Research Article
Improved UWB Wireless Sensor Network Algorithm for Human Intruder Localization

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Abstract: In this study we present a WSN algorithm for localization which increases efficiency in time, energy and cost of localization radar systems. The algorithm is designed using a hybrid of two widely used localization techniques, Time of Arrival (ToA) and Received Signal Strength Indicator (RSSI). The target is to achieve a design which is more efficient than RSSI and requires no nodes synchronization which is fundamental in ToA. Virtual References Tags (VRTs) play a key role in improving efficiency by providing a reference point near the target which is discussed in experimental results of WSN with four different number of VRTs and lastly a comparison of proposed with existing methods is given.

INTRODUCTION

Technology advances as well as Wireless Sensor Networks (WSNs). Due to its vast applications, these types of networks became popular over the past years. WSNs mainly consist of a number of sensor nodes for surveillance over a specific region. These nodes can have different state depending on design of the algorithm. The commonly used terms for nodes in surveillance area are:

Unknown node: These types of nodes do not have any information about their position. Their position estimation is the main goal of system.

Settled node: The location of these nodes is not known previously, using the system they can get information about position.

Beacon node: Their location is predefined by the system.

Reference node: Their position is used as a reference by unknown nodes to estimate their location.

The main methods or algorithms used by localization systems are Received Signal Strength Indicator (RSSI), Angle of Arrival (AoA), Time (Difference) of Arrival (ToA/TDoA). Auto-organization, scalability, robustness and efficient are the key requirements of localization systems. Focusing on these requirements, this study presents a localization technique which is hybrid of RSSI and ToA. Also reference tagging concept is introduced which is commonly used in RFID systems (Ni *et al*., 2011). The algorithm design uses Ultra wideband (UWB) frequency. UWB has numerous advantages. The biggest advantage is that it introduces unlicensed wideband spectrum for usage, which greatly increases efficiency of WSNs. Other benefits include low power transmission and robustness (Huseyin *et al*., 2006). Reference tags are used in some narrow band tracking systems providing reference to track intruder or object. These systems use a number of sensor nodes. Reference tags are symmetrically placed over the surveillance area and a tag is given to the intruder while entering in surveillance area (Ni *et al*., 2011). There are number of limitations to these kinds of systems. For example for an unknown intruder with no tags cannot be localized, positioning of actual reference tags symmetrically over surveillance area makes the system complicated, greater number of sensor nodes are used making these system suitable only in case of limited surveillance area. In this study we have given an improved radar algorithm design which virtualizes reference tags and their information is kept in receiving nodes. Secondly numbers of sensor nodes are reduced to four (having one transmitting node and three receiving nodes) and hybrid of ToA and RSSI tracking techniques are used in which there is no need of intruder to carry a tag. Whenever intruder arrives in surveillance area it is monitored with RSSI and ToA hybrid localization technique and VRTs provide reference point closest to actual intruder location. This algorithm design has no synchronization problem (like in ToA) and has greater accuracy than RSSI.

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INTRUDER LOCALIZATION METHODS

In network based localization systems, that target or intruder position is monitored in a centralized system located at a specific distance from target. A specific set of receivers are used to get the signal reflected by the target, which is then used as information to calculate its position (Ghavami *et al*., 2004).

Received Signal Strength Indicator (RSSI): The strength of signal received by the node is used to measure its distance from signal source in RSSI. The main disadvantage is in actual environment the signal gets interrupted by noise, clutters and antenna type, causing high inaccuracy in localization. The strength of signal received by the node is used to measure its distance from signal source. Greater the distance, lower the signal strength when it arrives to node. The signal strength weakens as the inverse of square distance, theoretically. The disadvantage is that in actual environment the signal gets interrupted by noise, clutters and antenna type, causing high inaccuracy in localization. An error of 2 to 3 m is shown in surveillance area communication range of 10 m through experimentation (Savvides *et al*., 2001).

