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석사학위논문

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지도교수 변 재 영

이 논문을 공학석사학위신청 논문으로 제출함.

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김범훈의 석사학위 논문을 인준함

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2015 년 5 월

조 선 대 학 교 대 학 원

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Acronyms

UWB : Ultra-Wideband
IR-UWB : Impulse Radio-Ultra Wideband
FCC : Federal Communications Commission
RSSI : Received signal strength Indication
AOA : Angle of arrival
TOA : Time of arrival
TDOA : Time difference of arrival
AP : Access Point
DAA : Detection and Avoid
CFAR : Constant False Alarm Rate
CA-CFAR : Cell Averaging Constant False Alarm Rate
KF : Kalman Filter
EKF : Extanded Kalman Filter
IEKF : Iterative Extanded Kalman Filter
IPS : Indoor Positioning system

ABSTRACT

2D object tracking with IR-UWB radar

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Indoor positioning system (IPS) is required for rescue, surveilance, and security applications. In this thesis, impulse radio-ultra wide band (IR-UWB) radar is used for IPS, because this system has several advantages such as high spatial resolution, ultra low power, low cost, and ability to penetrate the non-metallic materials. However, the location and number of radars should be considered to improve the accuracy of IR-UWB based IPS. Also, to track the moving target included unwanted clutter signal and noise, signal-processing procedures should be applied to the raw data measured by IR-UWB radars. This procedure consists of clutter reduction, target detection, localization, and tracking steps. In the case of tracking step, extended kalman filter (EKF) based tracking algorithm has been introduced, but its performance was still limited when the target moves drastically.

This thesis proposes the object tracking method using iterative extended kalman filter (IEKF) in 2 dimension. As a first step, to reduce unwanted signals, the conventional kalman filter (KF) based clutter reduction is used on the obtained IR-UWB signal. After that, the modified CLEAN detection technique is applied for detection of objects. With the detection of the moving target makes, location of the target in coordinates is observed and used for the object tracking. The proposed method was evaluated in comparison with the EKF based

conventional object tracking method and the root mean square error for estimating trajectories was found improved about 5% in the real-time system.

초 록

IR-UWB 레이더를 활용한 2차원 물체 추적

김범훈
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실내 위치 파악 시스템 (Indoor Positioning System : IPS)은 구출작업, 원격감시와 보안 응용 프로그램들에서 요구되어진다. 본 논문에서는 실내 위치 파악 시스템을 위해 IR-UWB (Impulse Radio-Ultra Wideband) 레이더를 사용하였다. 이 시스템은 높은 해상도, 초저전력, 저비용, 그리고 비금속 물질을 투과하는 하는 투과성 등 장점을 가졌기 때문이다. IR-UWB를 기반으로 하는 IPS의 경우, 레이더들의 수와 위치가 고려되어야 하며, IR-UWB 레이더를 통하여 관측 된 원시데이터의 경우, 불필요한 클러터 신호와 잡음을 포함하므로, 이동하는 물체를 추적하기 위해서 신호 처리 과정이 반드시 적용되어야한다. 이러한 신호처리 과정은 클러터 제거, 대상 신호 검출, 위치 측정 및 위치 추적단계로 구성되며, 특히 위치 추적단계의 경우 확장 칼만 필터 (Extended Kalman Filter : EKF)를 기반으로 하는 추적 알고리즘이 소개되고 있으나, 여전히 급격히 움직이는 대상의 추적에 성능이 제한되고 있다.

본 논문에서는 반복 확장 칼만 필터 (Iterative Extended Kalman Filter : IEKF)를 사용하여 2차원에서 움직이는 물체를 추적하는 방법을 제안하고자 한다. 물체를 추적하기 위해서, IR-UWB 레이더에 의해 관측 된 신호는 기존의 칼만 필터 (Kalman Filter : KF) 클러터 제거기술에 의해서 원하지 않는 신호들을 제거하였고, 대상을 검출하기 위해서 수정 된 CLEAN 검출 기술을 적용하였다. 이 처리된 신호는 거리 값으로 변환되어 좌표에서 위치가 결정되고 위치 추적에 사용되어 진다. 제안하는 방법은 기존의 반복 확장 칼만 필터 기반의 위치 추적 방법과 성능비교를 통하여 평가되었으며, 실시간 환경에서 측위 오차의 실효치가 5% 정도 성능이 향상 된 것을 확인할 수 있었다.

I. Introduction

A. Research background and objective

In order to track the moving target in indoor environment, tracking techniques have been implemented by ultrasonic, Wi-Fi, infrared rays, and impulse radio-ultra wide band (IR-UWB) radar. These technique are required for rescue, surveillance, emergency, and security situations in indoor environment, because outdoor positioning system including global position system (GPS) is not working at all in indoor. But, the object location in indoor environment can be recognized by the reflected signal from the object based on other systems [1]. For the accuracy of target location, i consider IR-UWB radar system. In addition to the enhanced accuracy, this system possesses several superior advantages such as high spatial resolution, ultra low power, and low cost [2,3]. In this thesis, the IR-UWB radar is used for location detection, localization, and tracking of the moving target in indoor environment. This impulse radar consists of two antennas for transmitting and receiving signals. These two devices exchange the extremely narrow pulse. The received signal includes several pulses such as target signal, noise, and static object signal. Therefore, the signal processing procedures must be applied for extracting the target signal [4]. These procedures consist of clutter reduction, detection, localization, and tracking steps in order.

The purpose of signal processing except for the tracking step is to remove the unwanted signal and to decide the location of target. However, the processed signal still includes clutters and noises. Thus, the tracking step is needed for the more accurate result.

This thesis propose a new object tracking method in 2-dimension coordinates for the real-time system.

B. Research objectives

The main objective of this thesis is research on applications of UWB radar in the detection and tracking of moving object. To detect and track the moving target, the raw data captured by IR-UWB radar is provided to kalman filter (KF) clutter reduction technique to remove the unwanted signal. And then, the processed signal is applied for the modified CLEAN detection technique to detect the target location and to compensate the signal attenuation. After that, the location and distance of target are decided by the processed signal through the distance conversion. However, this result still has error because of clutters and noises. Thus, the noise reduced signal is conveyed to the target tracking step. The objective of this thesis is to improve the conventional tracking method for the accuracy.

C. Thesis organization

The remainder of this thesis is organized as follows:

Chapter Ⅱ presents the background information about the overall IR-UWB technique related on this thesis. Chapter Ⅲ explains the signal processing procedures for tracking the moving target. Chapter Ⅳ describes the proposed tracking algorithm and compares with the performance of the conventional tracking algorithm. Finally, the conclusion of this work is followed by chapter Ⅴ.

II. Range Detection using UWB

A. Ultra Wideband Regulations

UWB defined by Federal Communications Commission (FCC) has a bandwidth greater than 500 MHz or fractional bandwidth greater than 20 percent [7]. Generally, UWB can transmit with high bit rates more than 100 Mbps at 3.1–10.6 GHz bandwidth. On the other hand, UWB technique based on impulse has the several advantage such as low power, low consumption, high energy usage efficiency, high speed, mitigation multipath fading, and so on. Also, this impulse based UWB can apply for the positioning system, because it can measure accurately in the centimeter unit because of using a extremely narrow pulse [8]. Figure 1 presents the frequency of UWB defined by FCC.

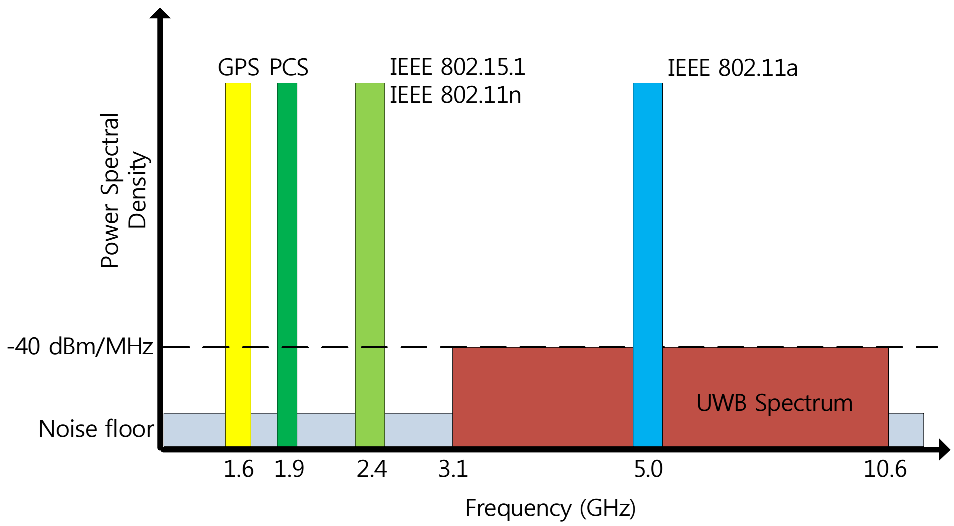

Figure 1. The frequency range of UWB

Table 1. Emission FCC limits for UWB communication application [5]

Application		Frequency band (GHz)					
		0.96 to 1.61	1.61 to 1.99	1.99 to 3.1	3.1 to 10.6	10.6 to 22	22 to 29
EIRP (dBm)	indoor	75.3	53.3	51.3	41.3	51.3	51.3
	outdoor	75.3	63.3	61.3	41.3	61.3	61.3

Table 1 shows the emission of communication systems assigned by FCC. The domestic UWB frequency is used at low band (3.1-4.8 GHz) and high band (7.2-10.2 GHz). The low band must be used only for the UWB system using avoidance technique of interference because of frequency interference with the preassigned communication system. Also, its power spectral density limit for low band is -41.3 dBm/MHz and high band is -71.3dBm/MHz in indoor and outdoor communication [8].

