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Master’s Degree Thesis

Improved Target Detection and Tracking Techniques for Moving Objects with IR-UWB Radar

Graduate School of Chosun University

Department of Information and Communication Engineering

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IR-UWB Radar를 이용한 향상된 이동 물체 탐지 및 추적 기법

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Advisor: Prof. Jae-Young Pyun

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Graduate School of Chosun University

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응구엔반한의 석사학위논문을 인준함

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Acronyms

ADC	Analog to Digital Converter
BS	Base Station
CFAR	Constant False Alarm Rate
EA	Exponential Averaging
EIRP	Equivalent Isotropically Radiated Power
EKF	Extended Kalman Filter
GPR	Ground Penetrating Radar
GPS	Global Positioning System
IR-UWB	Impulse Radio Ultra Wideband
KF	Kalman Filter
MS	Mobile Station
RMSE	Root Mean Square Error
SVD	Singular Value Decomposition
TOA	Time of Arrival
UWB	Ultra Wideband
WSN	Wireless Sensor Network

ABSTRACT

Improved Target Detection and Tracking Techniques for Moving Objects with IR-UWB Radar

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Object detection, localization, and tracking are important for the purposes of rescue, surveillance, and security applications. Generally, these techniques are based on Global Positioning System (GPS), and/or Radar systems. However, in indoor environment, GPS and Radar system cannot apply because they have high error. In recent years, Ultra Wide-band (UWB) has become a possible solution for object detection, localization, and tracking in indoor environment, due to its high range resolution, compact size, and low cost.

This thesis work presents the improved target detection and tracking techniques of moving objects with Impulse Radio UWB (IR-UWB) Radar in a short range indoor area. This purpose is archived through several signal processing steps such as: clutter reduction, target detection, and target tracking. In the clutter reduction step, a method using Kalman Filter (KF) is proposed. In the target detection, the modification of conventional CLEAN algorithm is applied. After that, the output is fed up the target localization and tracking step in which the target distance and location will be determined and tracked in 1 dimension and 2 dimensions,

respectively. In each step, the proposed and/or modified methods are evaluated in comparison with the conventional methods to show their performances. To evaluate the performances of various methods, the experiments are made with real IR-UWB radar in different scenarios. Then, the raw data are processed with these signal processing steps. The results verify that the proposed methods can improve the probability of target detection and tracking efficiently.

초 록

IR-UWB Radar를 이용한 향상된 이동 물체 탐지 및 추적 기법

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물체의 탐지, 위치측정과 위치추적은 응급을 요하는 상황과 보안 등의 응용분야에서 중요한 부분을 차지하고 있다. 일반적으로, 이들은 위성 항법 시스템 (GPS) 혹은 레이더 시스템에 기반을 두고 있다. 그러나 실내환경에서는 높은 에러율 때문에 GPS와 레이더 시스템을 적용할 수 없는 실정이다. 최근 몇년간 Ultra Wide-band (UWB)는 높은 거리 해상도, 소형크기 및 저비용으로 실내환경에서 물체추적, 위치측정과 위치추적을 수행할 수 있는 하나의 해결책이 되었다.

본 논문에서는 작은 실내공간에서 IR-UWB Radar (Impulse Radio UWB)에 기반하여 개선된 목표물 감지와 움직이는 물체의 추적기법을 제안하고자한다. 이 제안은 클러터제거, 목표물 감지 그리고 목표물 추적과 같은 다수의 신호처리단계로 구성되어있다. 클러터제거 단계에서는 칼만필터가 제안되었다. 목표물 감지단계에서는 수정된 CLEAN 알고리즘이 적용되었다. 이후에, 출력신호는 각각의 1차원과 2차원에서 목표물의 거리와 위치가 결정되고 추적되어질 목표물의 위치측정과 위치추적을 수행하는 단계에서 입력 신호로 들어간다. 각각의 단계에서,

제안된 방법은 기존의 방식과의 성능비교를 통하여 평가되었다. 그리고, 이 실험은 실제 IR-UWB radar를 이용하여 각기 다른 시나리오로 구성되었으며, 원시데이터를 위와 같은 신호처리단계를 적용하여 진행하였다. 그 실험결과는 제안된 기법들이 효율적으로 목표물 탐지와 추적할 수 있음을 입증할 수 있다.

I. Introduction

A. General overview

There are many applications which require the object's location such as: rescue, emergency, and security purposes. The approaches accessing to the object location are typically divided into two groups: the active and passive localization. In the first approach, the object is often with a Mobile Station (MS) in a communication network. Through the cooperation between MS and Base Stations (BSs), the object location is determined [1]. GPS, cellular networks, and wireless sensor networks (WSNs) are representatives of this group. In the second approach, the object does not communicate with others in the communication network. But, the object location can be recognized based on the reflected signal from the object [2]. Radar (RAdio Detection And Ranging), Sonar (SOund Navigation And Ranging), and Ladar (LAser Detection And Ranging) are the most common in this group. These methods have both pros. and cons. However, for indoor localization and tracking, GPS and traditional Radar bring too high errors. Cellular network and WSN are limited in complicated controls and protocols. Sonar and Ladar are degraded their performance by interference. Therefore, Ultra Wideband (UWB) Radar has become an emerging technology which is appropriate for indoor localization and tracking. The reason is that it has many advantages: high spatial resolution, mitigating interference, through the wall visibility, simple transceiver, and low cost [3].

For the purpose of detection, localization, and tracking of moving target in indoor environment, an UWB radar usually has one or more transmitters and one or more receivers. The transmitter(s) send very narrow pulses and the receiver(s) receive the reflected pulses from the targets. After that, the received signal should be passed through several signal processing steps to extract the target signal. The most challenge is that the target signal is perturbed by clutters and noises. Especially, if the target is far away from the radar, the signal attenuation will be more serious. Thus, it will be more difficult to detect target signal. Therefore, removing clutters and noises is the crucial task to improve target detection ability.

This thesis proposes a signal processing procedure in which the clutters and noises are reduced as well as the signal attenuation of far target is compensated. Hence, the overall target detection probability is improved. Finally, the target signal is processed to localize and track its distance and location in 2-dimension coordinates.

B. Objectives

The main objectives of this thesis are research on applications of UWB radar in detection, localization and tracking of moving objects, and to suggest new techniques to improve the target detection and tracking. The specific objectives are:

(1) Survey on UWB technology, UWB radar, and their applications.

(2) To obtain a robust clutter and noise removal technique.

(3) To improve the target detection probability, specifically for the far target.

(4) To measure the distance from target to radar, localize target position, and track target trajectory.

C. Thesis contribution

This thesis presents an application of Impulse Radio UWB (IR-UWB) radar system for detection, localization and tracking of moving target. It is proposed some new algorithms in order to improve the system performance in term of target detection probability and tracking. This IR-UWB radar system can be used for surveillance in small area, or inside a building. It is also possible to use this system for detection of moving target in dangerous and limited visual environment. Nevertheless, the signal processing procedure may be extended for through the wall imaging and collision avoidance system in transportation. The main contributions of this thesis are as follows:

New algorithms: A new algorithm based on Kalman Filter is applied for clutter reduction. It shows the better estimation of clutter in comparison with other methods. In addition, a modified CLEAN algorithm is proposed for target detection in which concerns with the compensation of signal attenuation. The combination of these algorithms is suggested in this thesis.

Signal processing procedure: The recommended signal processing procedure is given in this thesis. It consists of clutter reduction step, detection step, localization and tracking step.

Matlab code: A set of simulation code written in Matlab R2012a demonstrates the signal processing procedure and each step performance.