Time of Arrival (ToA): In ToA the distance between two nodes is calculated by measuring the difference of time at which signal was send by one node and received by the other. Once distance is calculated Trilateration or Multilateration is used for localization. Experiments show error of about 23 cm, with nodes in a distance of 2 m (Whitehouse, 2002). ToA technique requires very high level nodes synchronization and the time when signal left transmitting node, which itself is a challenge to design.

System design: The proposed design consists of four nodes, which are placed at the edges of surveillance area. All four nodes are set as beacon nodes in which one acts as transmitter and three as receivers (multistatic radar design). VRTs are designed at different symmetric locations inside the surveillance area. The number of VRTs for different design can vary depending on design requirements. These virtual references not only increases efficiency but also overcomes nodes synchronization problem. The information stored in each reference is shown in Table 1.

Since location of every VRT is known, we can calculate distance of VRT form three receivers using simple distance formula:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{1}$$

To calculate the Received signal power we use Friis formula for Narrowband (NB) pulses:

$$P_{r-NB}^{LOS} = \frac{P_t G_t G_r \lambda^2}{l^2 (4\pi)^2} \tag{2}$$

Here P_{r-NB}^{LOS} represents the line-of-sight received signal power at receiver. P_t is the transmitted signal power, G_t and G_t represents transmitter and receiver antenna gains. l is length between transmitter and receiver and λ is the wavelength. For received signal power calculation of a signal in Narrowband (NB) that is reflected from the target Eq. (3) is used:

$$P_{r-NB}^{target} = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 (l_1 . l_2)^2} \tag{3}$$

In Eq. (3) l_1 and l_2 are distances from transmitter to target and from target to receiver. σ represents radar cross section. Radar cross section for different shaped object is different, depending on objects physical shapes and reflection properties (Dybdal, 1987; Schultz *et al*., 1958). In our case we take RCS to be 1 m^2 (approximated RCS of human body). To calculate received signal power for UWB, we integrate the equation over all wave lengths of signal band (f_L, f_U). This will give us Eq. (4) and (5) which can be used to calculate received signal power (Scholtz *et al*., 2005; Hongsan *et al*., 2003):

$$P_{r-UWB}^{LOS} = \frac{S_t G_t G_r c^2}{l^2 (4\pi)^2} \left(\frac{1}{f_L} - \frac{1}{f_L + B} \right) \tag{4}$$

$$P_{r-UWB}^{target} = \frac{S_t G_t G_r \sigma c^2}{(l_1 . l_2)^2 (4\pi)^3} \left(\frac{1}{f_L} - \frac{1}{f_L + B} \right) \tag{5}$$

where,
c = The speed of light
S_t = One sided power spectral density
$B = f_U - f_L$ = The bandwidth of the transmitted signal

Minimum transmitted power P_{t-min} for a particular region can be calculated by measuring range of a TX-RX pair and then adjusting it for three receivers instead of one (Enrico *et al*., 2008).

When an intruding target enters in surveillance its reflected signal is received at all three receivers. These receivers use VRTs by comparing information stored in them and received signal strength from target. Comparing signal strengths the nearest VRT to the target is selected. Trilateration (Grosicki and Abed-Meraim, 2005) method is used by making three

Table 1: Information stored in each VRT

Information	Receiver 1	Receiver 2	Receiver 3
Distance from VRT	Distance of VRT from RX1	Distance of VRT from RX2	Distance of VRT from RX3
RSS from VRT	RSS at RX1 considering target location at VRT	RSS at RX2 considering target location at VRT	RSS at RX3 considering target location at VRT