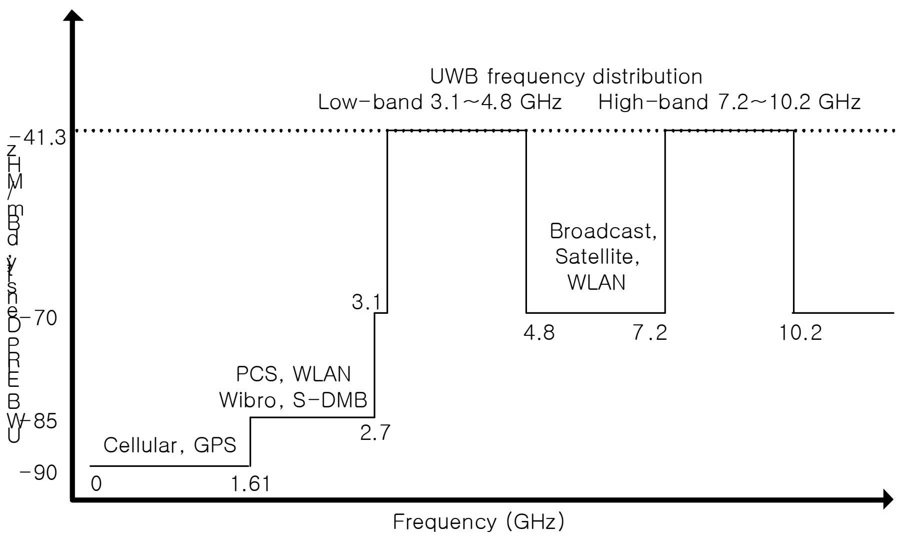

Figure 2. The distribution domestic UWB frequency

B. Features of UWB system

UWB radar has the several advantages derived from the unique characteristics. Firstly, the pulse of the UWB system is extremely narrow. Thus, the received signals of UWB system have the high spatial resolution. Secondly, UWB system has the low power and low cost. Because UWB does not use the modulation and demodulation using a complex carrier waveform, also dose not require the mixers, filters, amplifiers, and local oscillators. Thirdly, UWB can achieve the several Gbps under the distance of 1 to 10 meters [7]. Fourthly, UWB has the robust ability of mitigating multipath fading. Fifthly, UWB does not interfere with the conventional services, because UWB system uses the extremely low power transmission. Lastly, the signal of UWB has a penetrating ability for through-the-wall [8]. Whereas, the UWB system has limitations. Firstly, UWB system requires the very fast ADC (Analog-to-Digital Converter) ability when the signal transmits and receives because of high frequency synchronization. Secondly, UWB can interfere with other communication and equipment. Lastly, the information on the part of UWB can travel only short distances such as 1 to 10 meters because of low transmission power. However, UWB system has been discussed for using at the various application systems such as indoor positioning, medical, and rescue system because of the advantages of UWB system.

C. Impuls Radio UWB Radar

Radar is an wireless surveillance device that uses microwaves to find the distance, direction, altitude, and speed of object using the reflected electromagnetic wave at the object [9]. Figure 3 shows the principle operation of the fundamental IR-UWB Radar. IR-UWB radar using the extremely narrow pulse consists of one transmitter and one receiver. The observed signals at the receiver are the reflected signal from the target and other objects. The signals could be used for the many application system. Especially, these signals are used for the application of detection, localization, and tracking of moving target. In this case, the distance and location of target are determined through the time-of-arrival (TOA).

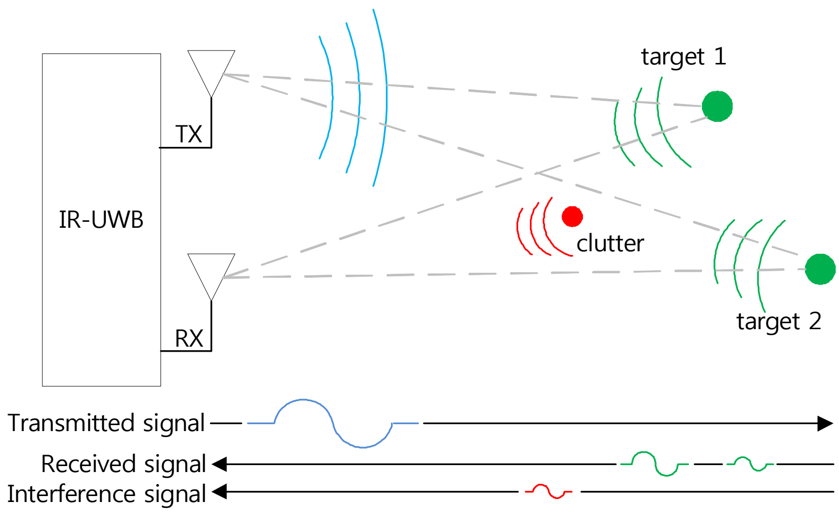

Figure 3. Principle operation of IR-UWB radar

D. Object detection and Distance measurement by IR-UWB Radar

In IR-UWB radar system, the reflected signal from object is expressed by Equation (2.1). $R(t)$ is a received signal including clutter, noise, and target signal. $R_t(t)$ is a target signal, $R_c(t)$ is a clutter, and $n(t)$ is a noise. For the accurate object detection, the clutter and noise must be removed. This procedure is called to background subtraction or clutter reduction.

$$R(t) = R_t(t) + R_c(t) + n(t) \tag{2.1}$$

After the clutter reduction, the processed signal must be used for object detection and distance measurement. This thesis uses IR-UWB radar with NVA 6100 chipset developed by Novelda company [10]. Figure 4 shows a frame structure consisting of samples captured at IR-UWB radar receiver. The one frame consists of the of 512 samples in this thesis work. Thus, sample can be interpreted to signal propagation time and target distance. In the condition of 512 samples per frame, the time period of each sample is 27ps. The distance from radar gto the target could be expressed with a period of in (2.2). C is the radio wave speed in air.

$$d_{sampler} = \frac{C \times timeperiod}{2} \tag{2.2}$$

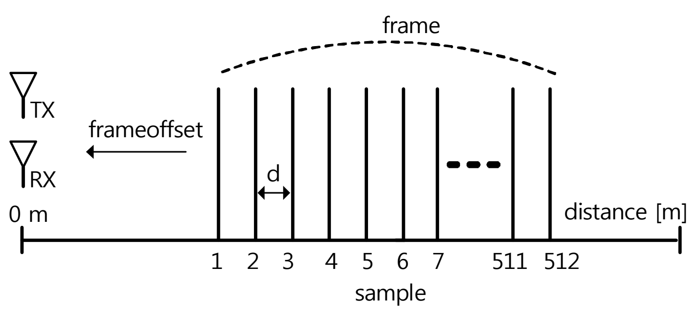

Figure 4. The frame construction of IR-UWB radar [10]

By using (2.2) the resolution of the observed distance could be about 4 millimeters as shown in (2.3). That is, the 512 samples can measure about 2 meters. To measure a distance over the 2 meters, the UWB radar system delays sampling times as long as the target locates [10].

$$\begin{aligned} d_{sampler} &= \frac{299792458[m/s]\times 27\times 10^{-12}}{2} \\ &= 0.00404719813[m] \\ &\approx 4[mm] \end{aligned} \tag{2.3}$$

III. Signal Processing Procedures for Target Tracking in 2D

These procedures consist of clutter reduction, detection, localization, and tracking steps in order as shown in Figure 5.

In the clutter reduction step, the major role is to remove the clutters in the raw data captured by IR-UWB radar. Because clutters are the reflected unwanted signals in indoor positioning application, the received signal including the clutter should be carefully handled [11]. There are the clutter reduction techniques such as kalman filter (KF), exponential average (EA), and singular value decomposition (SVD) [12]. This thesis works applied the conventional kalman filter (KF) based clutter reduction method.

In the detection step, the location of target is to specify where the target is. Firstly, the strength of clutter eliminated signal is compared with a threshold. If the signal strength is greater than the threshold, a target is considered as present. There are the detection techniques such as CLEAN, modified CLEAN, matched filter, and constant false alarm rate (CFAR) [13]. This thesis works applied the conventional modified CLEAN detection method.

In the localization and tracking steps, the distance to the target is observed by using the arrival time of the detected target signal. Indeed, the distance to the target is the target sample index multiplied by the sample resolution of IR-UWB radar. However, there are still contained errors, even though some of them has been eliminated by the previous processing steps. To localize and track the moving target, several methods such as trilateration, KF, and extended kalman filter (EKF) have been proposed [14,15].

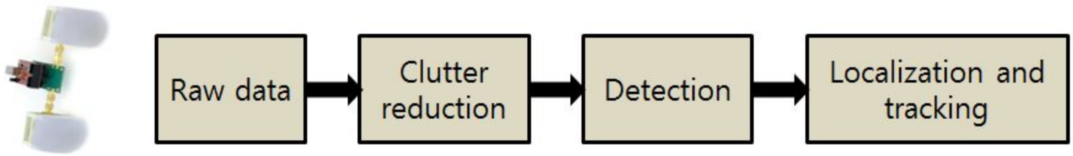

Figure 5. Signal processing procedures for target tracking application

The KF, this method has a good performance in linear system. However, this technique has higher estimation error due to nonlinear relationship between measurements and target position in two dimension. On the other hand, EKF has the better performance than conventional KF based tracking method in two dimension. However, it still has the problem of tracking because the measurement noise and error covariance matrix in EKF are affected by underestimating the substantial covariance matrices. Also, if the initial estimation state is wrong, this filter could diverge rapidly due to its linearization. As a result, the accuracy of tracking performance in EKF can be reduced when the target changes its direction drastically.

IV. Location and Tracking

In this thesis, the performance evaluations of both conventional EKF and proposed IEKF based target tracking method are shown. The IEKF method can estimate the target position in drastic direction change of moving target better than EKF can, because it has the additional iterative function. By using this method, this thesis estimate the target trajectories in both natural and drastic movement of target.

To track the moving object in IR-UWB radar system, this thesis apply the clutter reduction and detection techniques. Then, the target location is decided by detecting the target from sampled signals. The target signal samples indicating the target detection can be converted to distance to the target. To obtain the target distance, this thesis uses

$$Distance = N \times R, \tag{4.1}$$

where N is the target sample index of a frame stored after applying the detection technique, and R is the sample resolution of IR-UWB radar. For example, $Distance$ is 2 m, when N is 500 and R is 4 mm. Many localization and tracking works have been done to get the distance in one dimension. However, my experiments use two impulse radars in order to show the 2D coordinates. Therefore, the distance conversions to the coordinate can be expressed by the two circle intersection as follows:

$$(d_x - X_i)^2 + (d_y - Y_i)^2 = r_i^2. \tag{4.2}$$

X_i and Y_i are the X and Y coordinates of radar positions, where i is the number of radar. dx and dy are the X and Y coordinates of target locations from each radar. Each target distance makes a circle from radar position to target locations as shown in Figure 6. Thus, the coordinates can be obtained through these circles intersection. However, the observed target distance still has noise. Therefore, the additional filtering method for location estimation is needed. For the location estimation to decrease the noise, there are linear filter based approaches using KF and non-linear filter based approach using EKF and IEKF.