D. Thesis organization

The remainder of this thesis is organized in modular chapters and its outline is as follows:

Chapter II presents the background information related to the thesis. Section A of this chapter explains UWB including its historical millstones, definition, characteristics of UWB, and its applications. Section B concerns with the IR-UWB radar used in this thesis. The IR-UWB radar block diagram, features, parameters, and operation are demonstrated in this section. Finally the signal processing procedure is provided in section C.

Chapter III is the main of this thesis. In this chapter the signal processing procedure is explained in details. Section A deals with the clutter reduction problem. Section B focuses on detection of target and section C shows the localization and tracking of target. In each section, the proposed algorithms and conventional methods are discussed and evaluated carefully.

Chapter IV presents the concluding remarks with scope for further research work.

II. Background

A. Ultra Wideband

1. Brief historical development of UWB

Ultra-wideband communications is not a new technology; in fact, it was first employed by Guglielmo Marconi in 1901 to transmit Morse code sequences across the Atlantic Ocean using spark gap radio transmitters. However, the benefit of a large bandwidth and the capability of implementing multiuser systems provided by electromagnetic pulses were never considered at that time [4].

Approximately fifty years after Marconi, modern pulse-based transmission gained momentum in military applications in the form of impulse radars. Some of the pioneers of modern UWB communications in the United States from the late 1960s are Henning Harmuth of Catholic University of America and Gerald Ross and K. W. Robins of Sperry Rand Corporation. From the 1960s to the 1990s, this technology was restricted to military and Department of Defense (DoD) applications under classified programs such as highly secure communications. However, the recent advancement in microprocessing and fast switching in semiconductor technology has made UWB ready for commercial applications. Therefore, it is more appropriate to consider UWB as a new name for a long-existing technology.

As interest in the commercialization of UWB has increased over the past several years, developers of UWB systems began pressuring the Federal Communications Commission (FCC) to approve UWB for commercial use. In February 2002, the FCC approved the First Report and Order (R&O) for commercial use of UWB technology under strict power emission limits for various devices.

Afterward, many countries, organizations, and companies have approved and standardized UWB under certain restrictions. Nowadays, UWB has been authorized not only the US but also in Europe, Japan, Korea, China, and Singapore. Furthermore, it has become a recommended technology for Wireless Personal Area Network (WPAN) which appeared in IEEE 802.15.3a and IEEE 802.15.4a standards. Figure 1 summarizes the development timeline of UWB.

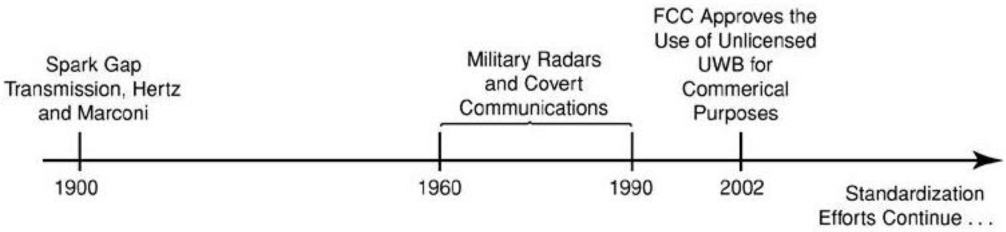


Figure 1: A brief history of UWB developments [4]

2. Definition of UWB

As defined by the First Report and Order of the Federal Communications Commission (FCC) in the USA, a signal is called UWB if it has an absolute bandwidth of greater than 500 MHz or a fractional bandwidth larger than 20 percent at all times of transmission [5]. The absolute bandwidth B is calculated as the difference between the upper frequency f_H of the -10 dB emission point and the lower frequency f_L of the -10 dB emission point. On the other hand, fractional bandwidth is a factor is defined by the ratio of bandwidth at -10 dB points to center frequency. Equation (2.1) shows this relationship.

$$B_f = \frac{B}{f_C} \times 100\% = \frac{(f_H - f_L)}{(f_H + f_L)/2} \times 100\% = \frac{2(f_H - f_L)}{f_H + f_L} \times 100\% \qquad (2.1)$$

Due to their ultra-wide bandwidth, UWB systems are characterized by very short duration waveform, usually in the order of nanosecond. An UWB signal can be any one of a variety of wideband signals, such as Gaussian, chirp, wavelet, or Hermite-based short-duration pulses [4].

Commonly, a UWB system transmits ultra-short pulses with a low duty cycle. In other words, the ratio between the pulse transmission instant and the average time between two consecutive transmissions is small. Such type of UWB system that transmits UWB pulses with low duty cycle is called Impulse Radio (IR) UWB system.

Figure 2 presents a Gaussian monocycle as an example of a UWB pulse in the time and frequency domains.

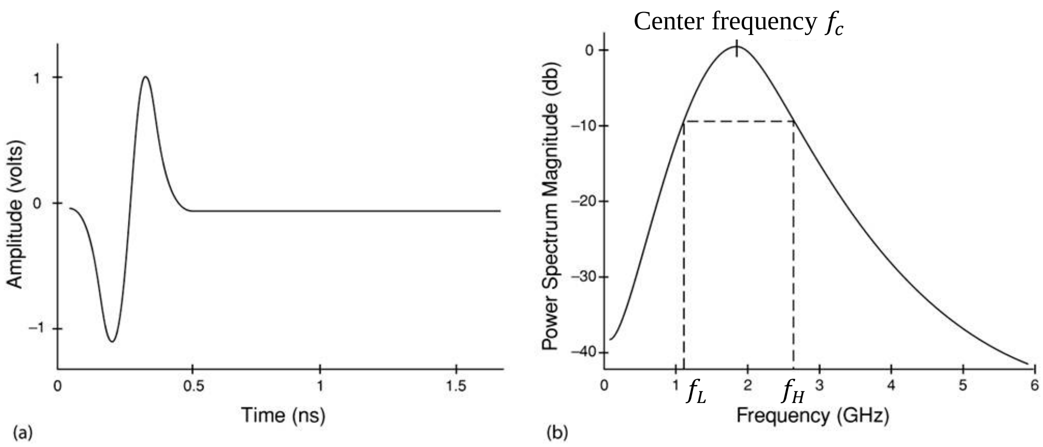


Figure 2: An example of UWB signal [4]

As shown in Figure 2, a 500-picosecond pulse generates a large bandwidth in the frequency domain with a center frequency of 2 GHz. In Figure 2.2(b), the lowest and highest cut-off frequencies at -10 dB are approximately 1.2 GHz and 2.8 GHz, respectively, which lead to a fractional bandwidth:

$$B_f = \frac{2(2.8-1.2)}{2.8+1.2} \times 100\% = 80\%$$

The fractional bandwidth is larger than the minimum fractional bandwidth required by FCC. Therefore, this is an UWB signal.

3. UWB regulations

UWB signals have unique properties that prove to be very useful for communications, ranging, and radar applications. However, since UWB signals occupy a very large portion in the spectrum, they need to coexist with the incumbent systems without causing significant interference. Therefore, a UWB transmitter must meet certain requirements in order not to cause any adverse effects on the functionality of other systems.

In order to benefit from advantages of UWB without degrading the performance of other systems, the FCC started a regulation for UWB in 1998. Then, in February 2002, it announced its “First Report and Other”, which allowed the limited use of UWB devices [5]. According to this regulation, UWB systems must transmit below certain power levels in order not to cause significant interference to the other systems in the same frequency spectrum. Specifically, the power spectral density must not exceed -41.3 dBm/MHz for frequency range from 3.1 GHz to 10.6 GHz, and it must be even lower outside this frequency band, depending on the specific applications. The FCC regulation assigned the spectral power mask for three systems: The communication systems, the vehicular radar systems, and the imaging systems. The details are summarized in Table 1.

