International Journal of Integrated Engineering, Vol. 4 No. 3 (2012) p. 65-71

Ultra Wide Band localization and tracking hybrid technique using VRTs

Mohd Shamian Zianal[1], Hadi Abdullah[1], Ijaz Khan[1]

[1]Department of Electrical
University Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Malaysia.

Received 1 october 2012; accepted 1 December 2012, available online 20 December 2012

Abstract: This research presents hybrid radar tracking technique consisting of Time Of Arrival (TOA) and Received Signal Strength (RSS) techniques. This hybrid design increases efficiency, accuracy and sensitivity of radar system. The radar used in this research is multistatic radar with one transmitter and three receivers. One common drawback in RSS and TOA techniques is high level synchronization in transmitter and receivers. The hybrid design also suffers from transmitter-receiver synchronization. To overcome TX-RX synchronization problem Virtual Reference Tags (VRTs) are used. These tags are virtually mapped over the surveillance area giving radar design different reference points from which it can accurately locate intruder and monitor its movements. Also four cases of different number of VRTs in design are discussed and based on simulation results accuracy of design is calculated.

Keywords: Multistatic radar, Received signal strength (RSS), Surveillance area, Time of arrival (TOA), Virtual reference tags (VRTs)

1. Introduction

With increase in technology radar system have also been developed to a newer level. Form monostatic to multistatic radar system each have different properties according to the field in which they are used [1]. Multistatic radars are ones having multiple transmitters and/or receivers, for example one transmitter and multiple receivers or one receiver and multiple transmitters [2]. These radars have greater sensitivity and enhanced target classification and recognition. But some drawbacks like synchronization between transmitters and receivers and sharing of information between transmitters and receivers have put their use to a limit.

Ultra wide band (UWB) technologies combined with multistatic radars provide a promising solution for anti intruder scenario. In USA according to the Federal communication commission (FCC) a signal is classified as UWB if it has a bandwidth of greater than 500MHz or a fractional band width of greater than 0.2 [3]. The property of UWB signals passing through common materials like walls and foliage [4] provides good resolution results and enhanced precision in localization.

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 (mostly nine) spread at the edges of surveillance area. Reference tags are symmetrically placed over the surveillance area and a tag is given to the intruder while entering in surveillance area [5]. There are number of limitations to these kind of systems. For example for an unknown intruder with no tags cannot be located, spreading reference tags all over surveillance area makes system difficult to install, radio frequency can easily be breached if intruder carries a transmitter transmitting same frequency signals, number of sensor nodes are high and also these system are not suitable for large surveillance areas. In our design we have virtualized reference tags and saved their information in receivers, reduced number of sensor nodes to four (having one transmitter and three receivers), and used hybrid of TOA and RSS tracking techniques in which there is no need of intruder to carry a tag. Whenever intruder arrives in surveillance area it is monitored with RSS and TOA hybrid radar technique and VRTs provide reference point closest to actual intruder location giving our design high precision.

2. Ultra Wide Band positioning techniques

2.1 Time of arrival (TOA)

In this positioning technique the time signal took to be reflected by the object or target is measured at each receiver. When the propagation time of the signal is known, the measured time provides the distance between the target and respective receiver [6]. Considering three receivers as center of circles and their respective distance from target as radius of circle we get three circles that intersect on a single point. This intersecting point of three circles is the

*Corresponding author: shamian@uthm.edu.my

penerbit.uthm.edu.my/ojs/index.php/ijie

position of target. Figure 1 shows an example of TOA positioning system.

This system is very easy to implement but the main drawback is that the transmitter and receivers must be synchronized with the same clocks. Even a small error in synchronization can cause huge error. For example a clock error of just 1µs can cause an error of 300m. Also this system can generate error from multipath propagation effect [6].

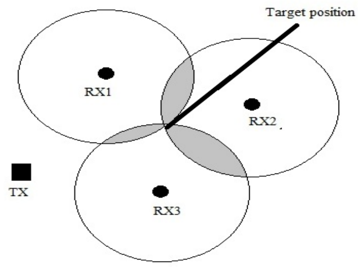


Fig. 1. TOA positioning principle, showing one transmitter and three receivers.