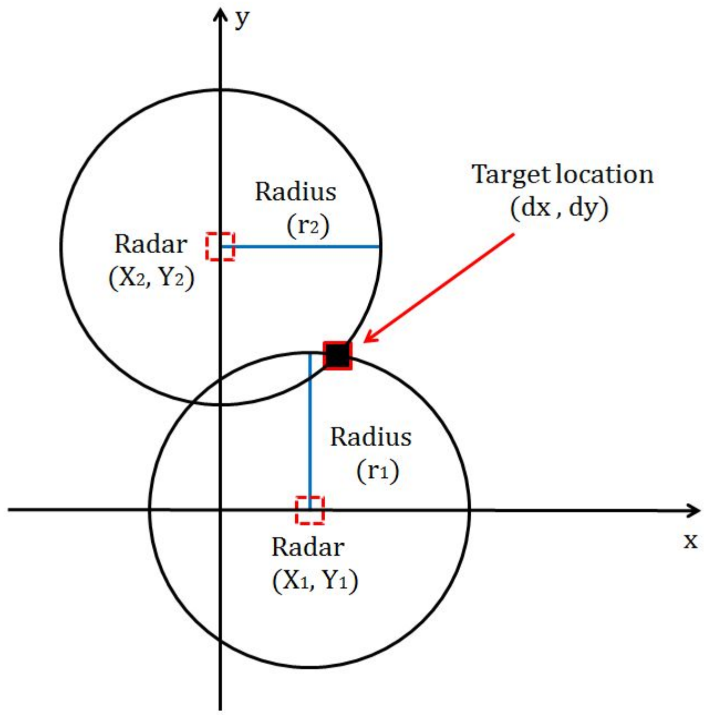

Figure 6. Two circles intersection

In my experiments, i carried out location estimation using EKF and IEKF for tracking of moving target. EKF and IEKF estimation methods are governed by non-linear system [16].

These two estimation methods provide the optimized models for non-linear system. The system model x and measurement model z are described as follows:

$$x_k = f(x_{k-1},\ u_{k-1}) + w_{k-1} \tag{4.3}$$

$$z_k = h(x_k) + v_k, \tag{4.4}$$

where k is the time index of target, u is the control input, w is the process noise, and v is the measurement noise. When applying the estimation methods, i have to define the appropriate target state vector in those methods as follows:

$$x_k = [dx,\ vx,\ dy,\ vy]^T \tag{4.5}$$

where dx is the location in the x coordinate, dy is the location in the y coordinate, and v is the velocity of target.

A. EKF estimation for 2D target tracking

The EKF state model is same as KF state model because EKF is non-linear version of KF. The EKF state model is made of the motion estimation of target which is needed for tracking system.

$$x_{k=} f(x_{k-1}, u_{k-1}) + w_{k-1} = Ax_{k-1} + Bu_{k-1} + w_{k-1} \tag{4.6}$$

Equation (6) is the state model in KF, EKF, and IEKF. This state model can be changed by the target state vector for estimation as follows:

$$x_k = \begin{bmatrix} dx_k \\ vx_k \\ dy_k \\ vy_k \end{bmatrix} = \begin{bmatrix} dx_{k-1} + vx_{k-1}t + at^2 \\ vx_{k-1} + at \\ dy_{k-1} + vy_{k-1}t + at^2 \\ vx_{k-1} + at \end{bmatrix} + w_{k-1} \tag{4.7}$$

where $w_k = N(0,\ Q)$ is the additive process noise as covariance matrix Q. The transition matrix A is given by

$$A = \begin{bmatrix} 1 & t & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & t \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{4.8}$$

where t is one. The control input matrix B is given by

$$B = \begin{bmatrix} \frac{t^2}{2} & 0 & 0 & 0 \\ 0 & t & 0 & 0 \\ 0 & 0 & \frac{t^2}{2} & 0 \\ 0 & 0 & 0 & t \end{bmatrix}. \tag{4.9}$$

The input vector u is given by

$$u_k = \begin{bmatrix} a_x \\ a_x \\ a_y \\ a_y \end{bmatrix}, \tag{4.10}$$

where a_x and a_y are the accelerations of target. Also, i define the EKF measurement model derived as follows:

$$z_k = \begin{bmatrix} r1 \\ r2 \end{bmatrix} = \begin{bmatrix} \sqrt{(d_x - X_1)^2 + (d_y - Y_1)^2} \\ \sqrt{(d_x - X_2)^2 + (d_y - Y_2)^2} \end{bmatrix} + v_k, \tag{4.11}$$

where X_1, X_2, Y_1, and Y_2 are the locations of each radar in the x and y coordinates as shown in Figure 2. In addition, $v_k = N(0, R)$ is the additive measurement noise as covariance matrix R. Next is the estimation process which consists of prediction and correction steps. The prior mentioned problem is how to transform the non-linear target state vector to the linear target state vector. This problem in EKF have resolved by Jacobian matrix [16]. The EKF algorithm recursively carries out prediction and correction steps in order given by these equations:

$$initialize: x_{k-1}^-, P_k^- \tag{4.12}$$

$$\hat{x}_k^- = Ax_{k-1} + Bu_{k-1}, \tag{4.13}$$

$$P_k^- = AP_{k-1}A^T + Q, \tag{4.14}$$

$$K_k = P_k^- H_k^T (H_k P_k^T + R)^{-1}, \tag{4.15}$$

$$\hat{x}_k = \hat{x}_k^- + K_k (z_k - h(\hat{x}_k^-)), \tag{4.16}$$

$$P_k = (I - K_k H_k) P_k^-. \tag{4.17}$$

The prediction step operates as shown in equation (12),(13), and (14). $\hat{x}_{k-1}^-$ is the state vector and P_k^- is the error covariance diagonal matrix having a same size as the number of state vector. In equation (13), the current location is estimated by x_{k-1}. Also, P_k^- is updated by P_{k-1} and Q to get the next estimated location position. Q is the process noise covariance diagonal matrix having a same size as the number of state vector:

$$Q=\begin{bmatrix} q_k & 0 & 0 & 0 \\ 0 & q_k & 0 & 0 \\ 0 & 0 & q_k & 0 \\ 0 & 0 & 0 & q_k \end{bmatrix}, \qquad (4.18)$$

where q is a variance of each process noise defined by user.

The correction step is shown in equation (15),(16), and (17) for computing the kalman gain, updating the estimation state, updating the error covariance, and computing the Jacobian matrix. Jacobian matrix is as follows:

$$H_k=\begin{bmatrix} \frac{\partial h_1}{\partial x_k} \\ \frac{\partial h_2}{\partial x_k} \end{bmatrix} = \begin{bmatrix} \frac{dx_k - X_1}{\sqrt{(dx_k - X_1)^2 + (dy_k - Y_1)^2}}, 0, \frac{dy_k - Y_1}{\sqrt{(dx_k - X_1)^2 + (dy_k - Y_1)^2}}, 0 \\ \frac{dx_k - X_2}{\sqrt{(dx_k - X_2)^2 + (dy_k - Y_2)^2}}, 0, \frac{dy_k - Y_2}{\sqrt{(dx_k - X_2)^2 + (dy_k - Y_2)^2}}, 0 \end{bmatrix}. \qquad (4.19)$$

In equation (15), R is the measurement noise covariance matrix having a size as the number of radius as follows:

$$R=\begin{bmatrix} c_k & 0 \\ 0 & c_k \end{bmatrix}, \qquad (4.20)$$

where c is a variance value of each measurement noise defined by user. I is the identity matrix in equation (17) [16].

B. IEKF estimation for 2D target tracking

Generally, EKF is being used to localize and track a moving target. Sometimes EKF has the low tracking performance, when the moving path of the target is drastically changed. It happens because EKF uses a fixed initial filter parameters. In order to improve this weakness of EKF, IEKF has additionally chosen a recursive strategy which is the iterative calculation of certain filter parameters. In added strategy, IEKF defines the threshold which is to limit a difference between current estimated location and previous estimated location. If the difference value is bigger than the predefined threshold, the added iterative function restarts to gain the current location by the randomly changed measurement noise covariance R [17,18]. This added strategy makes the target tracking system operates in the various situation of the target movement.

IEKF has the state model and measurement model same as EKF and also has prediction and correction steps like EKF. The prediction step of IEKF is same as that of EKF. However, the correction step of IEKF adds iterative process in that of EKF. The correction step of IEKF has next four processes. First, Jacobian matrix H_k is computed for updating the kalman gain. Second, the kalman gain K_k is computed by Jacobian matrix H_k and measurement noise covariance R. The value of R is randomly chosen whenever repeated before updating kalman gain in added strategy. Third is to estimate next location as follows:

$$\hat{x}_n = \hat{x}_k^- + K_n(z_n - h(\hat{x}_n^-) - H(\hat{x}_k^- - \hat{x}_n)), \tag{4.21}$$

where n is the iteration count in added function and is increased by one from zero. If the difference between estimated next location $\hat{x}_n$ and current location $\hat{x}_k^-$ is bigger than the predefined threshold, n increases one and equation (21) is refreshed. These three processes are the added iterative strategy. Last, error covariance P_k is updated like equation (17). The measurement noise covariance R has an effect on the estimation results due to the change of R [19].

When i compare EKF and IEKF, the difference is whether the R is continuously changed or not. This difference shows that EKF cannot be applied in the various experiment. However, R of IEKF is continuously changed to gain results having the higher accuracy. Consequently, IEKF can be applied in the real-time system.

C. Experiment Scenario

To perform the experiments of moving target tracking, i use IR-UWB radars with NVA 6100 chipset developed by Novelda and Vivaldi directional antennas with opening angle of 42 degree [20]. This radar can observe a target located in 8 m far away position. EKF and IEKF based tracking system consisting of two IR-UWB radars was used for experiments in indoor environment of 6 $m \times 6$ m space. To get the coordinates of target, the moving target was designed to move on the observation area covered by two IR-UWB radars as shown Figure 3. Firstly, i have carried out the tests by changing the position of radar to find the better locations for radars. In the first test (case 1 shown in Table 2), the two radars are located at (2 m, 0 m) and (0 m, 2 m). In the second test (case 2), the two radars are located at (4 m, 0 m) and (0 m, 2 m). In the last test (case 3), the two radars are relocated at (6 m, 2 m) and (0 m, 2 m). Under these conditions, the target moves from (5 m, 3 m) to (3 m, 5m) as shown in Figure 7.

Secondly, i carried out another experiment with the two trajectories as shown in Figure 8. In this experiment, the two radars are located in the selected location such as (2 m, 0 m) and (0m , 2 m) and evaluated the proposed IEKF based target tracking method.