After the FCC legalized the use of UWB signals in the USA, a considerable amount of effort has been put into development and standardization of UWB systems. In Europe, the Electronic Communications Committee (ECC) of the Conference of European Posts and Telecommunications (CEPT) completed report on the protection requirement of radio communication systems from UWB applications in 2007 [6]. In contrast to the FCC regulation which defined single emission mask level entire UWB band (i.e. 3.1 GHz to 10.6 GHz), this report proposed two sub-bands with the low band ranges from 3.1 GHz to 4.8 GHz and the high band is from 6 GHz to 8.5 GHz. The emission limit for low band is -70 dBm/MHz and high band is -41.3 dBm/MHz. In Japan, the Ministry of Internal Affairs and Communications (MIC) authorized the regulation for indoor UWB communication in 2006 [7]. However, the initial regulations are likely to be modified and extended in the future, in which the outdoor and vehicular UWB devices will be investigated. In the proposed regulations, there were two usable bands 3.4 GHz to 4.8 GHz and 7.25 GHz to 10.25 GHz with the equivalent isotropically radiated power (EIRP) are -41.3 dBm/MHz and -70 dBm/MHz, respectively.

Table 1: Emission FCC limits for various UWB applications in each operational band [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)	Communication	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
	Imaging		53.3	51.3	41.3	41.3	41.3	51.3
	Vehicular Radar		75.3	63.3	63.3	63.3	41.3	41.3

4. UWB advantages and disadvantages

UWB systems are distinct from traditional communication systems. Traditional communication systems usually modulate continuous-waveform (CW) RF signals with a specific carrier frequency to transmit and receive information. A continuous waveform has well-defined signal energy in a narrow frequency band that makes it very vulnerable to detection and interception. In contrast, UWB systems use carrierless, short-duration (picosecond to nanosecond) pulses with a very low duty cycle (less than 0.5 percent) for transmission and reception of the information. The nature of the short-duration pulses used in UWB technology offers several advantages over narrowband communications systems. Besides that, it may bring some unavoidable drawbacks that should be concerned in design and development of UWB systems. The major advantages and disadvantages are listed in Table 2 and Table 3 as below.

Table 2: Advantages and benefits of UWB communications [4]

Advantage	Benefit
Coexistence with current narrow band and wide band radio services	Avoids expensive licensing fees
Large channel capacity	High bandwidth can support real-time high-definition video streaming.
Ability to work with low SNRs	Offers high performance in noisy environments.
Low transmit power	Provides high degree of security with low probability of detection and intercept.
Resistance to jamming	Reliable in hostile environments.
High performance in multipath channels	Delivers higher signal strengths in adverse conditions.
Simple transceiver architecture	Enables ultra-low power, smaller form factor, and better mean time between failures, all at a reduced cost.

Table 3: Disadvantages and problems of UWB communications [4]

Challenge	Problem
Pulse-shape distortion	Low performance using classical matched filter receivers.
Channel estimation	Difficulty predicting the template signals.
High-frequency synchronization	Very fast ADCs required.
Multiple-access interference	Detecting the desired user's information is more challenging than in narrowband communication.
Low transmission power	Information can travel only short distances.

5. Applications of UWB

The trade-off between data rate and range in UWB systems holds great promise for a wide variety of applications in military, civilian, and commercial sectors. Three main categories of UWB applications are given in Table 4.

Table 4: Applications of UWB [4]

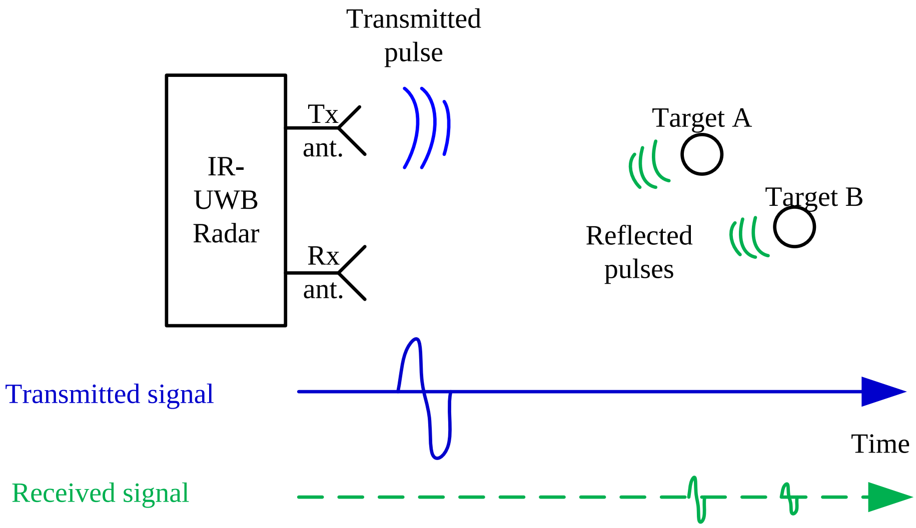
Applications		
	Military and Government	**Commercial**
Data communications	- Secure LPI/D communications - Covert wireless sensor networks (battlefield operations)	- Local and personal area networks - Wireless streaming video distribution (home networking) - Wireless sensor networks (health and habitat monitoring, home automation)
Radar	- Through-wall imaging (for law enforcement, firefighters) - Ground-penetrating radar (for rescue operations) - Surveillance and monitoring	- Medical imaging (remote heart monitoring) - Ground-penetrating radar (detection of electrical wiring, studs, etc. on construction sites) - Automotive industry (collision avoidance, roadside assistance) - Home security (proximity detectors)
Localization	- Personnel identification - Lost children - Prisoner tracking	- Inventory tracking - Tagging and identification - Asset management

B. Impulse Radio UWB Radar

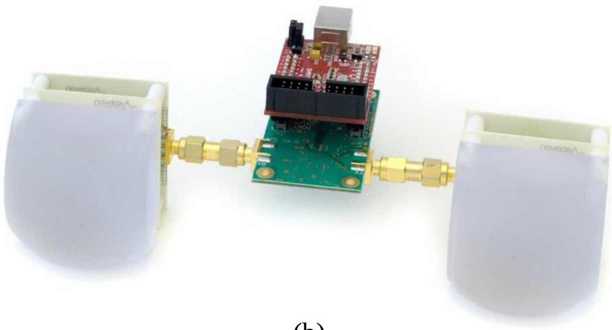
Radar (acronym for Radio Detection and Ranging) is an object-detection system that uses radio waves to determine the range, altitude, direction, or speed of objects [8]. Nowadays, the modern uses of radar are highly diverse in both military and civil such as: air traffic control, air-defense system, ocean surveillance system, and ground penetrating radar (GPR)… etc. As stated in the previous sections, UWB has many advantages which are suitable for radar applications. This section describes the IR-UWB radar used in this thesis including basic principles, features, and parameters.

1. IR-UWB radar principles

The fundamental IR-UWB radar is shown in Figure 3 (a). An IR-UWB radar typically has one transmitter and one receiver which operates in bistatic mode – i.e. transmitter and receiver are separated in the same location. The transmitter emits very weak, low duty cycle, and narrow electromagnetic pulses (blue waves). After reflected from the targets, these pulses are captured by the receiver (green waves) in order to extract the targets' features. The main difference of target between traditional radar and UWB radar is that, the transmitted UWB signal wavelength is shorter in the size of target, whereas the traditional radar has the signal wavelength longer than target size. Therefore, the UWB received signal is a collection of various pulses reflected from different parts of target, in contrast, the received signal is unique from target in the case of traditional radar. In the application of detection and localization and tracking of moving target, the time-of-arrival (TOA) of reflected signal must be determined and converted to target distance.



