access scheme for indoor UWB localization systems used in medical environments," in *Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS), 2011 IEEE Topical Conference on*. IEEE Society, January 2011, pp. 75–78.

[18] S. Al-Jazzar, A. Muchkaev, A. Al-Nimrat, and M. Smadi, "Low complexity and high accuracy angle of arrival estimation using eigenvalue decomposition with extension to 2D AOA and power estimation," *EURASIP Journal on Wireless Communications and Networking*, vol. 2011, no. 1, pp. 1–13, 2011, ISSN: 1687-1499.

[19] N. Reddy and B. Sujatha, "TDOA Computation Using Multicarrier Modulation for Sensor Networks," *International Journal of Computer Science & Communication Networks*, vol. 1, no. 1, pp. 85–90, 2011, ISSN: 2249-5789.

[20] S. Gezici *et al.*, "Localization via ultra-wideband radios: a look at positioning aspects for future sensor networks," *Signal Processing Magazine, IEEE*, vol. 22, no. 4, pp. 70–84, 2005, ISSN: 1053-5888.

[21] J. Xu, M. Ma, and C. Law, "AOA Cooperative Position Localization," in *Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008. IEEE*. IEEE Society, November 2008, pp. 1–5.

[22] Y. Lee, "Weighted-Average Based AOA Parameter Estimations for LR-UWB Wireless Positioning System," *IEICE transactions on communications*, vol. 94, no. 12, pp. 3599–3602, 2011, ISSN: 1745-1345.

[23] A. Subramanian, "UWB Linear Quadratic Frequency Domain Frequency Invariant Beamforming and Angle of Arrival Estimation," in *Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th*. IEEE Society, April 2007, pp. 614–618.

[24] E. Mok, L. Xia, G. Retscher, and H. Tian, "A case study on the feasibility and performance of an UWB-AoA real time location system for resources management of civil construction projects," *Journal of Applied Geodesy*, vol. 4, no. 1, pp. 23–32, 2010, ISSN: 1862-9024.

[25] W. Gerok, M. El-Hadidy, S. El Din, and T. Kaiser, "Influence of the real UWB antennas on the AoA estimation based on the TDoA localization technique," in *Antennas and Propagation (MECAP), 2010 IEEE Middle East Conference on*. IEEE Society, October 2010, pp. 1–6.

[26] J. Chóliz, M. Eguizabal, A. Hernandez-Solana, and A. Valdovinos, "Comparison of Algorithms for UWB Indoor Location and Tracking Systems," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*. IEEE Society, May 2011, pp. 1–5.

[27] G. Fischer, O. Klymenko, D. Martynenko, and H. Luediger, "An impulse radio UWB transceiver with high-precision TOA measurement unit," in *Indoor Positioning and Indoor Navigation (IPIN), 2010 International Conference on*. IEEE Society, September 2010, pp. 1–8.

[28] P. Tome *et al.*, "UWB-based Local Positioning System: From a small-scale experimental platform to a large-scale deployable system," in *Indoor Positioning and Indoor Navigation (IPIN), 2010 International Conference on*. IEEE Society, September 2010, pp. 1–10.

[29] N. Rowe, A. Fathy, M. Kuhn, and M. Mahfouz, "A UWB transmit-only based scheme for multi-tag support in a millimeter accuracy localization system," in *Wireless Sensors and Sensor Networks (WiSNet), 2013 IEEE Topical Conference on*. IEEE Society, January 2013, pp. 7–9.

[30] S. Wang *et al.*, "System implementation study on RSSI based positioning in UWB networks," in *Wireless Communication Systems (ISWCS), 2010 7th International Symposium on*. IEEE Society, September 2010, pp. 36–40.

[31] S. Pittet, V. Renaudin, B. Merminod, and M. Kasser, "UWB and MEMS based indoor navigation," *Journal of Navigation*, vol. 61, no. 3, pp. 369–384, 2008, ISSN: 0373-4633.