Table 2. The average distance to the starting and ending positions of target movement from radars

case of radar position	start position	end position
Case 1	4.67 m	4.67 m
Case 2	4.13 m	4.67 m
Case 3	3.26 m	4.24 m

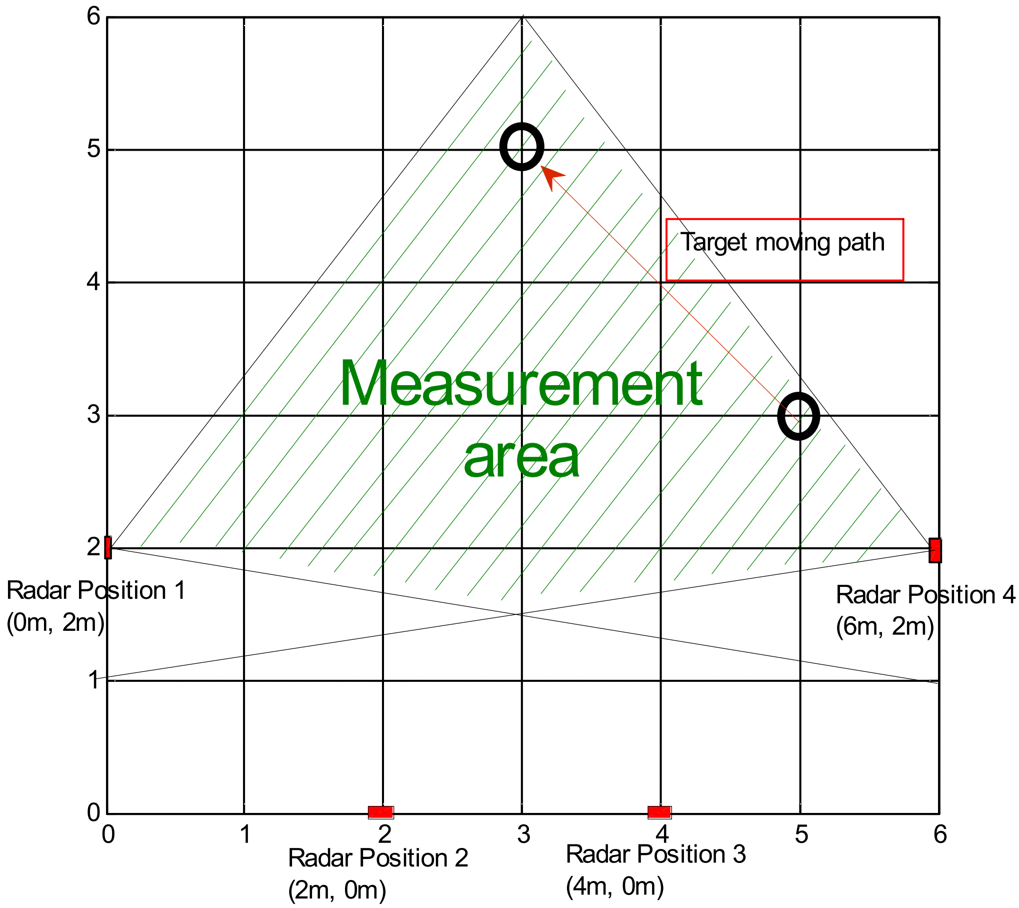

Figure 7. The measurement area generated by antenna angle of the selected radars. In this example, the radar position 1 and 4 are chosen.

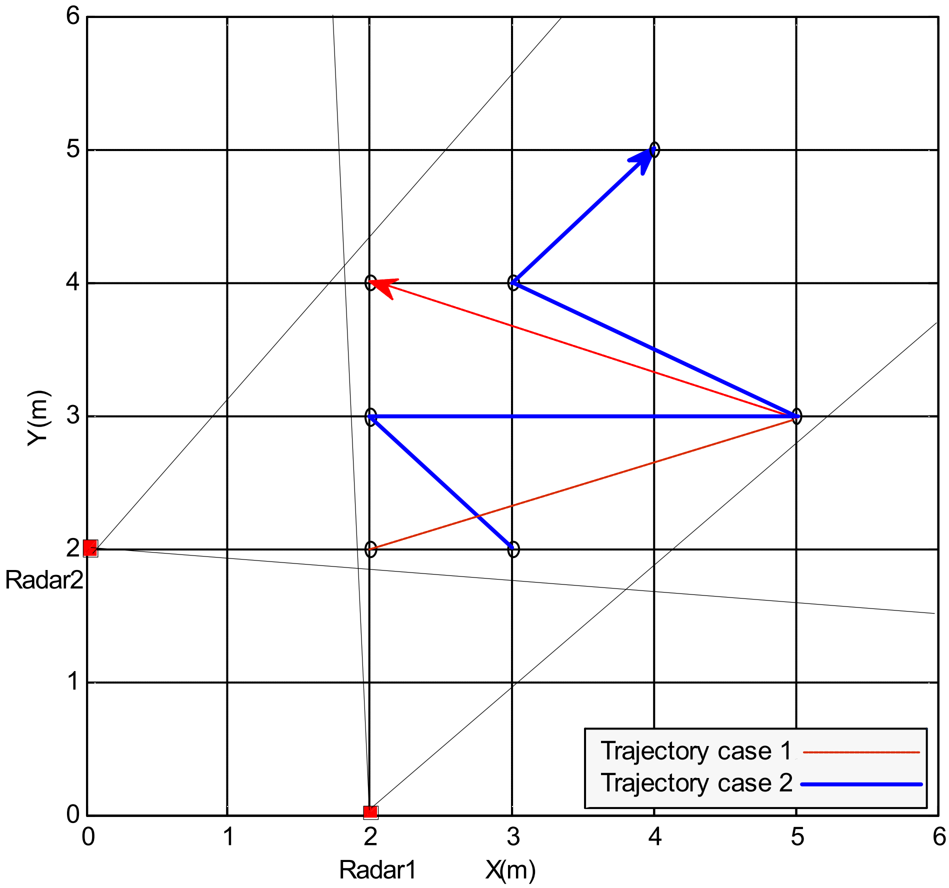

Figure 8. The trajectories of the moving target when two radars are located at the position $(0m,\ 2m)$ and $(2m,\ 0m)$.

D. Experiment Results

1. Selection of radar location

In these experiments, i consider three types of radar location to track the moving target as shown in Figure 7. The raw signals observed at the time of moving period of target are consecutively processed by KF clutter reduction and modified CLEAN detection technique. Then, IEKF and EKF filtering methods are used for the tracking estimation of moving target. In the first experiment, i carried out the three cases for the location determination of radar antennas as shown in Figure 9, 10 and 11.

These figures show the orthogonal set up for two radars (Rx and Tx) that is natural to monitor a confined area [21]. As an example in Figure 5, two radars are located at (2 m, 0 m) and (0 m, 2 m) when a target moves from (5 m, 3 m) to (3 m, 5 m). This test of case 1 shows the worst tracking result as compared to two other cases, because the distance from radar antennas to the target is the longest among three radar position cases. Table 2 gives an average distance to the starting and ending positions of target movement. As i expected, the distance to the target determines the accuracy of tracking even when the tracking filters are applied. In this work, the radar locations (2 m, 0 m) and (0 m, 2 m) of case 1 are chosen, because the proposed IEKF based target tracking method could be evaluated and compared with the conventional ones in the poor environment. If the comparison results are shown enhanced in the poor case, the performance will be expected advanced in all cases.

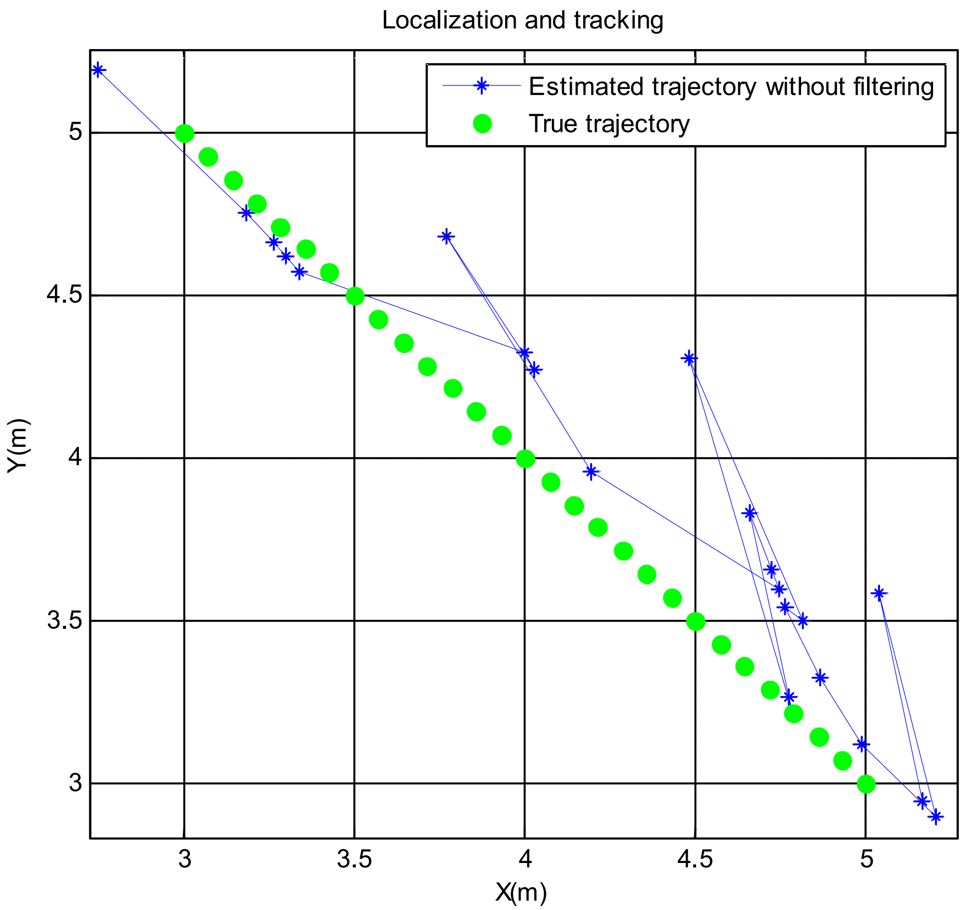

Figure 9. [Case 1]Estimated tracking results of the moving target in 2D coordinates when the radars are located in ($2m$, $0m$) and ($0m$, $2m$).