(a)



(b)

Figure 3: IR-UWB Radar: (a) principle operation; (b) Novelda commercial IR-UWB radar test board [10]

A commercial IR-UWB radar shown in Figure 3 (b) which was invented and commercialized by Novelda company, is used for the application in this thesis [9]. The transmitted signal is the first order of Gaussian pulse, and emission power is allowed by Korean UWB regulation. Figure 3 shows the transmitted signal in time and frequency domains. The receiver is considered as several samplers which deploy very high speed ADC (Analog-to-Digital Converter). It captures, samples, and stores received signals in the frames, or alternatively, radar scans. In fact, the data stored in the captured frame is the strength of the signal over a short period of time. The length of the time period over which the signal is captured corresponds to the spatial span of the frame. A standard frame consists of 512 samples corresponds to approximately 2 m spatial range. Thus, the resolution of the radar (i.e. the corresponding distance between two consecutive samples) is 4 mm. An example of a frame is presented in Figure 5 (a) where the target is located at sample number of 250. If several frames captured in a period of observation time are sorted continuously, it will produce a radargram as shown in Figure 5 (b). In this figure, the yellow-red curves show the target track.

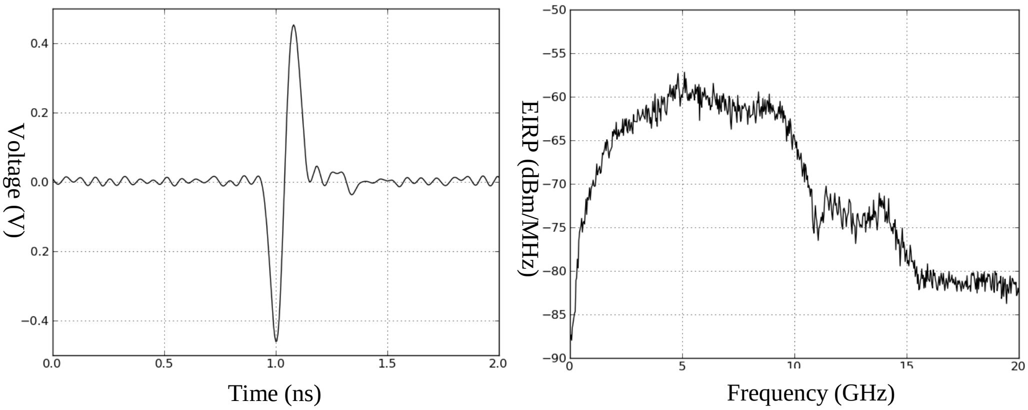


Figure 4: An example of transmitted pulse in time and frequency domain

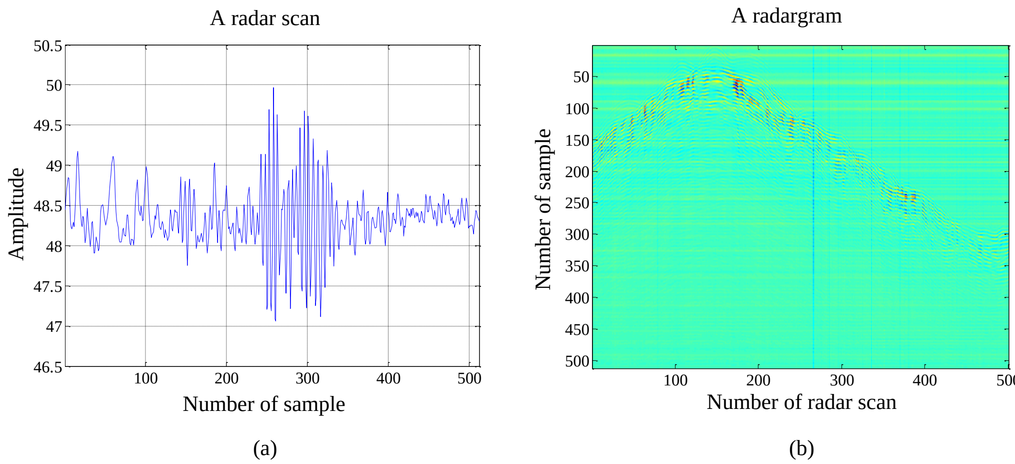


Figure 5: Received signal: A radar scan and a radargram

2. Novelda IR-UWB radar features and parameters

Taking advantages in nano-electronic technology, Novelda IR-UWB radar has some interested features [10]. The key features are as follows:

- Single-chip impulse-based radar transceiver.
- Programmable input amplifier gain for increased dynamic range.
- Ultra-high-speed programmable sample, giving up to 4 mm spatial resolution in normal mode.
- Interleaved sampling for sub-mm resolution.
- 512 points sampling window.
- A minimum of external components required.
- Easily adapt UWB regulation.
- Powerful development tools.

The important parameters of IR-UWB radar are given in Table 5.

Table 5: Novelda IR-UWB radar parameters [10]

Parameter	Unit
Operation frequency	845 – 9550 MHz
Pulse width	0.5 ns
Nominal output power	-53 dBm/MHz
Instantaneous output amplitude	500 mV
Number of sample in a frame	512
Sensitivity	-95 dBm
Frame range	Approximately 2 m
Pulse repetition frequency (PRF)	48 MHz

C. Signal processing for moving target detection, localization, and tracking using IR-UWB radar

The impulse used in IR-UWB radar has very ultra wide bandwidth and very weak transmission power, thus, it is a noise-liked signal. Therefore, it is inefficient to process IR-UWB signal in frequency domain. The better way for IR-UWB signal processing must be done in time domain. Assume that p(t) is an elementary IR-UWB waveform, the transmitted signal is:

$$s(t) = \sum_{k=-\infty}^{+\infty} p(t - kT_s) \ , \tag{2.2}$$

where T_s is the pulse repetition period. Consider the transmission path from transmitter via reflected objects to the receiver is the channel. The indoor radio channel response is [11]:

$$h(t) = \sum_{n=1}^{L} \alpha_n \delta(t - \tau_n), \tag{2.3}$$

where L is the number of multipath components, $\delta(t)$ is a Dirac impulse, α_n and τ_n are the amplitude and the propagation delay of nth path, respectively. At the receiver, the received signal consists of reflected signal and additive Gaussian noise $\aleph(t)$. It is expressed as [12]:

$$r(t) = \sum_{k=-\infty}^{+\infty} \sum_{n-1}^{L} \alpha_{n,k} p'(t - \tau_{n,k} - kT_s) + \aleph(t) \tag{2.4}$$

with $p'(t)$ is the “filtered” version of $p(t)$ through the channel. Because the IR-UWB radar receiver samples the received signal and stores them in frames. Then, a frame is a discrete time signal and denoted as $r[n]$, where n is the sample index.

In the application of detection, localization, and tracking of moving object, the interested target is considered to be moving with the radar and other objects. Consequently, it is convenient to represent received signal as:

$$r[n] = r_t[n] + r_c[n] + \aleph[n], \tag{2.5}$$

where $r_t[n]$ is the target signal that reflected from moving target $r_c[n]$, is the clutter that reflected from static objects and radar coupling (i.e. the direct transmission path from transmitter to receiver). The clutter and noise must be rejected as much as possible from the received signal. It is done via a procedure of signal processing as described in Figure 6.

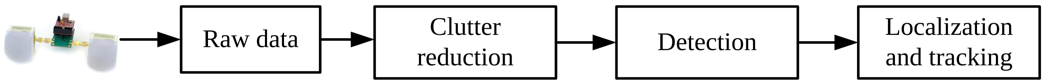


Figure 6: Signal processing procedure

Each step in the radar signal processing provides some specific functions and its outputs are the inputs for the next step. The purposes of these steps are presented as follows.

- Raw data: This is the first step of the signal processing chain. The raw data are captured directly from the radar and stored for the prospective step. The raw data are often in radargram form.
- Clutter reduction: The input of this step is the raw data. The aim of this step is to remove unwanted signals as much as possible. The expected output of clutter reduction is the target signal.
- Detection: In this step, the presence or absence of target is decided. Normally, the decision is reached based on the threshold. If the signal strength is greater than a certain threshold, a target is considered present. Otherwise, the target is absent.