[32] T. Gigl, G. Janssen, V. Dizdarevic, K. Witrisal, and Z. Irahhauten, "Analysis of a UWB Indoor Positioning System Based on Received Signal Strength," in *Positioning, Navigation and Communication, 2007. WPNC '07. 4th Workshop on*. IEEE Society, March 2007, pp. 97–101.

[33] N. Kodippili and D. Dias, "Integration of fingerprinting and trilateration techniques for improved indoor localization," in *Wireless And Optical Communications Networks (WOCN), 2010 Seventh International Conference On*. IEEE Society, September 2010, pp. 1–6.

[34] L. Jiang, L. Hoe, and L. Loon, "Integrated UWB and GPS location sensing system in hospital environment," in *Industrial Electronics and*

*Applications (ICIEA), 2010 the 5th IEEE Conference on*. IEEE Society, June 2010, pp. 286–289.

[35] F. Cao and M. Li, "An Algorithm for UWB Signals Tracking Based on Extended H Filter," *Physics Procedia*, vol. 33, pp. 905–911, 2012, ISSN: 1875-3892.

[36] J. Liu, Q. Wang, J. Xiong, W. Huang, and H. Peng, "Indoor and Outdoor Cooperative Real-Time Positioning System," *Journal of Theoretical & Applied Information Technology*, vol. 48, no. 2, pp. 1066–1073, 2013, ISSN: 1992-8645.

[37] L. Mucchi, F. Trippi, and A. Carpini, "Ultra Wide Band real-time location system for cinematic survey in sports," in *Applied Sciences in Biomedical and Communication Technologies (ISABEL), 3rd International Symposium on*. IEEE Society, November 2010, pp. 1–6.

[38] T. Deissler, M. Janson, R. Zetik, and J. Thielecke, "Infrastructureless indoor mapping using a mobile antenna array," in *Systems, Signals and Image Processing (IWSSIP), 2012 19th International Conference on*. IEEE Society, April 2012, pp. 36–39.

[39] J. Digel *et al.*, "Integrator and Digitizer for a non-coherent IR-UWB Receiver," in *Silicon Monolithic Integrated Circuits in RF Systems (SiRF), 2013 IEEE 13th Topical Meeting on*. IEEE Society, January 2013, pp. 93–95.

[40] X. Jiang, H. Zhang, and W. Wang, "NLOS error mitigation with information fusion algorithm for UWB ranging systems," *The Journal of China Universities of Posts and Telecommunications*, vol. 19, no. 2, pp. 22–29, 2012, ISSN: 1005-8885.

[41] S. Srimathi and P. Kannan, "Literature Survey for Performance evaluation of various time hopping ultra-wideband communication system," *International Journal of Scientific & Engineering Research*, vol. 4, no. 2, pp. 1–3, 2013, ISSN: 2229-5518.

[42] M. Hämäläinen, V. Hovinen, and M. Latva-aho, "Survey to Ultra Wideband Systems," *European Cooperation in the Field of Scientific and Technical Research*, vol. 262, pp. 1–7, 1999.

[43] R. Aiello and A. Batra, Eds., *Ultra wideband systems: technologies and applications*. Newnes-Elsevier, June 2006, ISBN: 978-0750678933.

[44] L. Miller, "Why uwb? a review of ultrawideband technology," Tech. Rep., 2003, technical Report to NETEX Project Office, DARPA by Wireless Communication Technologies Group, National Institute of Standards and Technology, Gaithersburg, Maryland, URL: http://www.ntis.gov/search/product.aspx?ABBR=PB2012113101 [accessed: 2014-08-01].

[45] S. Ye, J. Chen, L. Liu, C. Zhang, and G. Fang, "A novel compact UWB ground penetrating radar system," in *Ground Penetrating Radar (GPR), 2012 14th International Conference on*. IEEE Society, June 2012, pp. 71–75.

[46] D. Porcino and W. Hirt, "Ultra-wideband radio technology: potential and challenges ahead," *Communications Magazine, IEEE*, vol. 41, no. 7, pp. 66–74, 2003.