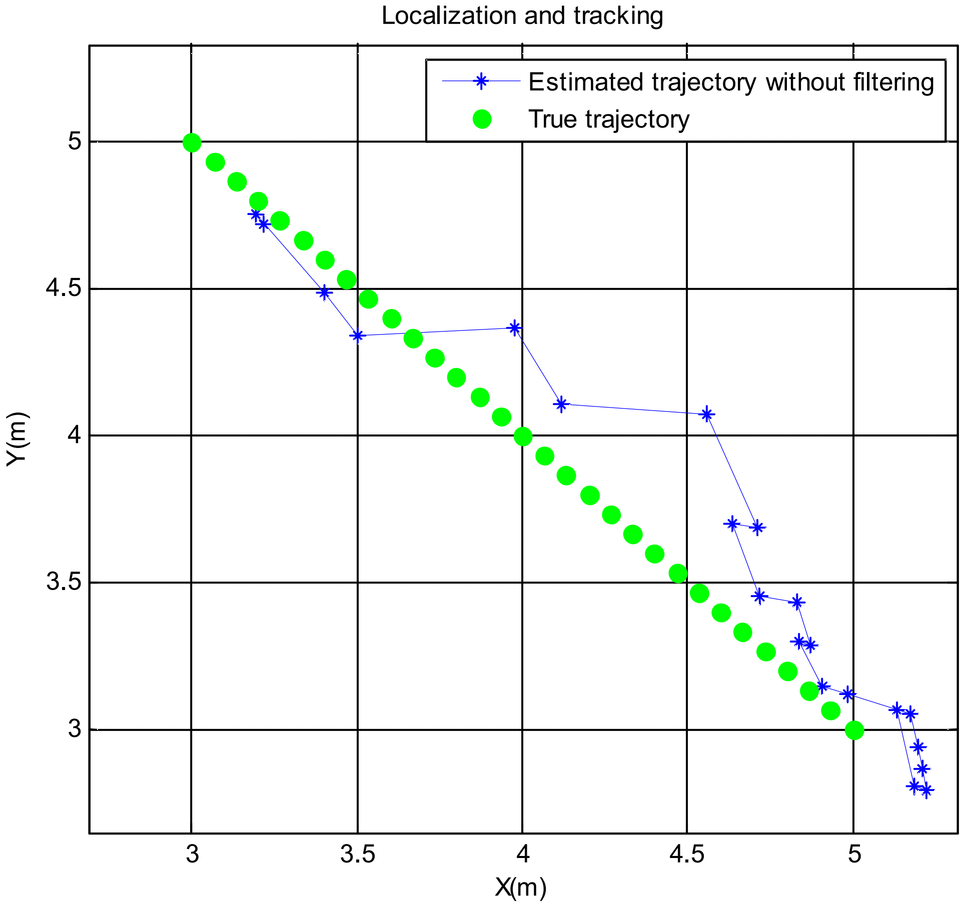

Figure 10. [Case 2]Estimated tracking results of the moving target in 2D coordinates when the radars are located in $(4m,\ 0m)$ and $(0m,\ 2m)$.

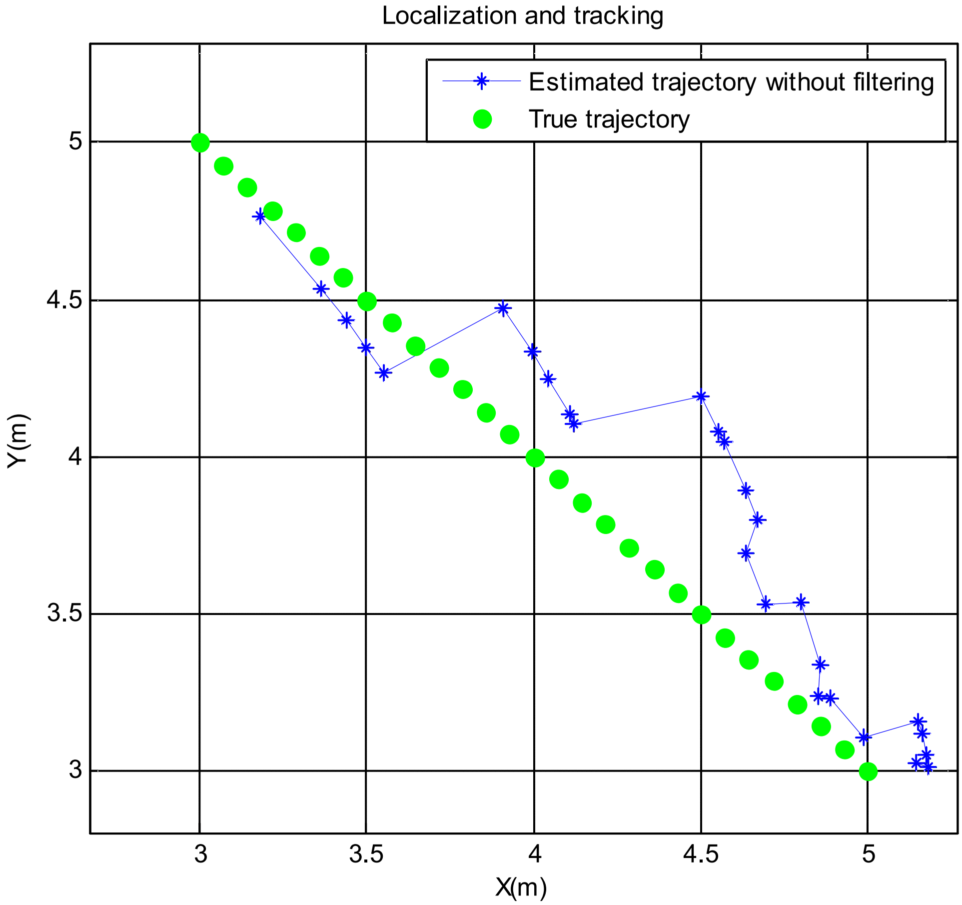

Figure 11. [Case 3]Estimated tracking results of the moving target in 2D coordinates when the radars are located in ($6m$, $2m$) and ($0m$, $2m$).

2. Selection of radar location

For the performance evaluation of IEKF and EKF based tracking methods, two trajectories are tested in Figure 8. In these experiments, the radars location are fixed to (2 m, 0 m) and (0 m, 2 m) in coordinates. To track the moving target, KF clutter reduction and modified CLEAN detection techniques are used on the raw data before starting the tracking process. Then, IEKF and EKF filtering methods are adopted. The estimated tracking results are depicted in Figure 14, 15, 16, 17, 18, 19, 20, and 21. As figures and tables have shown, the applied IEKF filtering method is shown as tracking closer to the real target position than the EKF filtering method. Also, the value of covariance R has an effect on the estimation tracking result. The large covariance R is to generally increase the range of estimation error, whereas the small covariance R is to decrease the range of estimation error. But the smallest covariance R is not always to decrease the range of estimation error as shown in Table 2 and 3. Thus, EKF filtering method using the constant covariance R may not be fit in the various indoor environment [22]. However, IEKF filtering method can be used for real-time system because of changeable covariance R. When the various moving path is tracked, IEKF filtering method could find the appropriate covariance R. Table 3 and 4 show the root mean square error (RMSE) for the estimated trajectories using two filtering methods, trajectories without filtering, and true trajectories. When the coefficient c in EKF filtering method is changed, RMSE of estimated trajectory is changed as shown in Table 3 and 4. That is, whenever the trajectory is changed, the coefficient c must be ideally defined by the experimenter in the case of EKF. However, in the case of IEKF filtering method, the coefficient c is randomly chosen to find the ideal value without the help of experimenter. This result verifies that the EKF and IEKF can improve the precision of estimated target path. Also, the IEKF filtering method shows the better RMSE of 0.2270 and 0.2145, whereas the EKF has the RMSE of 0.2321 and 0.2378.

Table 3. Performance comparison of different localization and tracking methods in trajectory (1)

Method	RMSE	Covariance R
Without filtering	0.2478	None
EKF (1)	0.2373	c = 0.01
EKF (2)	0.2321	c = 0.05
EKF (3)	0.2373	c = 0.1
IEKF (4)	0.3373	c = 0.5
IEKF (1)	0.2270	c is randomly chosen
IEKF (2)	0.2285	c is randomly chosen
IEKF (3)	0.2289	c is randomly chosen
IEKF (4)	0.2289	c is randomly chosen

Table 4. Performance comparison of different localization and tracking methods in trajectory (2)

Method	RMSE	Covariance R
Without filtering	0.2526	None
EKF (1)	0.2378	c = 0.01
EKF (2)	0.2393	c = 0.05
EKF (3)	0.2336	c = 0.1
IEKF (4)	0.3135	c = 0.5
IEKF (1)	0.2167	c is randomly chosen
IEKF (2)	0.2198	c is randomly chosen
IEKF (3)	0.2198	c is randomly chosen
IEKF (4)	0.2145	c is randomly chosen

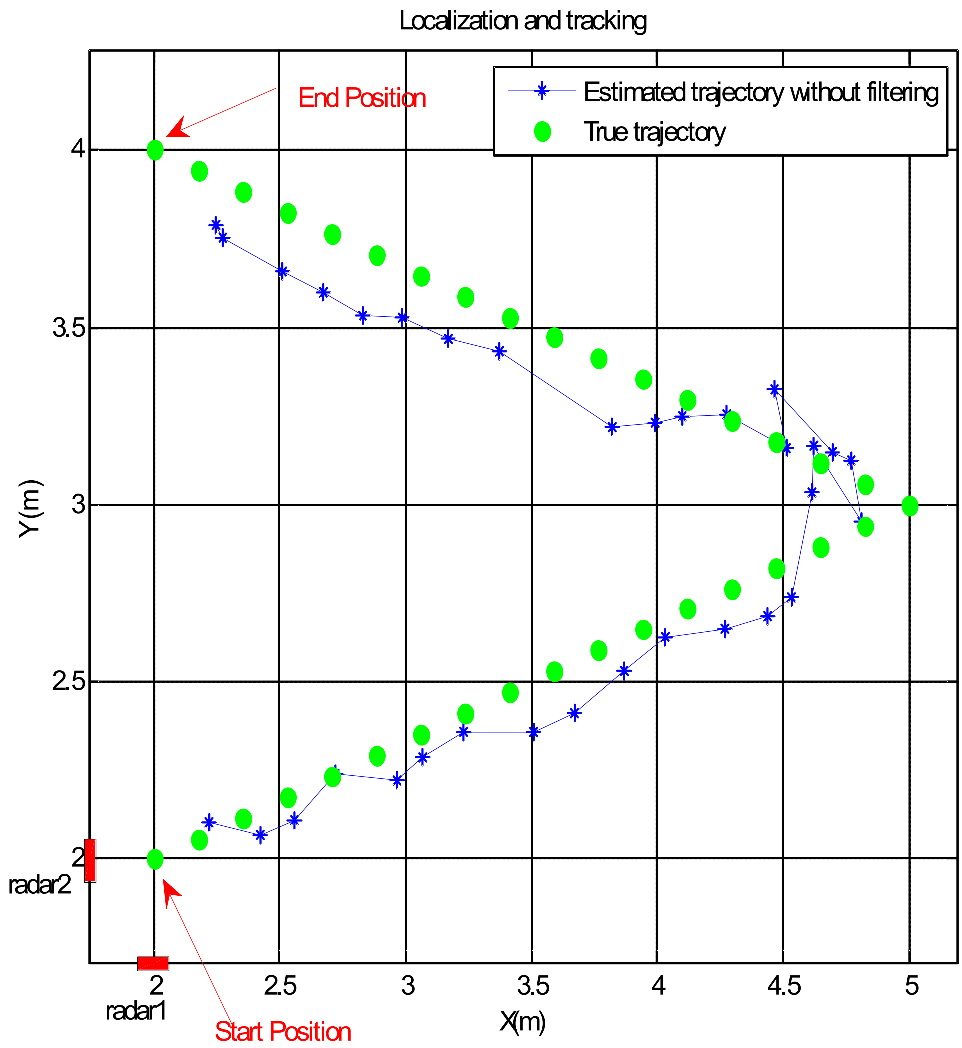

Figure 12. Estimated tracking results (trajectory case 1) of the moving target in 2D coordinates in the case of no filtering.