- Localization and tracking: The output of detection step is fed in this step. Suppose the target is present, first of all, the distance from target to radar is converted based on the target signal located in the frame. After that, the distance is tracked during the target moving interval. By using two radars cooperating, the target location and its trajectory can be determined in the 2-dimension coordinates.

In this thesis, several algorithms are proposed or modified in order to increase the probability of target detection. Specifically, the far target and multiple targets are concerned. The radar signals are processed in off-line mode. All the algorithms are demonstrated using Matlab R2012a. However, the signal processing algorithms can be extended to work in online-mode (real time) and other embedded systems.

III. Signal processing for improved target detection and tracking of moving objects based on IR-UWB radar

A. Raw data and pre-processing

Firstly, the IR-UWB radar must be connected with a computer through COM port, in order to get the data. Secondly, a Matlab script is used to interface with the radar. By doing this, the radar parameters are set up properly for the application. Although a frame range is approximated 2 m, the observed frame range can be adjusted and extended by setting Frame Offset (FO) and Frame Stich (FS) parameters. As illustrated in Figure 7, the frame can be positioned at different depths by adjusting the FO parameter. The smaller FO is, the closer to the radar frame is and vice versa. In addition, by setting the FS parameter, two or more frames can be combined to produce a longer frame. Thus, the observed frame range can be increased.

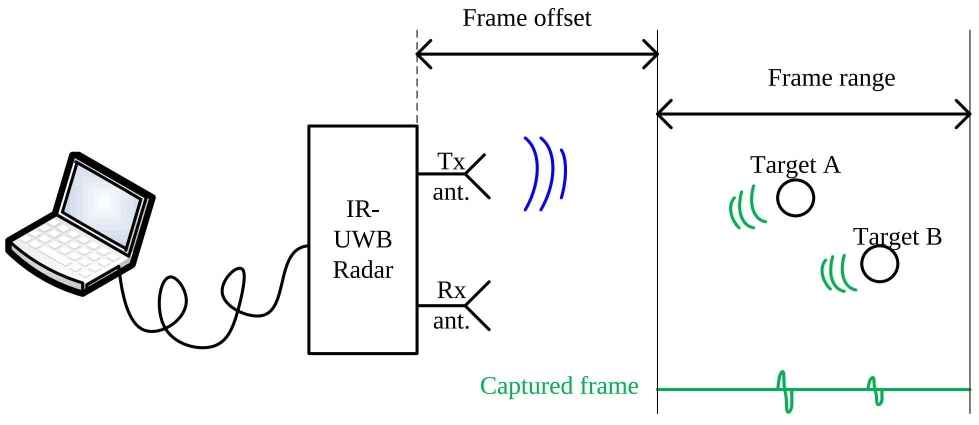


Figure 7: Illustration of frame offset and frame range

The raw data are the captured frames which may be represented as radar scans or radargrams. A radar scan (i.e. a captured frame) is denoted as $r[n]$, where n is the number of sample index. A radargram is generated by sorting m radar scans continuously in an observed time interval. It is a $n \times m$ matrix $X_{n\times m} = [r_1[n]', r_2[n]', ..., r_m[n]']$ in which each column is a radar scan. For convenience, since then, if there are not special reasons, the sample index n will be ignored in the data symbol notation.

B. Clutter reduction

IR-UWB radar transmits low duty cycle pulses and receives backscattered electromagnetic (EM). If the targets are present, the received signal can be divided in three parts: the target signal r_t – i.e the refleted signal from moving target, the clutter r_c - i.e. the refleted from static objects, and noise $\aleph$. In most circumstances, r_t is smaller than r_c. Therefore, reducing r_c to enhance r_t is a crucial task in IR-UWB radar signal processing. The technique that reduces r_c from received signal r is called clutter reduction or background subtraction.

Clutter reduction in IR-UWB radar for moving target detection and tracking systems in short range indoor surveillance area is similar to the background subtraction techniques in visual surveillance systems [13] and clutter reduction techniques in Ground Penetrating Radar (GPR) applications [14]. The aim of clutter reduction is estimating of clutter and subtracting it from the received signal to achieve target signal. Thus, the performance of clutter reduction methods depends on how precise it estimates the clutter.

The simplest clutter reduction method in IR-UWB radar uses a *mean* method which assumes clutter is the average of a number of previous frames [15]. After that, target signal is obtained by subtracting the estimated clutter from the incoming frame. This method is simple but its performance is poor and the clutter cannot be updated. An innovation of mean method is *exponential averaging* (EA) method [16]. In this method, clutter can be updated and its performance is improved. The more common clutter reduction method is to be based on *Singular Value Decomposition (SVD)* [17]. This method is efficient for through-wall imaging systems, but it can be used for moving target detection, localization, and tracking systems. The disadvantage of this method is that it costs much memories and computational resources to store and compute matrix.

In this section, a new clutter reduction algorithm using *Kalman Filter* (KF) is proposed. In this method, clutter is estimated by Kalman filter for each sample in the frame, separately. Target signal is determined by residual between incoming frame and estimated clutter. The advantage of this method is that it applies recursive computing mechanism, thus, can reduce significantly memory demand and is suitable for real-time system. The following parts present the common methods and proposed method and their performance comparisons.

1. Exponential Averaging (EA) method

In [16], a clutter reduction method is proposed by applying exponential averaging. In this method, the raw data to be processed are radar scans. Given an initial estimated clutter $r_{\tilde{c}(k-1)}$, the new estimated clutter $r_{\tilde{c}(k)}$ is computed recursively from the previous clutter estimation $r_{\tilde{c}(k-1)}$ and the new incoming frame r_k, where k is time index, according to the following equation:

$$\begin{aligned} r_{\tilde{c}(k)} &= \alpha r_{\tilde{c}(k-1)} + (1-\alpha) r_k \\ &= r_{\tilde{c}(k-1)} + (1-\alpha)\left(r_k - r_{\tilde{c}(k-1)}\right) \\ &= r_{\tilde{c}(k-1)} + (1-\alpha) z_k , \end{aligned} \tag{3.1}$$

where α is the constant scalar weighting factor and $z_k = r_k - \tilde{r}_{c(k-1)}$ is one dimensional vector with the size $n \times 1$ with n is the number of samples in a frame. Thus, the new estimated clutter takes a fraction of previous estimation and a fraction of current frame. The weighting factor α is an empirical scalar which takes values between 0 and 1. It controls the amount of averaging in the estimated clutter. Vector z_k is the result of subtracting previous estimated clutter from current incoming frame and it is considered the target signal.