receiving nodes as centre of circle and distance of target from them as radius, resulting in three circles with one intersecting point (location of target). Figure 1 shows the design of VRTs and four nodes over a surveillance area. Number of VRTs in a design also effects its efficiency. VRTs not only overcome synchronization problem but also in some aspects help in identifying objects other than target.
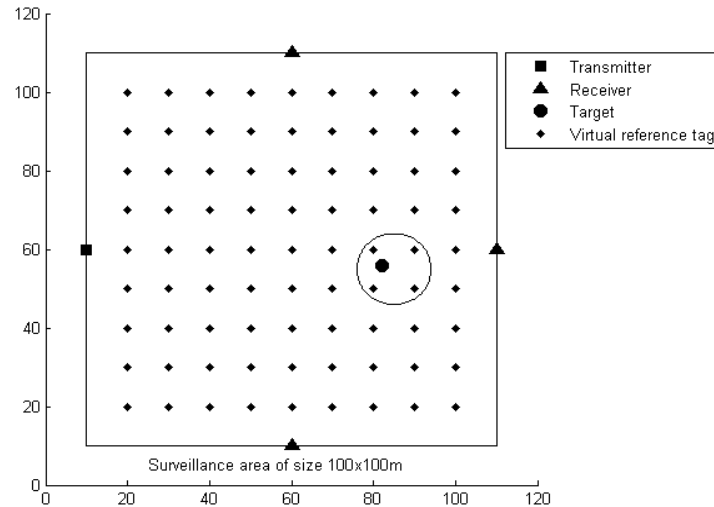

Fig. 1: Hybrid WSN localization design with four nodes planted on the borders of surveillance area acting as transmitter and three receivers. And VRTs are symmetrically distributed over surveillance area
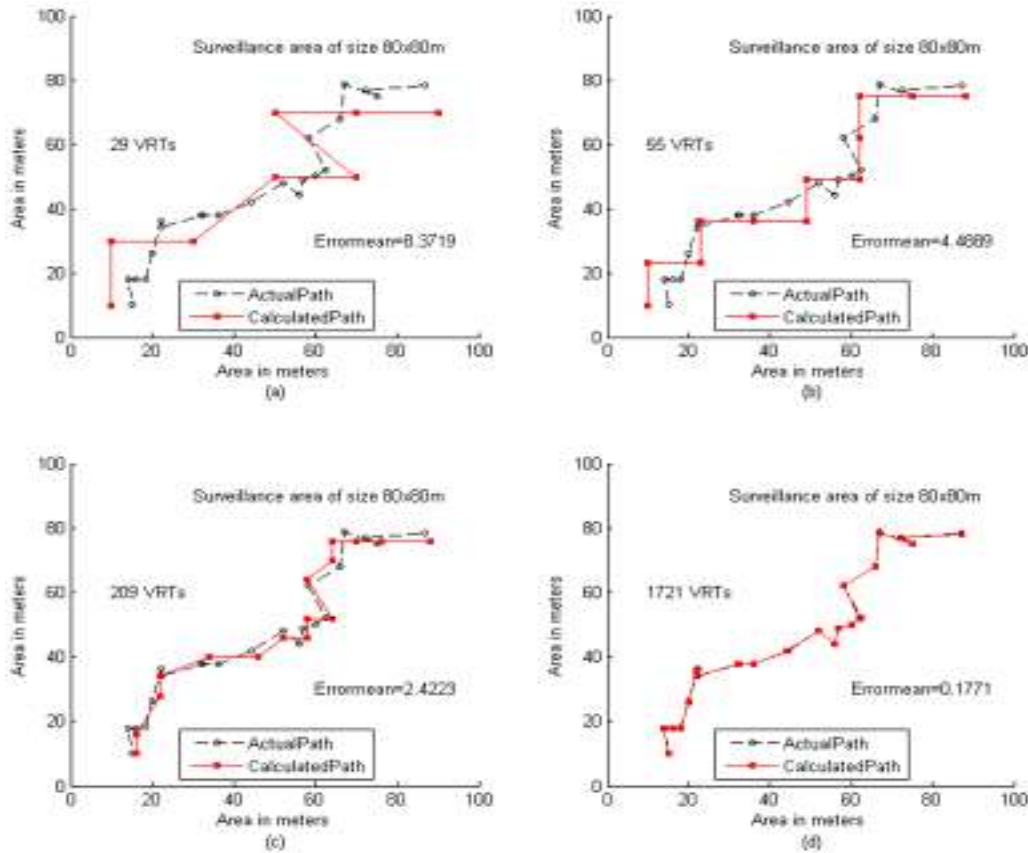