2.2 Received signal strength (RSS)

This technique uses strength of the signal which is reflected from the target at all corresponding receivers. Considering an ideal case each measurement of the signal strength at receivers will give the distance of receiver from the target, same like in case of TOA. But in RSS the accuracy decreases in case of multi path fading environment and shape of circle gets distorted. So it becomes difficult to get an exact intersection of distorted circles. This can produce a considerable amount of error in the target positioning [7],[8].

3. Virtual Reference Tags (VRTS)

As discussed in section 2 both the positioning techniques have some drawbacks. To overcome these drawbacks a system that uses both TOA and RSS along with virtual reference tags is used. These VRTs contain information about the characteristics of target reflected received signal in respective three receivers. Each VRT has its own information. Table 1 shows the information stored at that each VRT.

Table 1. Information or data 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*

Since location of every VRT is known, distance of VRT form three receivers can be calculated using simple distance formula.

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

To calculate the Received signal power friis formula for narrowband (NB) pulses is used[3].

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

Here P^{LOS}_{r-NB} represents the line-of-sight received signal power at receiver. P_t is the transmitted signal power, G_t and G_r 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 equation (3) is used.

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

In equation (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 [9],[10]. 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 equation (4) and (5) which can be used to calculate received signal power [11],[12].

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

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

Here c is the speed of light, S_t is one sided power spectral density and $B = f_U - f_L$ is 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 [13].

4. Radar Configuration and Design

The layout of radar is simple; it consists of one transmitter and three receivers. Transmitter and receivers are placed such that they are at the edges of surveillance area. Figure 2 shows the placement of radar sensors.

Once TX-RXs are placed at their location, virtual reference tags are planned at different positions within the surveillance area [14]. The number of VRTs can vary in different configurations depending on radar design and characteristics of surveillance area. Figure 3 demonstrates a case in which we have 25 VRTs.

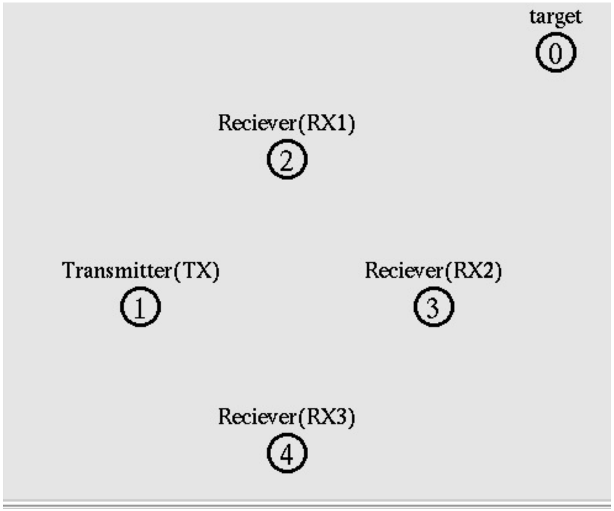


Fig. 2. NS2 simulation scenario of radar design.

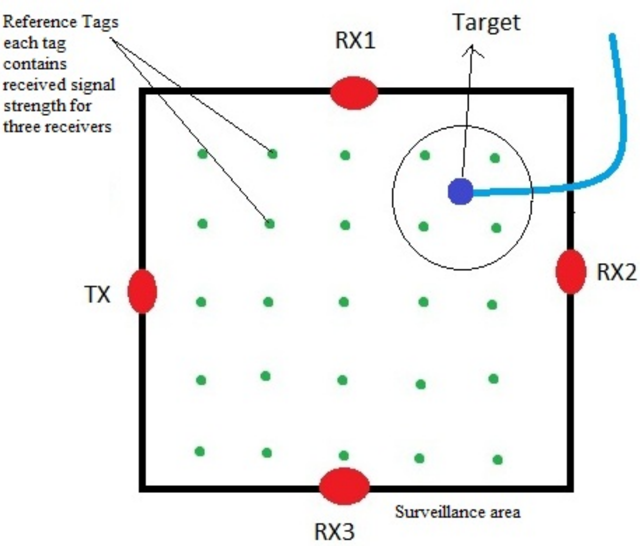


Fig. 3. VRTs positioning in surveillance area.