2. Singular Value Decomposition (SVD) method

In the through the wall imaging systems using UWB radar, a clutter reduction technique based on SVD is often used [17]. However, this method can apply in moving target detection, localization, and tracking system using IR-UWB radar. SVD is a matrix factorization technique. Therefore, the raw data used in this method must be a radargram $X_{n\times m}$. The SVD of matrix $X_{n\times m}$ is given by:

$$X_{n\times m} = USV^T, \tag{3.2}$$

where U and V are $n\times n$ and $m\times m$ unitary matrices, respectively. V^T is the transposed matrix of V. S is a $n \times m$ diagonal matrix – i.e. $S = \mathrm{diag}(\sigma_1, \sigma_2, \ldots, \sigma_r)$ with $\sigma_1 \geq \sigma_2 \geq \cdots \sigma_r$. SVD of matrix $X_{n\times m}$ can alternatively be represented by “rank-1 decomposition” as below:

$$X_{n\times m} = USV^T = \sigma_1 \begin{pmatrix} \cdots \\ u_1 \\ \cdots \end{pmatrix} \left(\ldots v_1^T \ldots\right) + \ldots + \sigma_n \begin{pmatrix} \cdots \\ u_n \\ \cdots \end{pmatrix} \left(\ldots v_n^T \ldots\right)$$

$$= \sum_{i=1}^{m} \sigma_i u_i v_i^T = M_1 + M_2 + \ldots + M_N = \sum_{i=1}^{m} M_i, \tag{3.3}$$

where M_i are matrices of the same dimension with X, and called as modes or i^{th} eigenimage. Subsequently, a radargram X is splitted into three parts: target signal matrix M_t, clutter matrix M_c, and noise matrix M_n, expressed by

$$X_{n\times m} = M_t + M_c + M_n. \tag{3.4}$$

Because the clutter is higher than target signal and noise, then, M_1 represents for clutter, M_2 represents for target signal and the rests are noise. They are:

$$M_c = M_1 = \sigma_1 u_1 v_1^T$$

$$M_t = M_2 = \sigma_2 u_2 v_2^T$$

$$M_n = \sum_{i=3}^{N} \sigma_i u_i v_i^T \ . \tag{3.5}$$

3. Kalman Filter (KF) method

In estimation theory, KF is an optimal state estimation technique for linear dynamic systems [18]. Assume the system is a discrete system. The general state estimation problem is stated as follows. Suppose the state x_k of a dynamic system is governed by the state transition equation given by

$$x_k = f(x_{k-1}, u_{k-1}) + w_{k-1}, \tag{3.6}$$

where u_{k-1} is the input, w_k is the additive noise, and k is the time index. $f(.)$ is a function. Because of noise, the state is hidden. We just only observed the measurement of the state which relates to the state as the measurement equation:

$$z_k = g(x_k) + v_k, \tag{3.7}$$

where z_k is the measurement of state and v_k is the additive noise. g(.) is a function.

If $f(.)$, $g(.)$ are linear functions and w, v are Gaussian additive noises with covariance matrices Q and R, respectively, the state transition equation (3.6) and measurement equation (3.7) can be rewritten as:

$$x_k = Ax_{k-1} + Bu_k + w_{k-1},$$

$$z_k = Hx_k + v_k, \tag{3.8}$$

where A, B and H are state transition matrix, control input matrix, and measurement matrix, respectively. All the matrices are known. In this case, the state is estimated optimal through KF algorithm. The KF algorithm working recursively has two steps: time update, and measurement update given by these equations as below.

- Time update:
  (1) Initial state and error covariance: $x_{k-1}^{\sim}$, P_{k-1}
  (2) Project the state ahead: $x_k^{\wedge} = Ax_{k-1}^{\sim} + Bu_{k-1}$
  (3) Project the error covariance ahead: $P_k^{\wedge} = AP_{k-1}A^T + Q$
- Measurement update:

(1) Compute the Kalman gain: $K_k = P_k^{\wedge} H^T \left(HP_k^{\wedge} H^T + R\right)^{-1}$

(2) Update estimate with measurement z_k: $x_k^{\sim} = x_k^{\wedge} + K\left(z_k - Hx_k^{\wedge}\right)$

(3) Update the error covariance: $P_k = (I - K_k H)P_k^{\wedge}$.

In the application of clutter reduction, KF is used to estimate the clutter which consists of n samples of a radar scan (i.e. $x_k^{\sim} = r_{c(k)}$). Hence, the KF estimates n points of clutter, independently. The measurements are the raw data in form of radar scans (i.e. $z_k = r_k$). Because the clutter is the reflection from static objects, it is considered constant with time. Therefore, the values assigned to the matrices are: $\mathrm{A} = \mathrm{I}, \mathrm{B} = 0$, and $\mathrm{H} = \mathrm{I}$, where I is an identity matrix.The KF equations for clutter reduction application are reduced to:

- Time update:

  (1) Initial state and error covariance: $x_{k-1}^{\sim}$, P_{k-1}

  (2) Project the state ahead: $x_k^{\wedge} = x_{k-1}^{\sim}$

  (3) Project the error covariance ahead: $P_k^{\wedge} = P_{k-1} + Q$

- Measurement update:

  (1) Compute the Kalman gain: $K_k = P_k^{\wedge}\left(P_k^{\wedge} + R\right)^{-1}$

  (2) Update estimate with measurement z_k: $x_k^{\sim} = x_k^{\wedge} + K_k\left(z_k - x_k^{\wedge}\right)$

  (3) Update the error covariance: $P_k = (I - K_k)P_k^{\wedge}$.

Finally, the estimated clutter is subtracted from received frame in order to obtain the target signal.

4. Experimental results

To evaluate the performance of the clutter reduction techniques, the experiments are set up in a classroom which is occupied with tables, chairs, and whiteboard. In the first scenario, one person considered as a moving target person moves within the range of 3 – 5 m from the radar. The reflected signals are captured by the IR-UWB radar and processed by the three different clutter reduction methods. In the second scenario, the experiment is repeated exactly, without moving target so that there is only the clutter. This clutter is considered to be “true” clutter and will be compared with estimated clutter when there is moving target.

The results of the experiments are evaluated in two ways: in term of pictures of data before and after applied clutter reduction, and in term of average Root Mean Square Error ($a-RMSE$) between estimated clutter and “true” clutter. Figure 8 shows a radar scan before and after applying three different clutter reduction techniques. In this case, the target is indicated as the reflected pulse located around sample number of 150. Figure 9 shows a radargram before and after applied three clutter reduction methods. In this figure, the red patters indicate the target. It can be seen from both Figure 8 and Figure 9 that, before applying clutter reduction, it is difficult to recognize the target signal from the received signal, because the clutter affects to the target signal. However, after applied clutter reduction, the clutter is removed, thus, the target signal appears clearly. Secondly, comparison result of different $a-RMSE$ for each method is shown in Table 3.1. Average RMSE is difference between estimated clutter and “true” clutter that captured when there is not moving target. The definition of $a-RMSE$ is shown in equation (3.9). From the Table 6, the KF shows the better performance for estimated clutter in comparison with other methods.

$$a-RMSE=\frac{1}{M}\sum_{i=1}^{M}\left(\sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(r_{c(i,j)}-\hat{r}_{c(i,j)}\right)^{2}}\right) \tag{3.9}$$

Table 6: Performance comparison of different clutter reduction methods

Clutter reduction method	Average RMSE
Kalman Filter	0.0984
Exponential Average	0.1119
Singular Value Decomposition	0.1148