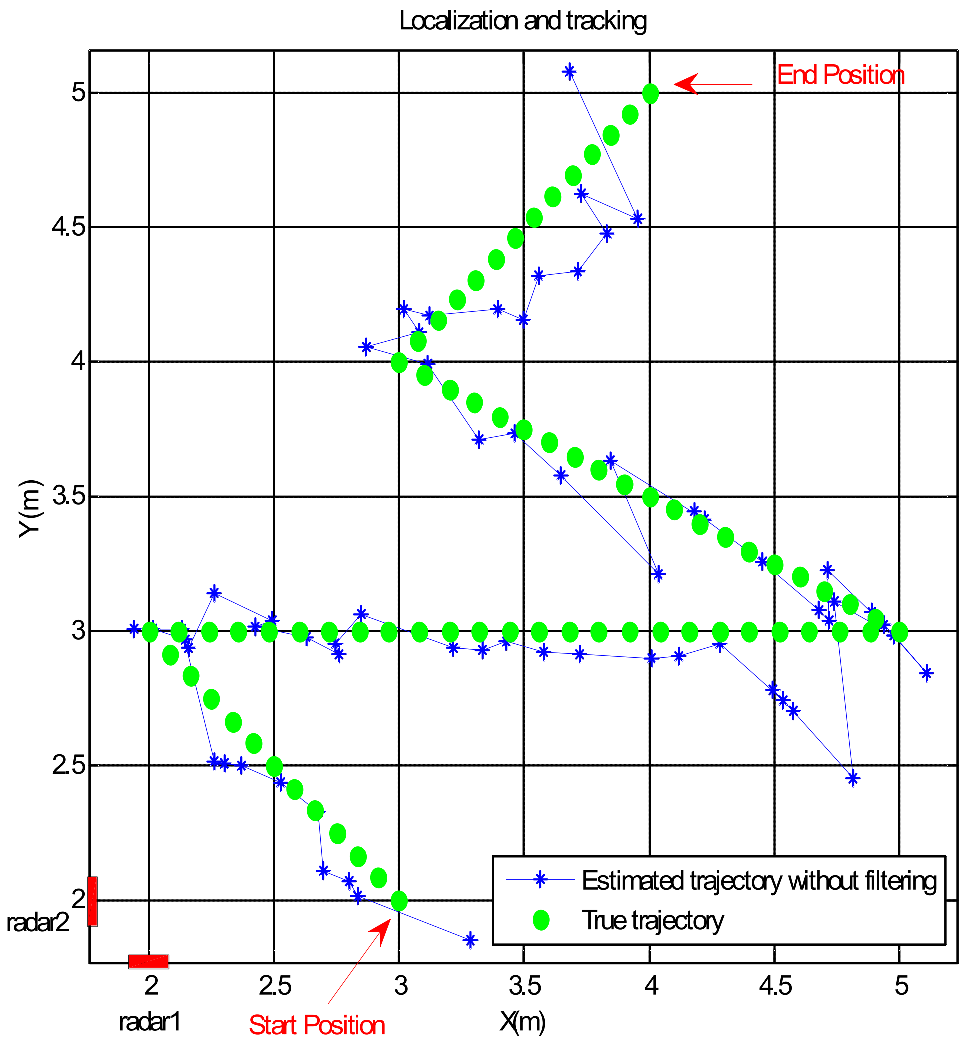

Figure 13. Estimated tracking results (trajectory case 2) of the moving target in 2D coordinates in the case of no filtering.

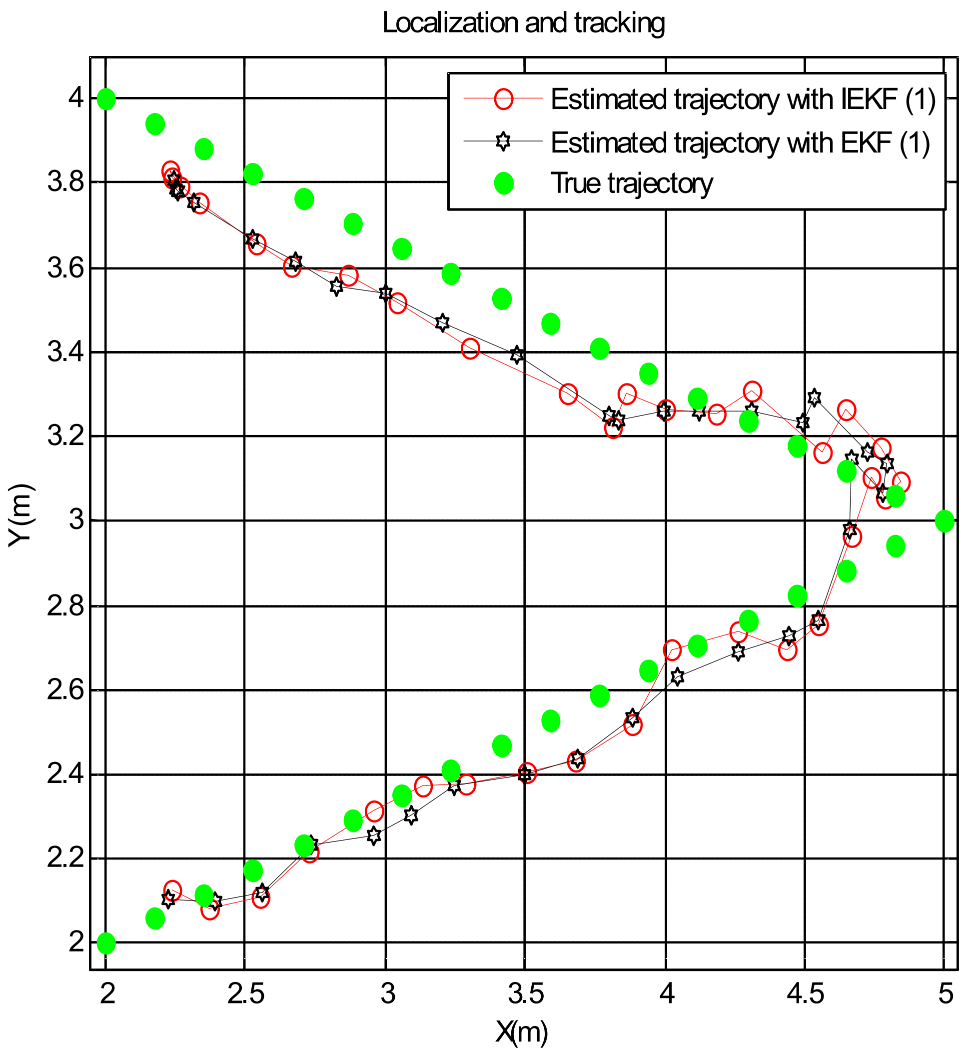

Figure 14. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.01).

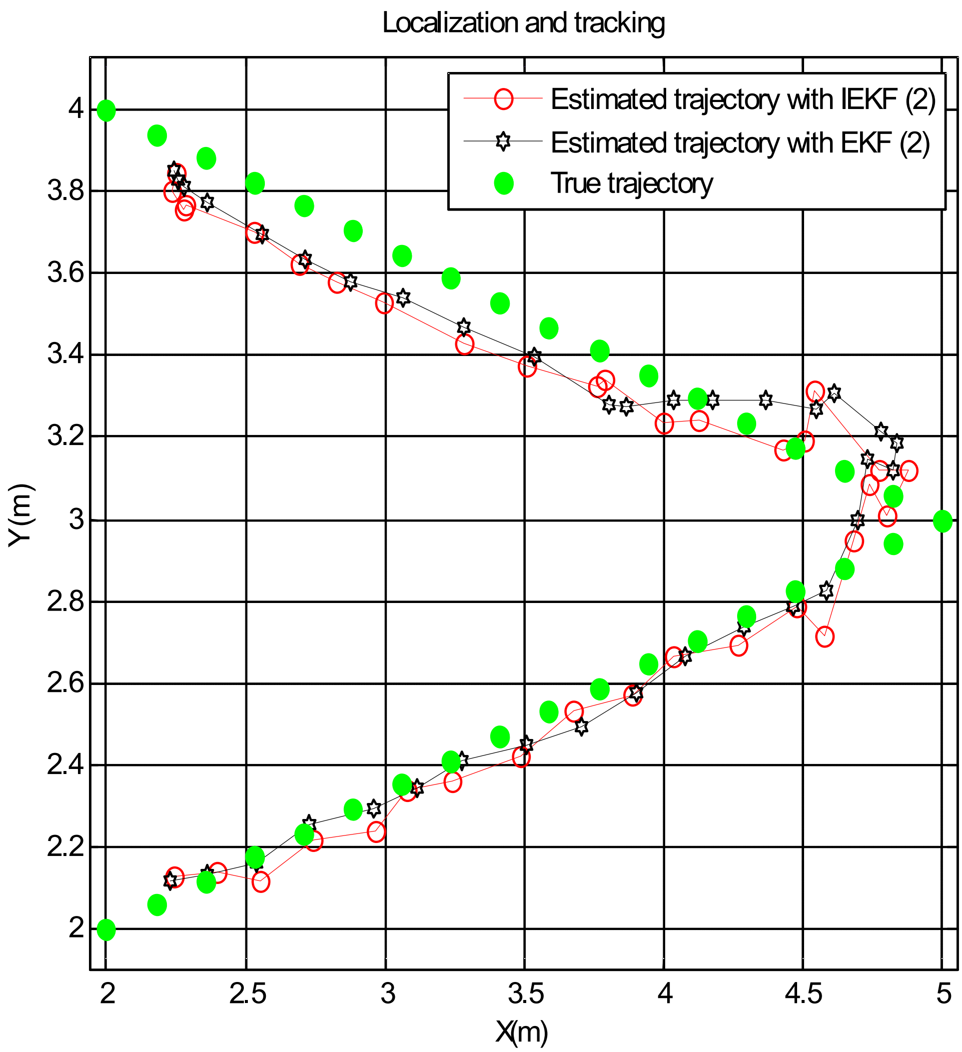

Figure 15. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.05).