Fig. 2: Comparison of target actual path and calculated path, (a) shows actual and detected path comparison with 29 VRTs over and area of 80×80 m. The error mean is 8.3719, (b) shows the comparison while using 55 VRTs and gives and error mean of 4.4889, (c) 209 VRTs used and error mean reduces to 2.4223, (d) shows the comparison while using 1721 VRTs which decreased error mean to 0.1771
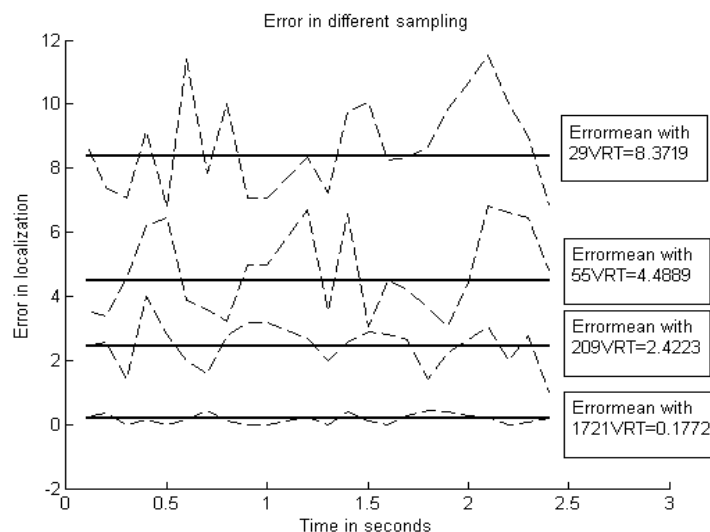
Fig. 3: Error in localization vs. time interval for 29, 55, 209 and 1721 number of VRT

Table 2: Comparison of proposed with existing localization methods

Method	Precision	Maximum distance	Extra hardware	Challenges
RSSI	Meters (2-4 m)	Communication range	None	Variation of the RSSI, interferences
ToA	Centimeters (2-3 cm)	Communication range	None	Nodes synchronization
TDoA	Centimeters (2-3 cm)	Few meters (2-10 m)	Ultrasound transmitter	Maximum distance of work
AoA	Degrees (5)	Communication range	Set of receivers	Work on small sensor nodes
Proposed method	Meters (0.1-0.4 m)	Communication range	High rate information storage	Virtual reference mapping

To detect objects other than target in surveillance area, additional information in form of a flag needs to be added in every VRT. The VRT closes to object can be given a positive flag so that whenever receivers' receivers signal reflection from object they can identify and ignore it.

NUMERICAL RESULTS

In this section some numeric results are shown which explain radar design in more practical manner. The surveillance area is configured to be 80×80 m. On this surveillance area four scenarios are taken in which target or intruder path is same but number of VTRs is changed. This helped us analyze radar performance. The target path is predefined and remains same in all four cases. UWB frequency of 5.5 GHz as upper and 5 GHz as lower frequencies are used making a bandwidth of 500 MHz. The design for localization and path detection of human intruder (Piuzzi *et al.*, 2012), so ideally the radar cross-section can be considered as 1 m^2. Both antenna gains are kept at 0 dB and 1.5 MHz of Pulse Repetition Frequency (PRF) is used. 29, 55, 209 and 1721 number of VRTs are used in four cases, respectively. The number of VRTs is selected randomly for experimentation purpose.