5. Numerical Results

In this section some numeric results are shown which explain radar design in more practical manner [15]. First some system parameters are set that are used in equations in section 3.

The surveillance area is configured to be 90X90 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. The movement of target in different time interval simulation is shown in figure 4.

Table. 2. System parameters.

Parameter	Symbol	Value
Surveillance area	A	*90x90 m*
Lower frequency	f_L	*5 GHz*
Upper frequency	f_U	*5.5 GHz*
Signal bandwidth	B	*500 MHz*
Transmitted antenna gain	G_t	*0 dB*
Receiver antenna gain	G_r	*0 dB*
Radar cross-section	σ	$1\ m^2$
Pulse repetition frequency	*PRF*	*1.5 MHz*

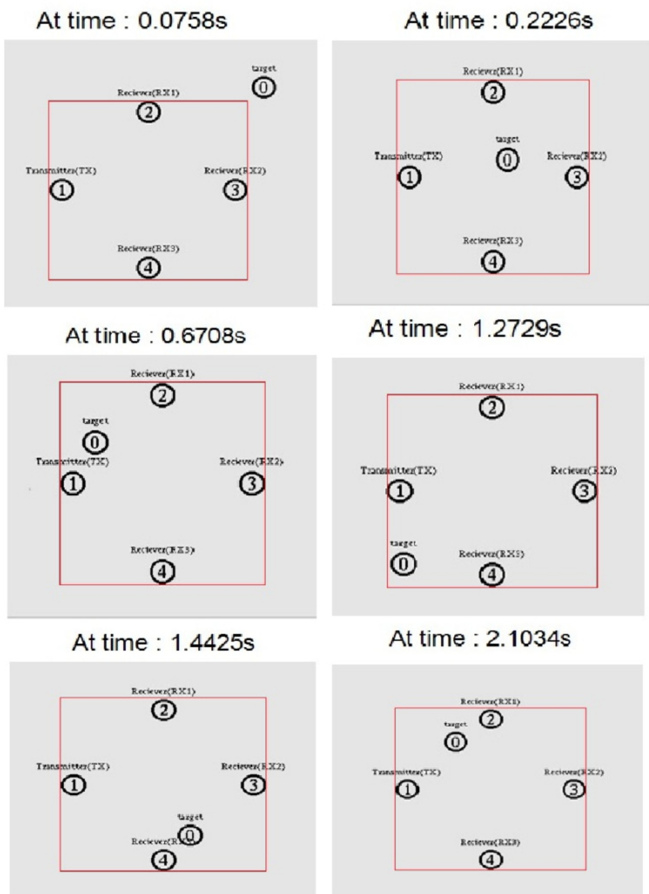


Fig. 4. Target movement in surveillance area.

5.1 Multistatic radar with 16 VRTs in area of 90x90 meters

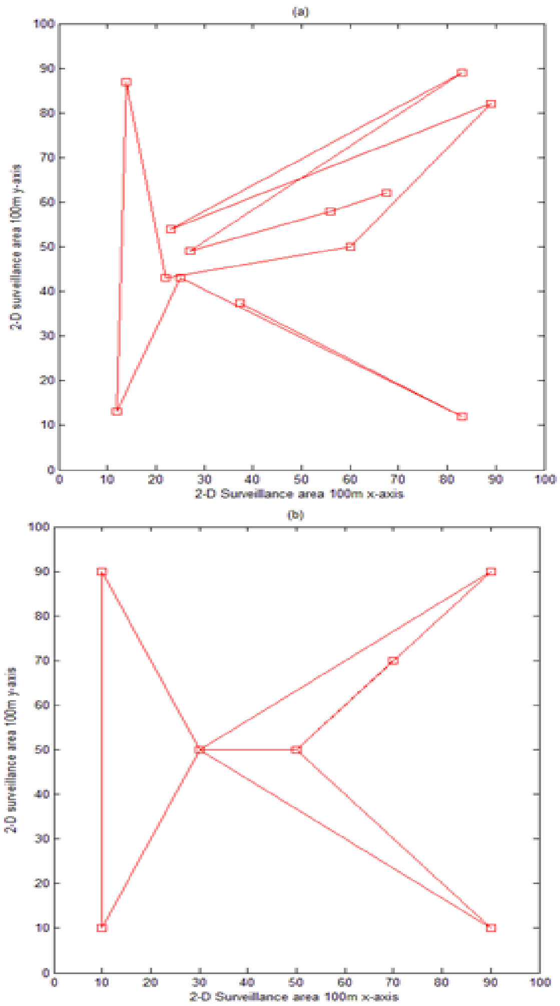
In this case we have set 16 VRTs in surveillance area of 90X90m. Figure 5 (a) shows the actual path of target in surveillance area and figure 5 (b) shows the path detected by our radar design consisting 16 VTRs.