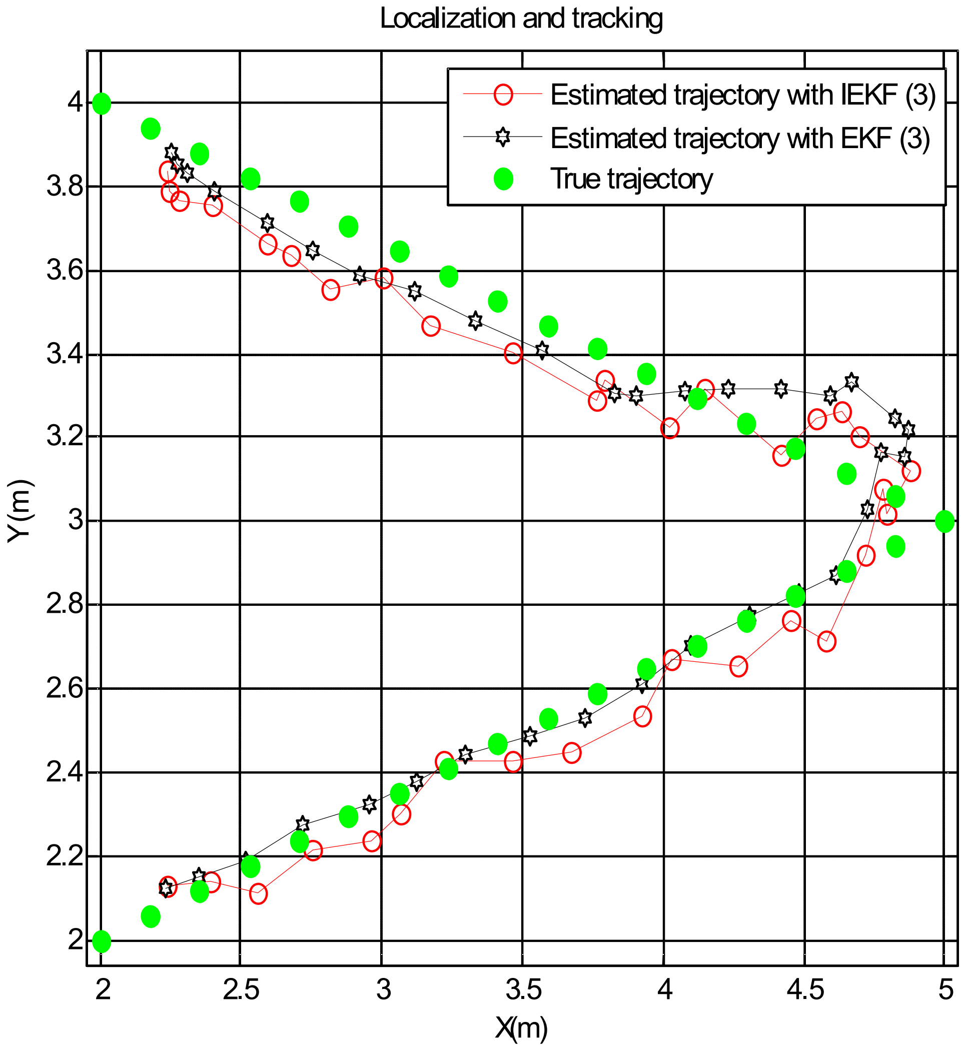

Figure 16. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.1).

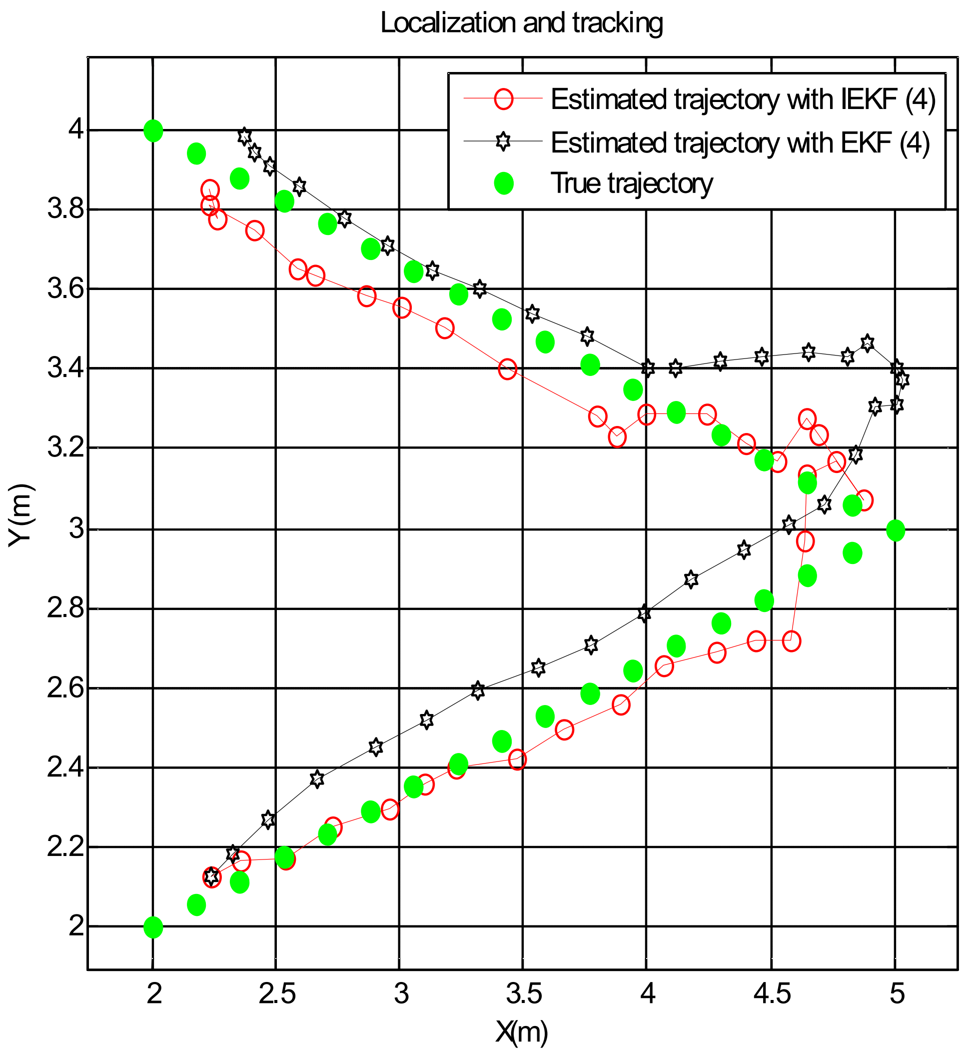

Figure 17. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.5).

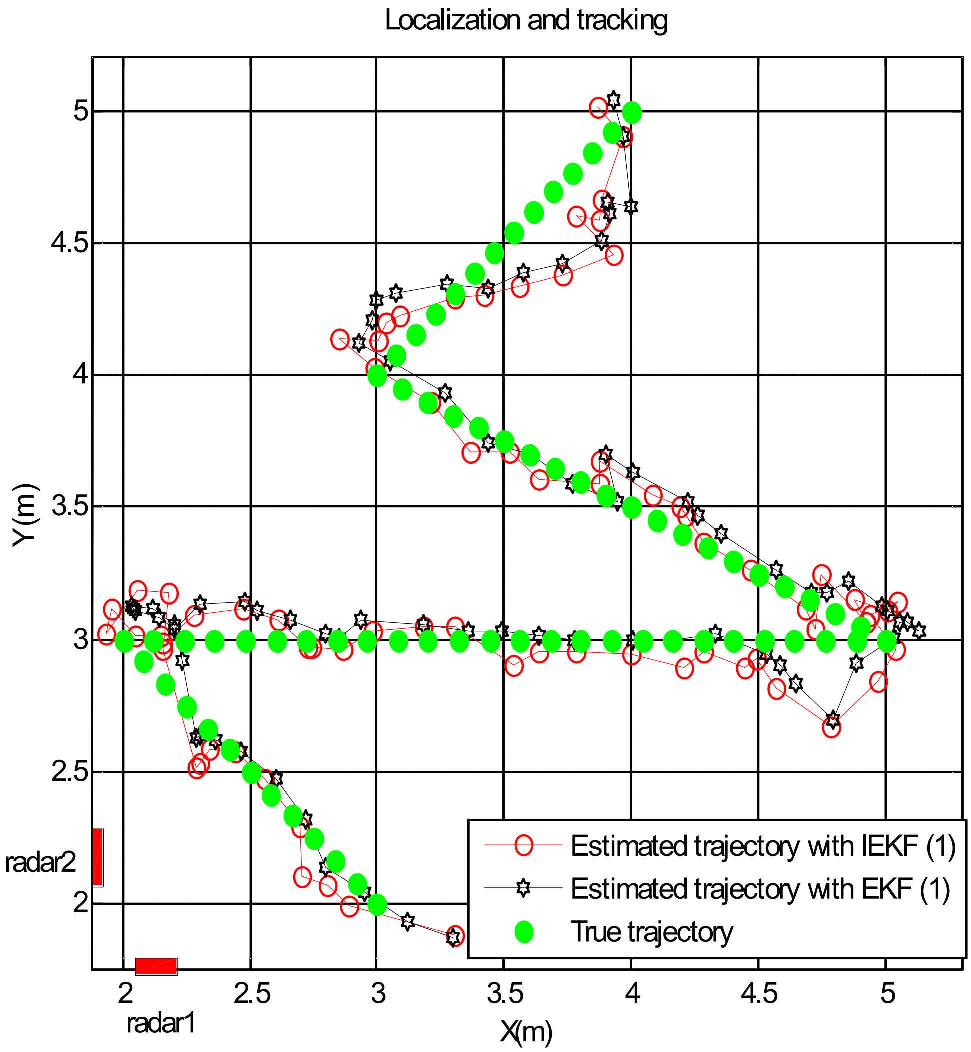

Figure 18. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.01).