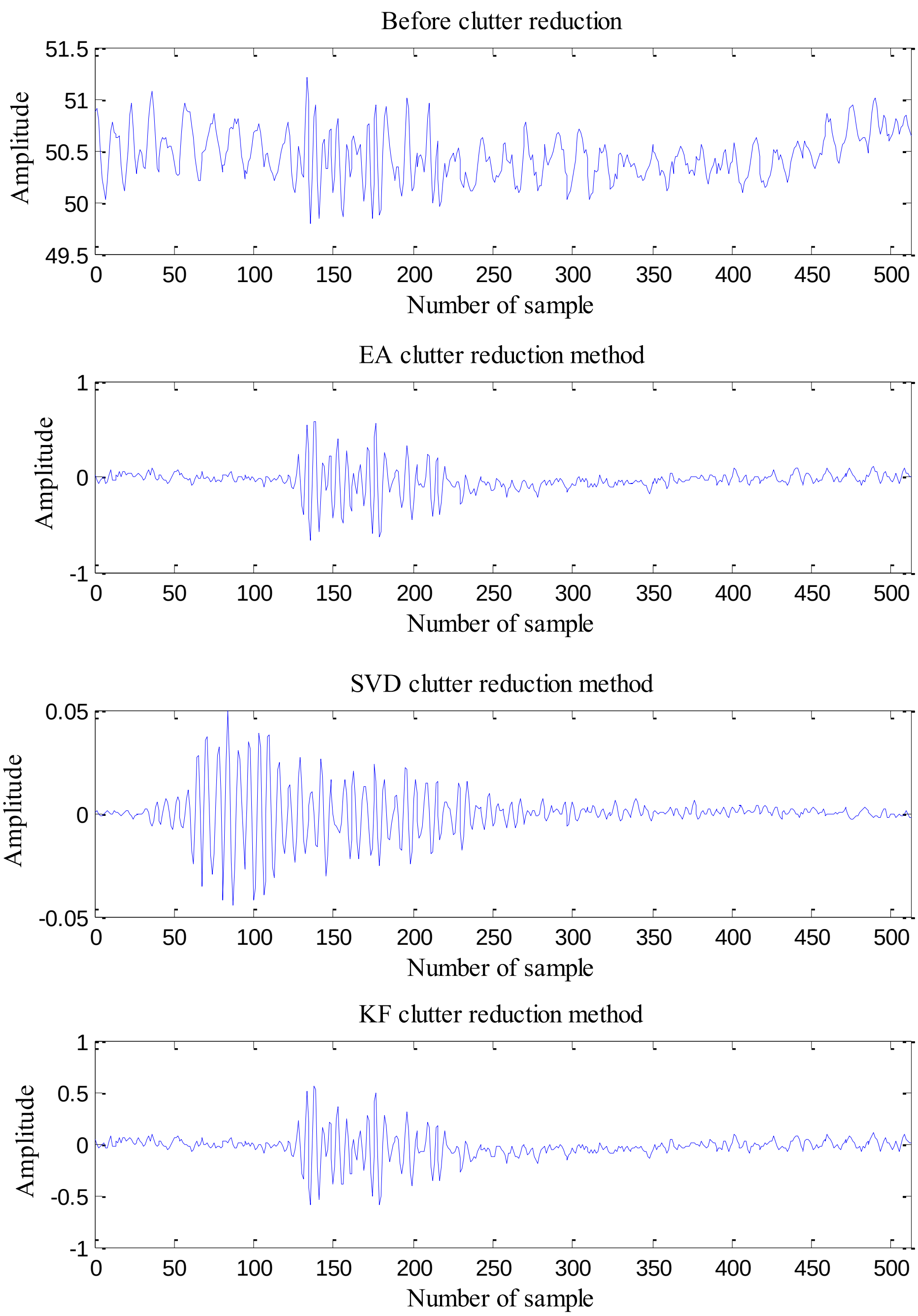


Figure 8: Radar scan before and after applied different clutter reduction methods

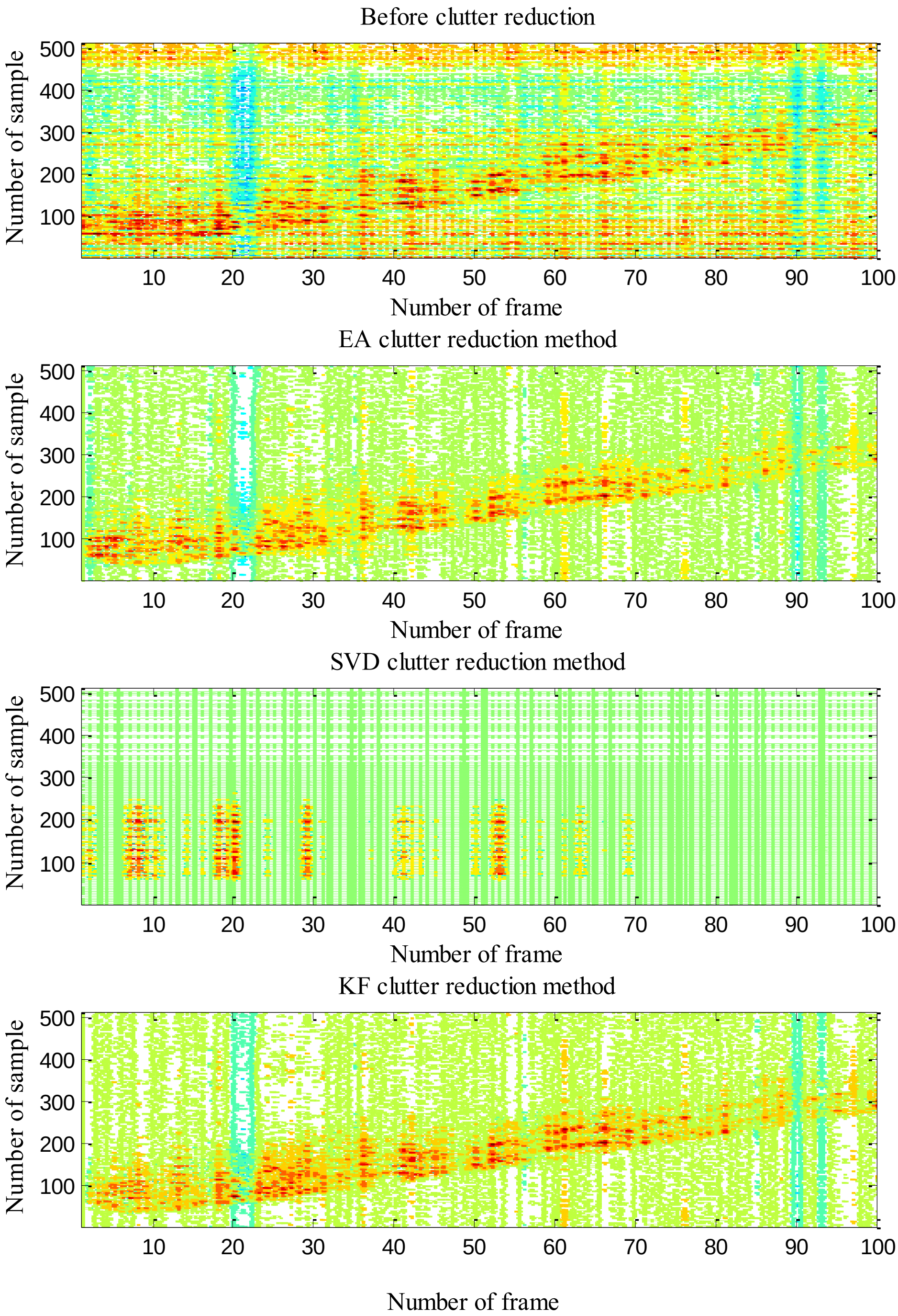


Figure 9: Radargram before and after applied different clutter reduction methods

In conclusion, clutter reduction is an important part in IR-UWB signal processing because it can improve SNR and target detection ability. Each clutter reduction method has a trade-off in performance and complexity. Based on the above comparisons, KF method is chosen for clutter reduction in this thesis. Its output is provided to the next step.

C. Detection

After clutter reduction, a majority of clutter is removed. However, recognition of target signal is challenge in some cases. For example, if the target is located far away from the radar, the reflected signal is as small as noise, due to the signal attenuation. Therefore, the signal processing for target detection is needed.

Detection of moving targets is the task to decide whether the targets are present or absent. It is equivalent to the detection of the pulses reflected from the targets in the captured signal. Typically, detection is often divided into two groups: optimal detector and sub-optimal detector. The optimal detector is based on statistic optimization and it can provide very accurate decision, however its structure could be extremely complex. Therefore, sub-optimal detector is often used. For the purpose of detection of moving target by IR-UWB radar, detection using matched filter is introduced in [15]. The precision of this method depends on how much the received signal and template is matched. In IR-UWB radar application, the pulse width is very narrow and the pulse waveform is affected strongly by target distance, material, and shape. Therefore, the matching ratio between reflected signal and template pulse is small. In [19], the Constant False Alarm Rate (CFAR) detection is proposed. In this method, the most difficulty is the determination of noise and clutter distribution in order to define a suitable threshold. In [20], the detection is done by CLEAN algorithm. It searches all the pulse presences by using the cross-correlation between received signal and template signal then compare with a threshold. However, it is noticed that the received signal strength will be weaker, when the target distance is longer. Therefore, it is not appropriate to interpret the received signal under the same condition.