The difference between actual and calculated path is huge. This is because VRTs are less in number and it overlaps targets path. Table 3 shows target actual and calculated path in 2-D in which difference can be monitored numerically.

Table. 3. Target actual and calculated path for 16 VRTs.

Time	*Actual Path*	*Calculated path*
At time: 0.1s	*Not in area*	*Not in area*
At time: 0.2s	*X: 67.517; Y: 61.988*	*X: 70.000; Y: 70.000*
At time: 0.3s	*X: 56.000; Y: 58.000*	*X: 50.000; Y: 50.000*
At time: 0.4s	*X: 27.000; Y: 49.000*	*X: 30.000; Y: 50.000*
At time: 0.5s	*X: 83.000; Y: 89.000*	*X: 90.000; Y: 90.000*
At time: 0.6s	*Not in area*	*Not in area*
At time: 0.7s	*X: 23.130; Y: 54.036*	*X: 30.000; Y: 50.000*
At time: 0.8s	*X: 89.000; Y: 82.000*	*X: 90.000; Y: 90.000*
At time: 0.9s	*X: 60.000; Y: 50.000*	*X: 50.000; Y: 50.000*
At time: 1.0s	*X: 22.000; Y:43.000*	*X: 30.000; Y:50.000*
At time: 1.1s	*X: 14.000; Y: 87.000*	*X: 10.000; Y: 90.000*
At time: 1.2s	*X: 14.000; Y: 87.000*	*X: 10.000; Y: 90.000*
At time: 1.3s	*X: 12.000; Y: 13.000*	*X: 10.000; Y: 10.000*
At time: 1.4s	*X: 25.000; Y: 43.000*	*X: 30.000; Y: 50.000*
At time: 1.5s	*X: 83.000; Y: 12.000*	*X: 90.000; Y: 10.000*
At time: 1.6s	*Not in area*	*Not in area*
At time: 1.7s	*Not in area*	*Not in area*
At time: 1.8s	*Not in area*	*Not in area*
At time: 1.9s	*Not in area*	*Not in area*
At time: 2.0s	*Not in area*	*Not in area*
At time: 2.1s	*Not in area*	*Not in area*
At time: 2.2s	*Not in area*	*Not in area*
At time: 2.3s	*Not in area*	*Not in area*
At time: 2.4s	*Not in area*	*Not in area*
At time: 2.5s	*Not in area*	*Not in area*
At time: 2.6s	*Not in area*	*Not in area*
At time: 2.7s	*Not in area*	*Not in area*
At time: 2.8s	*X: 37.355; Y: 37.355*	*X: 50.000; Y: 50.000*