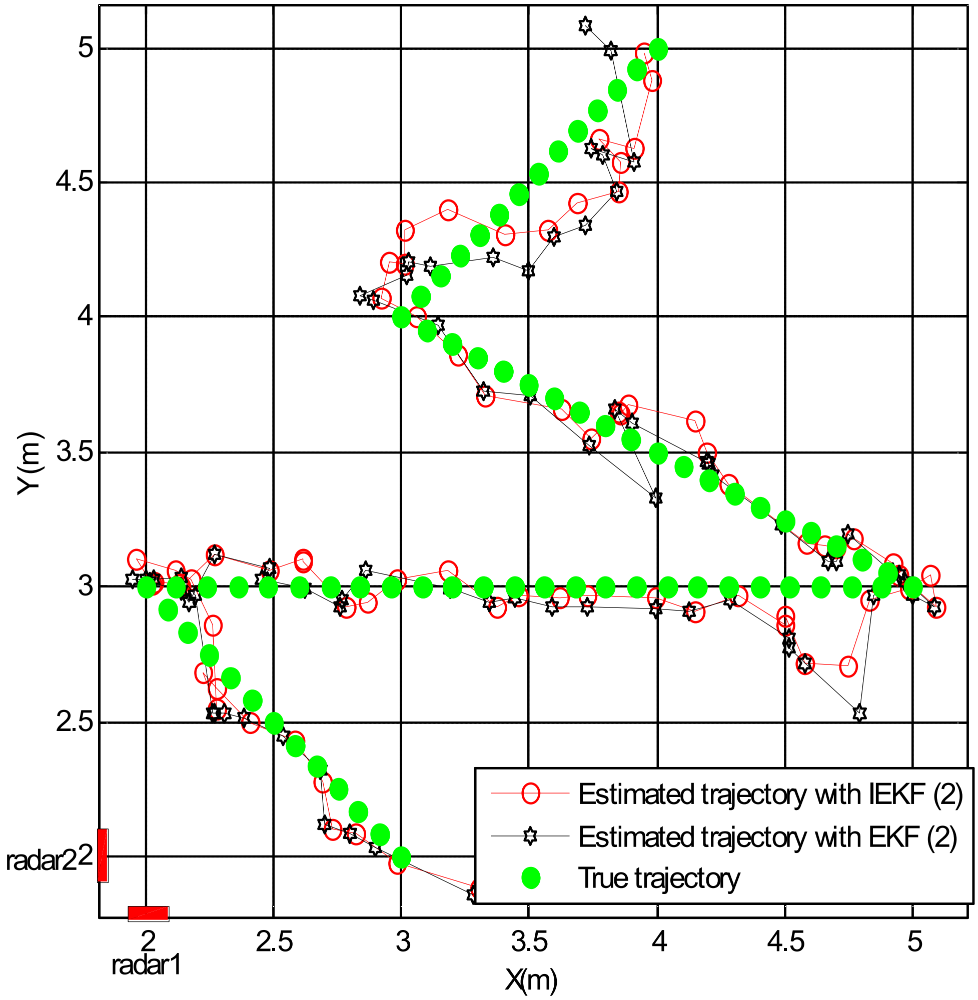

Figure 19. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.05).

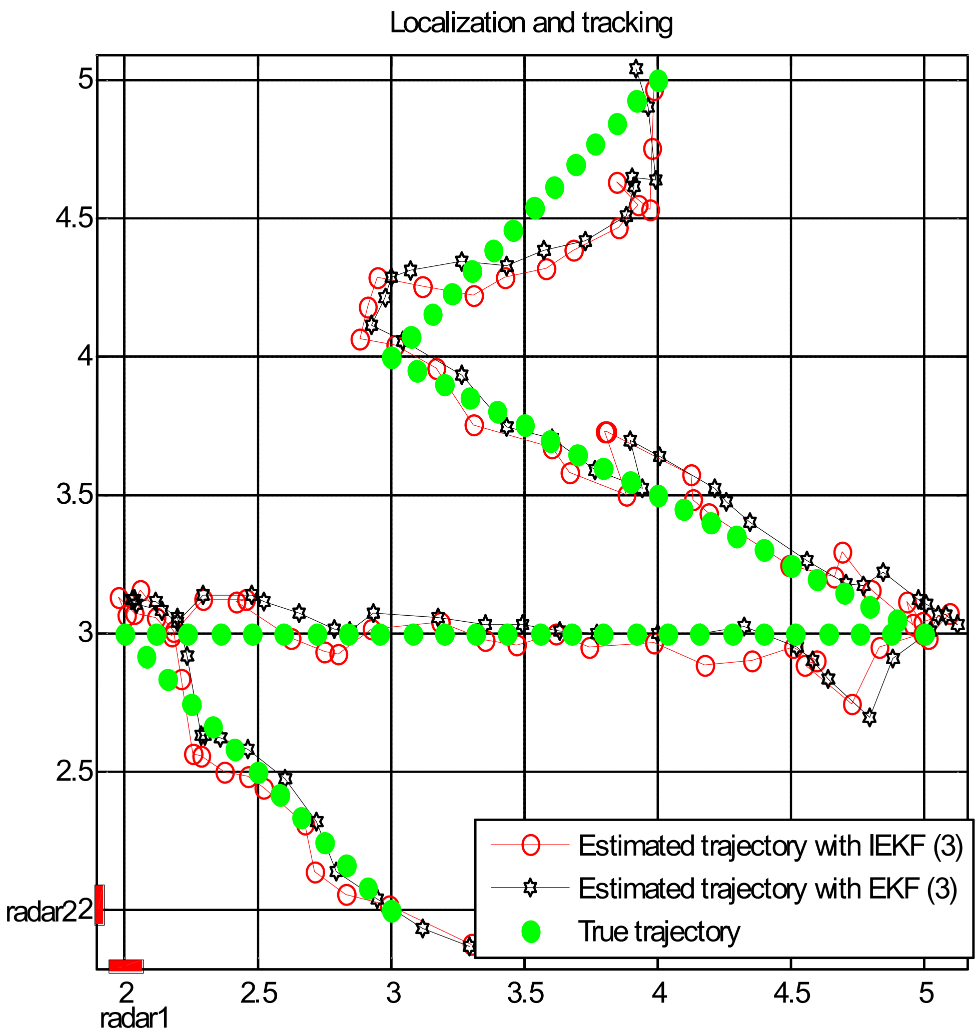

Figure 20. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.1).

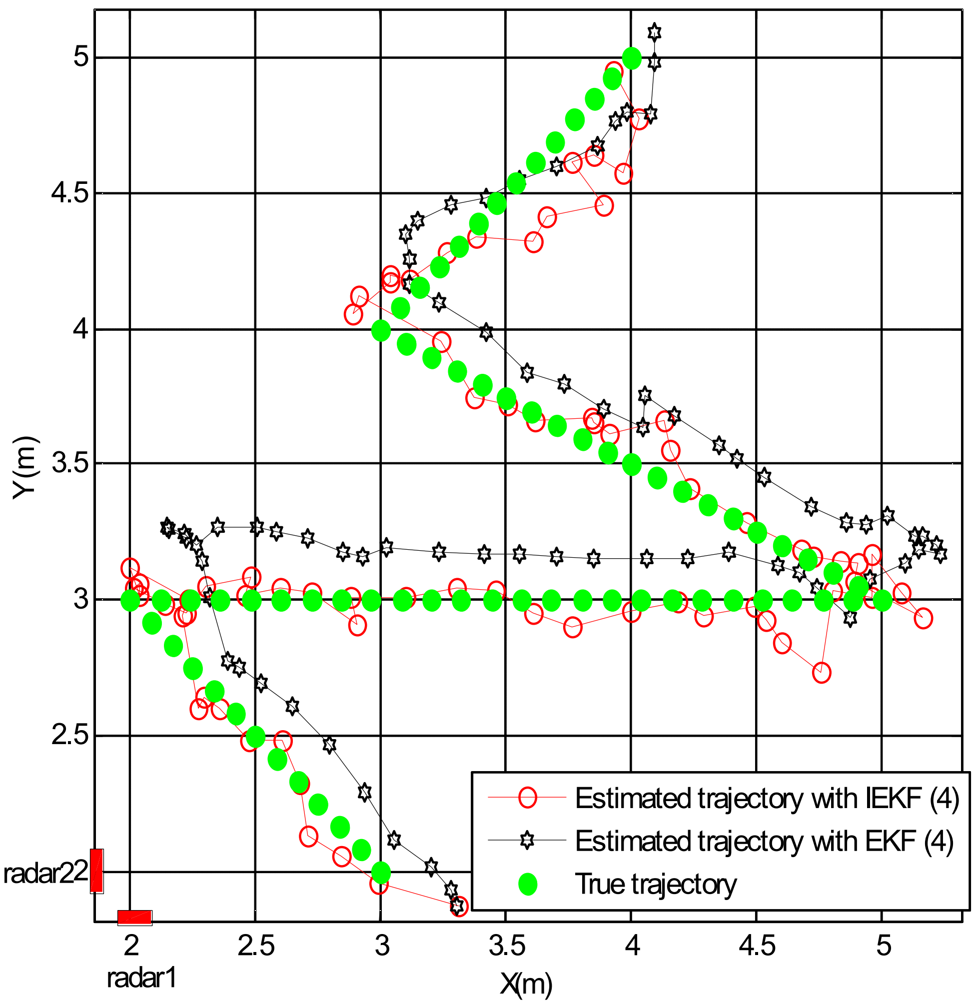

Figure 21. Estimated tracking results of the moving target in 2D coordinates in the case of EKF and IEKF filtering method (EKF using c of 0.5).

V. Conclusion

Through the signal processing procedures, the target distance observed by each radar is tracked and the position and trajectory of target are determined and tracked in 2D coordinates. The tracking of moving target is the most essential procedure in IR-UWB signal processing, because the velocity and direction of moving target cannot be predicted. In this thesis, i proposed the IEKF based target tracking method using two IR-UWB radars that can be used for surveillance, rescue, and emergency rescue jobs. In addition, it provides tracking results in 2-dimensional coordinates. This thesis is limited in detection and tracking of single target and the position of radar is considered in the worst environment. The proposed IEKF filtering method shows the better performance than the conventional EKF based target tracking method. Also, i could verify that the measurement area could be limited by beam width and the number of IR-UWB radars used.

This thesis limits the number of target in detection and tracking. However, in reality, it is needed to detect and track the multiple targets. When the multiple target is detected and tracked, the difficulty is the target association. Because the trajectories of targets can intersect and each target affects with each other. Therefore, In the future work, i would use the more radars not to limit the measurement area and track the multiple targets in 2D coordinates.

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