Figure 2 demonstrates actual and detection paths of these cases. As the number of VRTs increase so does the accuracy of system. But more number of VRTs means more high speed data storage in actual scenario. So number of VRTs for different radar design can vary depending on requirement. Figure 3 shows error of the four cases at different time interval. From these results we can conclude that for a radar design of human intruder localization and path detection with surveillance area of 100×100 m, if it has 2500 VRTs, it can monitor target's path with 0.18 m accuracy. And by increasing VRTs from 2500 localization accuracy will also increase. The results show that VRTs improved the precision of RSSI from 2-4 to 0.1-0.4 m. Further no node synchronization is required like in ToA and TDoA. Table 2 shows a comparison of precision, maximum distance covered, challenges and extra hardware required if any between existing methods and the proposed method (Boukerche, 2009).

CONCLUSION

In this research we have discussed a modified design of algorithm of localization for UWB radar sensor network. The design uses referencing techniques which are previously used in RFID based systems. Received signal strength and distance from three receivers are stored as information at virtually designed references known as VRTs. These VRTs provide a reference point and their stored information is used by applying trilateration to locate targets position. Results have also revealed that this localization method shows better results than RSSI in precision. ToA localization method shows better accuracy but requires high level nodes synchronization. The presented method can help in modification of radar design to the next level, which

can increase its application in different scenarios like detection of people trapped inside mines or under rubble of collapsed buildings, in automobile to provide road surveillance to drivers (specially in blind spots) and many more.

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REFERENCES

Boukerche, A., 2009. Alogrithms and Protocols for Wireless Sensor Networks. John Wiley and Sons, Hoboken, N.J., pp: 600.

Dybdal, R.B., 1987. Radar cross section measurements. Proc. IEEE, 75(4): 498-516.

Enrico, P., G. Andrea, C. Marco, M. Riccardo and M. Mauro, 2008. Localization capability of cooperative anti-intruder radar systems. EURASIP J. Adv. Sig. Pr., 2008: 726854, DOI: 10.1155/2008/726854.

Ghavami, M., L. Michael and R. Kohno, 2004. Ultra Wideband Signals and Systems in Communication Engineering. John Wiley and Sons, Chichester, pp: 334.

Grosicki, E. and K. Abed-Meraim, 2005. A new trilateration method to mitigate the impact of some non-line-of-sight errors in TOA measurements for mobile localization. Proceeding of the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 4: 1045-1048.

Hongsan, S., P. Orlik, A.M. Haimovich, L.J. Cimini Jr and Z. Jinyun, 2003. On the spectral and power requirements for ultra-wideband transmission. Proeceeding of the IEEE International Conference on Communications, 1: 738-742.

Huseyin, A., N.C. Zhi and D.B. Maria-Gabriella, 2006. Ultra Wideband Wireless Communication. John Wiley and Sons, Hoboken, pp: 474.

Ni, L.M., Z. Dian and M.R. Souryal, 2011. RFID-based localization and tracking technologies. IEEE Wirel. Commun., 18(2): 45-51.

Piuzzi, E., S. Pisa, P. D'Atanasio and A. Zambotti, 2012. Radar cross section measurements of the human body for UWB radar applications. Proceeding of the IEEE International Instrumentation and Measurement Technology Conference, May 13-16, pp: 1290-1293.

Savvides, A., H. Chih-Chieh and B.S. Strivastava, 2001. Dynamic fine-grained localization in ad-hoc networks of sensors. Proceeding of the 7th ACM/IEEE International Conference on Mobile Computing and Networking. New York, pp: 166-179.

Scholtz, R.A., D.M. Pozar and W. Namgoong, 2005. Ultra-wide-band radio. EURASIP J. Appl. Si. Pr., 2005: 252-272.

Schultz, F.V., R.C. Burgener and S. King, 1958. Measurement of the radar cross section of a man. Proc. IRE, 46(2): 476-481.

Whitehouse, K., 2002. The design of calamari: An ad hoc localization system for sensor networks. M.A. Thesis, University of California at Berkeley.