5.2 Multistatic radar with 29, 105 and 1681 VRTs in area of 90x90 meters



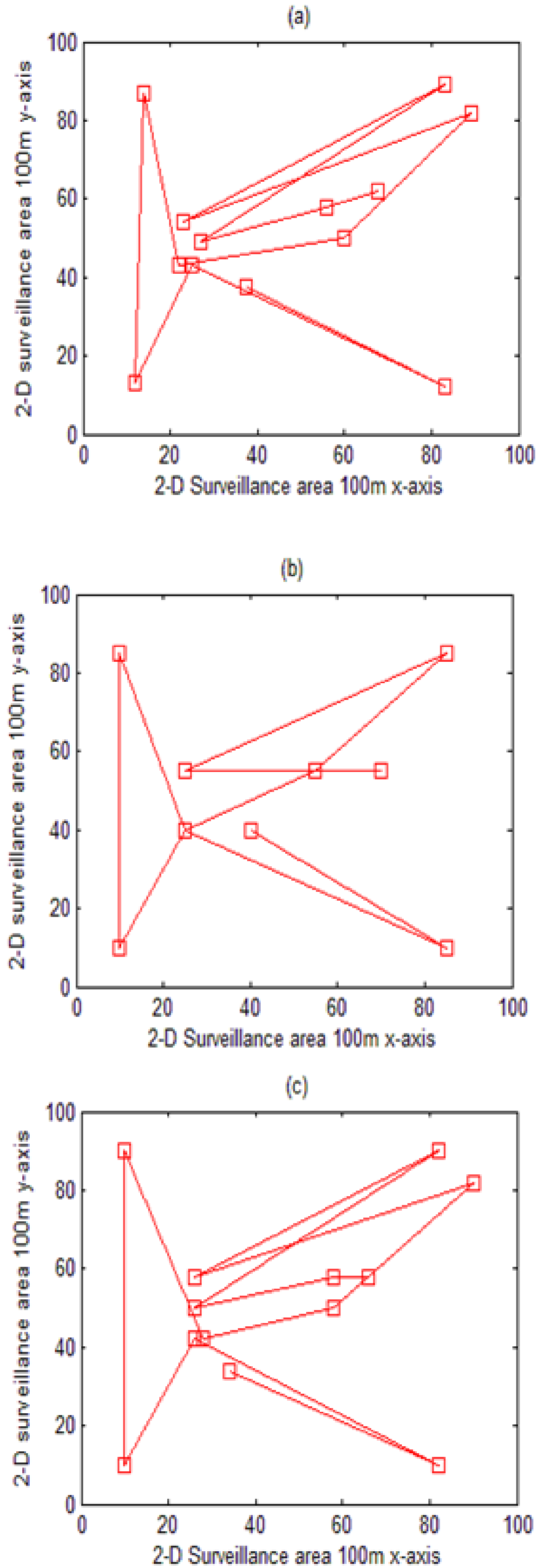
In section 5.1 number of VRT was only 16. Here we will discuss three more cases in which number of VRT is increased.

Fig. 5. In this figure x and y axis represent surveillance area in 2-D, which is 90x90 meters (a) target actual path, (b)target detected path by radar system.

As number of VRT is increased references for our radar are increased giving our system a better ground for locating position and monitoring path of intruder.
Figure 6 shows all three cases compared with the actual path of intruder. We can see when VRTs are increased the calculated path comes closer to actual path. This increases accuracy of our radar design and decreases a considerable amount of error seen in section 5.1. Table 4 shows more clear view on error reduction, it shows actual path value compared with three calculated path by our design.

Table. 4. Target actual path compared with calculated values for 29, 105 and 1681 VRTs

Time	Actual Path	Calculated path with 29 VRTs	Calculated path with 105 VRTs	Calculated path with 1681 VRTs
At time: 0.1s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 0.2s	*X: 67.517; Y: 61.988*	*X: 70.000; Y: 55.000*	*X: 66.000; Y: 58.000*	*X: 68.000; Y: 62.000*
At time: 0.3s	*X: 56.000; Y: 58.000*	*X: 55.000; Y: 55.000*	*X: 58.000; Y: 58.000*	*X: 56.000; Y: 58.000*
At time: 0.4s	*X: 27.000; Y: 49.000*	*X: 25.000; Y: 55.000*	*X: 26.000; Y: 50.000*	*X: 26.000; Y: 48.000*
At time: 0.5s	*X: 83.000; Y: 89.000*	*X: 85.000; Y: 85.000*	*X: 82.000; Y: 90.000*	*X: 82.000; Y: 88.000*
At time: 0.6s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 0.7s	*X: 23.130; Y: 54.036*	*X: 25.000; Y: 55.000*	*X: 26.000; Y: 58.000*	*X: 24.000; Y: 54.000*
At time: 0.8s	*X: 89.000; Y: 82.000*	*X: 85.000; Y: 85.000*	*X: 90.000; Y: 82.000*	*X: 88.000; Y: 82.000*
At time: 0.9s	*X: 60.000; Y: 50.000*	*X: 55.000; Y: 55.000*	*X: 58.000; Y: 50.000*	*X: 60.000; Y: 50.000*
At time: 1.0s	*X: 22.000; Y:43.000*	*X: 25.000; Y:40.000*	*X: 18.000; Y:42.000*	*X: 22.000; Y:42.000*
At time: 1.1s	*X: 14.000; Y: 87.000*	*X: 10.000; Y: 85.000*	*X: 10.000; Y: 90.000*	*X: 14.000; Y: 86.000*
At time: 1.2s	*X: 14.000; Y: 87.000*	*X: 10.000; Y: 85.000*	*X: 10.000; Y: 90.000*	*X: 14.000; Y: 86.000*
At time: 1.3s	*X: 12.000; Y: 13.000*	*X: 10.000; Y: 10.000*	*X: 10.000; Y: 10.000*	*X: 12.000; Y: 12.000*
At time: 1.4s	*X: 25.000; Y: 43.000*	*X: 25.000; Y: 40.000*	*X: 26.000; Y: 42.000*	*X: 24.000; Y: 42.000*
At time: 1.5s	*X: 83.000; Y: 12.000*	*X: 85.000; Y: 10.000*	*X: 82.000; Y: 10.000*	*X: 82.000; Y: 12.000*
At time: 1.6s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 1.7s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 1.8s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 1.9s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.0s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.1s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.2s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.3s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.4s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.5s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.6s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.7s	*Not in area*	*Not in area*	*Not in area*	*Not in area*
At time: 2.8s	*X: 37.355; Y: 37.355*	*X: 40.000; Y: 40.000*	*X: 34.000; Y: 34.000*	*X: 38.000; Y: 38.000*