[47] F. Cao and M. Li, "An Algorithm for UWB Signals Tracking Based on Extended H Filter," *Physics Procedia*, vol. 33, pp. 905–911, 2012, ISSN: 1875-3892.

[48] J. Liu, Q. Wang, J. Xiong, W. Huang, and H. Peng, "Indoor and Outdoor Coperative Real-Time Positioning System," *Journal of Theoretical and Applied Information Technology (JATIT)*, vol. 48, no. 2, pp. 1066–1073, 2012, ISSN: 1875-3892.

[49] "Realtime non-coherent UWB positioning radar with millimeter range accuracy: theory and experiment," *Microwave Theory and Techniques, IEEE Transactions*, vol. 58, no. 1, pp. 9–20, January 2010, ISSN: 0018-9480.

[50] M. Tuchler, V. Schwarz, and A. Huber, "Location accuracy of an UWB localization system in a multi-path environment," in *Ultra-Wideband, 2005. ICU 2005. 2005 IEEE International Conference on*. IEEE Society, September 2005, pp. 414–419.

[51] Y. Kilic, H. Wymeersch, A. Meijerink, M. Bentum, and W. Scanlon, "UWB device-free person detection and localization," *CoRR*, vol. abs/1303.4092, 2013.

[52] M. Mahfouz, M. Kuhn, Y. Wang, J. Turnmire, and A. Fathy, "Towards sub-millimeter accuracy in UWB positioning for indoor medical environments," in *Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS), 2011 IEEE Topical Conference on*. IEEE Society, January 2011, pp. 83–86.

[53] M. McCracken, M. Bocca, and N. Patwari, "Joint ultra-wideband and signal strength-based through-building tracking for tactical operations," in *Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2013 10th Annual IEEE Communications Society Conference on*. IEEE Society, June 2013, pp. 309–317.

[54] H. Jiang, Y. Zhang, H. Cui, and C. Liu, "Fast three-dimensional node localization in UWB wireless sensor network using propagator method digest of technical papers," in *Consumer Electronics (ICCE), 2013 IEEE International Conference on*. IEEE Society, January 2013, pp. 627–628.

[55] D. Yang, H. Li, Z. Zhang, and G. Peterson, "Compressive sensing based sub-mm accuracy UWB positioning systems: A space–time approach," *Digital Signal Processing*, vol. 23, no. 1, pp. 340–354, 2012, ISSN: 1051-2004.

[56] R. Mirza, A. Tehseen, and A. Kumar, "An indoor navigation approach to aid the physically disabled people," in *Computing, Electronics and Electrical Technologies (ICCEET), 2012 International Conference on*. IEEE Society, March 2012, pp. 979–983.

[57] C. Brown, "Real-time location of Jena's buses and trams with Ubisense RTLS," April 2010, ubisense Report, URL: http://www.ubisense.net/en/news-and-events/press-releases/real-time-location-of-jenas-buses-and-trams-with-ubisense-rtls.html [accessed: 2014-09-01].

[58] M. Baum, "RTL in Longueuil selects bus yard management solution provided by Solotech, ISR Transit and Ubisense," Oct 2011, ubisense Report, URL: http://www.ubisense.net/en/news-and-events/press-releases/rtl-in-longueuil-selects-bus-yard.html [accessed: 2014-09-01].

[59] C. Brown, "Ubisense launches Intrinsically Safe location tracking tags for personnel safety in the Oil and Gas industry," May 2010, ubisense Report, URL: http://www.ubisense.net/en/news-and-events/press-releases/ubisense-launches-intrinsically-safe-location-tracking-tags-in-the-oil-and-gas-industry.html [accessed: 2014-09-01].

[60] U. Cambridge, "Ubisense tag combines uwb and gps for 'best-of-both worlds' tracking named as csr location summit fast-pitch finalist," Oct. 2010, ubisense Report, URL: http://www.ubisense.net/en/news-and-events/press-releases/ubisense-tag-combines-uwb-and-gps-.html [accessed: 2014-09-01].