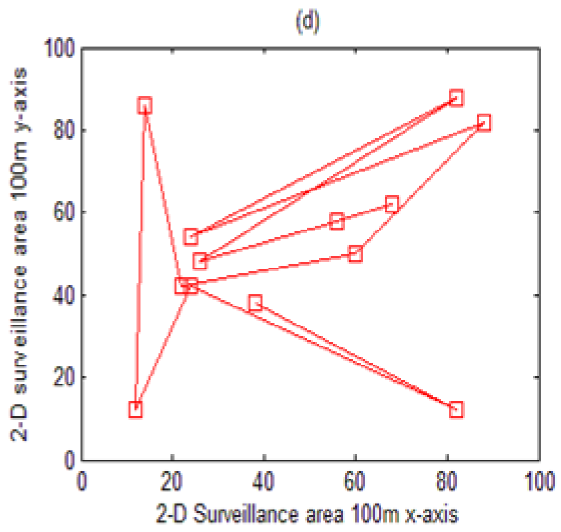


Fig. 6. Target movement in 2-D surveillance area of 90x90 meters, (a) Actual path of target, (b) Calculated target path with 29 VRTs, (c) Calculated target path with 105 VRTs, (d) Calculated target path with 1681 VRTs.

From these results we can conclude that for a surveillance area of 100x100 meters if we make 2500 VRTs we can monitor target path with 0.2 meter accuracy. And by increasing VRTs from 2500 we can get even more accurate results. Figure 7 shows how error is decreased exponentially by increasing VRTs.

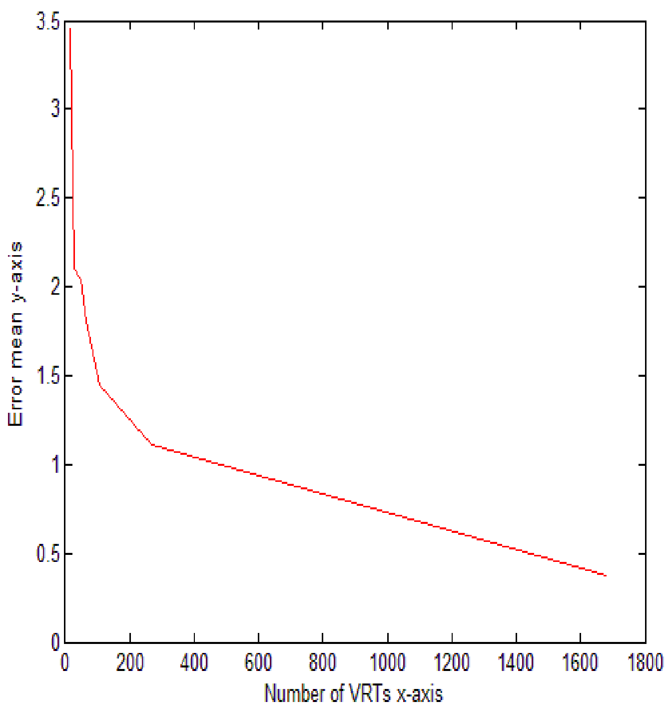


Fig. 7. Error mean (y-axis) Vs number of VRTs. (x-axis)

6. Conclusion and summary

In our study we have seen a hybrid design that uses virtual reference tags and how these tags affect the performance of our design. VRT has provided us with a new ground on which we can check measure and improve our radar system performance. These radar systems can be very efficient in places where high level security is required and only cameras don't provide enough security. Specially in case when there is fog or misty night one can't only rely on cameras. Also covering an area of 100x100 meters with cameras for security is a difficult issue. Our design can be easily implemented on FPGAs, giving and extra advantage of being low cost. This makes our design best for use in places like airports, hospitals, nuclear reactors, jails etc. With a little modification our design can also become mobile and can be used as a safety feature in automobiles. As safety feature in automobiles its can monitor situation outside and worn the driver if a close it observes a close impact with any object. Also our design can be used in hazard situations. It can locate humans if they are trapped under building rubble or in mines.

References

[1] P. Withington, *et al.*, "Enhancing homeland security with advanced UWB sensors," *Microwave Magazine, IEEE,* vol. 4, pp. 51-58, 2003.

[2] V. S. Chernyak, "Fundamentals of Multisite Radar System," 1998.

[3] F. C. Commission, "Revision of part 15 of the commission's rule regarding ultra-wideband transmission system, first report and order (ET Docket 98-153)," April 2002.

[4] E. H. S.Gauthier, and W.Chamma, "Surveillance through concrete walls," Tech. Rep. TM 2003-233, Defence R & D Canada2003.

[5] L. M. Ni, et al., "RFID-based localization and tracking technologies," *Wireless Communications, IEEE*, vol. 18, pp. 45-51, 2011.

[6] L. B. M. a. R. K. M. Ghavami, "Ultra Wideband Signals and Systems in Communication Engineering," John Wiley & Sons, Ltd, 2004.

[7] T. Gigl, *et al.*, "Analysis of a UWB Indoor Positioning System Based on Received Signal Strength," in *Positioning, Navigation and Communication, 2007. WPNC '07. 4th Workshop on*, 2007, pp. 97-101.

[8] A. Hatami, *et al.*, "On RSS and TOA based indoor geolocation - a comparative performance evaluation," in *Wireless Communications and Networking Conference, 2006. WCNC 2006. IEEE*, 2006, pp. 2267-2272.

[9] R. B. Dybdal, "Radar cross section measurements," *Proceedings of the IEEE,* vol. 75, pp. 498-516, 1987.

[10] F. V. Schultz*, et al.*, "Measurement of the Radar Cross Section of a Man," *Proceedings of the IRE,* vol. 46, pp. 476-481, 1958.

[11] D. M. P. R. A. Scholtz, and W. Namgoong, "Ultra-wide-band radio," EURASIP Journal on Applied Signal Processing, vol. 2005, no. 3, pp. 252–272, 2005.

[12] S. Hongsan*, et al.*, "On the spectral and power requirements for ultra-wideband transmission," in *Communications, 2003. ICC '03. IEEE International Conference on*, 2003, pp. 738-742 vol.1.

[13] A. G. a. M. C. Enrico Paolini, "Localization Capability of Cooperative Anti-Intruder Radar Systems," EURASIP Journal on Advances in Signal Processing, Volume 2008, Article ID 726854, 2008.

[14] L. Weifeng*, et al.*, "A novel indoor positioning method based on key reference RFID tags," in *Information, Computing and Telecommunication, 2009. YC-ICT '09. IEEE Youth Conference on*, 2009, pp. 42-45.

[15] X. Zuo*, et al.*, "Time domain spreading and frequency domain maximal ratio combining reception for frequency diversity enhancement in single carrier UWB communication systems," *Electrical and Computer Engineering, Canadian Journal of,* vol. 34, pp. 178-184, 2009.