In this section, the conventional CLEAN algorithm is modified in order to increase detection ability. Firstly, compensation of signal power attenuated according to distance is performed. Secondly, the false alarm reduction is applied by using the window method. The remaining of this section presents these detection of moving target methods and their performance evaluations will be conducted.

1. CLEAN detection algorithm

In [20], a detection algorithm is proposed and called CLEAN algorithm. The input of CLEAN algorithm detection are signal after clutter reduction $z[n]$, the template signal $v[n]$, and the predefined threshold T. The template signal is the reflected signal from a metal plate placed 1 m from the radar. The conventional CLEAN algorithm uses a fixed threshold for all frames. The threshold T is calculated by average energy in a frame multiplies by a scalar. In order to detect the target signal, the threshold must be lower than the target signal amplitude. Figure 10 shows a cycle of CLEAN algorithm operation for one frame coming. As shown in Figure 10, the CLEAN algorithm searches for reflected signals from targets based on the comparison of cross-correlation results and threshold. First of all, the incoming frame $z[n]$ is cross-correlated with a template signal $v[n]$. Secondly, the maximum amplitude of the cross-correlation result is compared with certain threshold. If it is greater than threshold, one sample of a reflected pulse will be found and the iteration is looped again from the cross-correlation step. Until the maximum of cross-correlation result is lower than the threshold, all the reflected pulses are found and the iteration will stop.

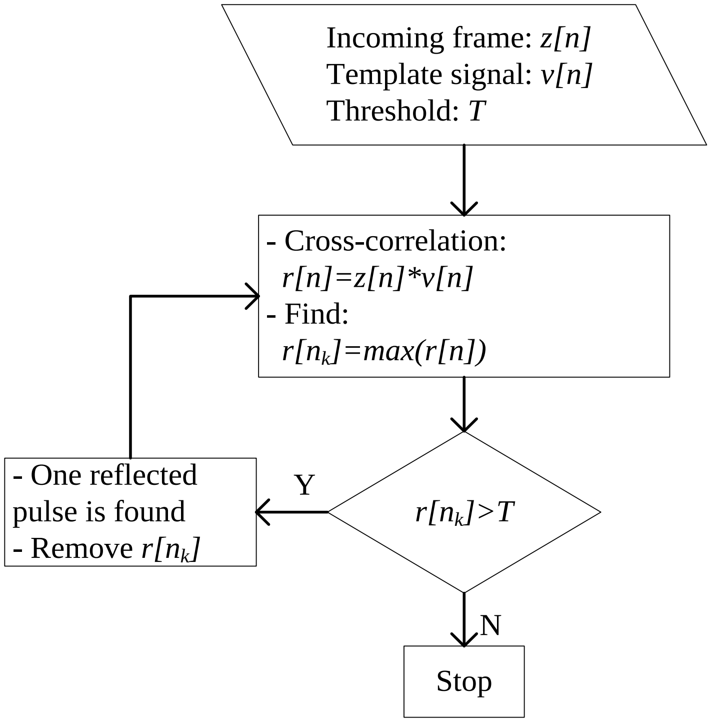


Figure 10: CLEAN detection algorithm

2. Modified CLEAN detection algorithm

While electromagnetic wave propagates in wireless channel, its power density is attenuated. This phenomenon is known as path loss (PL). PL is defined as the ratio of the received signal power P_{rx} to the transmitted signal power P_{tx}. For UWB system, PL is dependent on frequency of UWB signal and distance from radar to target. For simplicity, distance and frequency dependencies can be treated independently, as below

$$PL(f,d)=\frac{P_{rx}}{P_{tx}}=PL(f)PL(d), \tag{3.10}$$

where $PL(f) \propto f^{-2\kappa}$ and $PL(d) \propto d^{-n}$, with κ and n denoting the frequency decaying factor and the PL exponent, respectively. In indoor environment, n is approximately chosen as 2 [21]. In other word, the amplitude of received signal is inverse proportion with distance.

As the result of signal attenuation, the farther target is located, the weaker reflected signal is. To generate equal condition in the signal strength, the weak signal should be compensated before detection decision step. To compensate weak signal, it is simply multiplied with a weighted vector. The weaker part of signal must be multiplied with the higher scalar in the weight and vice versa. The final compensated signal is:

$$z'[n] = z[n]\alpha[n], \qquad (3.11)$$

where $z[n]$ is the signal before compensation and $\alpha[n]$ is the weighted vector, respectively. In our experiments, with the real data taken by Novelda IR-UWB radar, we determine the weighted vector is proportional according to the distance. After that, the conventional CLEAN algorithm is applied with the compensated signal.

Figure 11 (a) and Figure 11 (b) show observed signal before and after compensation. It can be seen that reflected signal strength from both near and far located targets are roughly same, thus threshold is fairly applied for both type of targets.

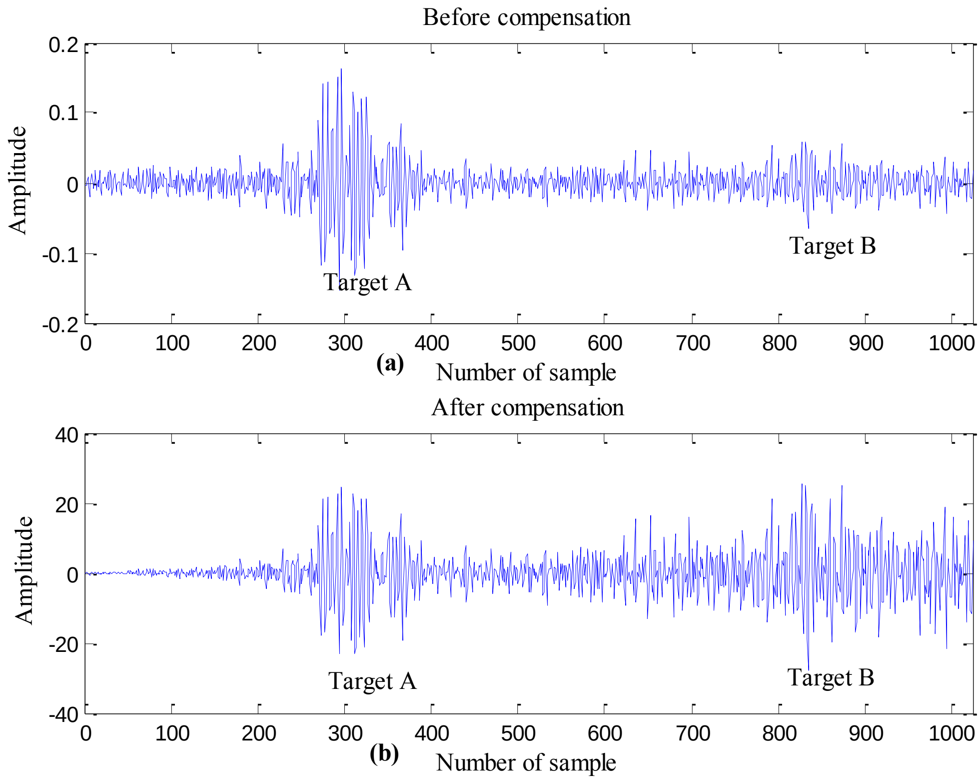


Figure 11: Compensation of weak signal (two targets are moving in this example): (a) Signal observed before compensation, (b) Signal observed after compensation

After applying CLEAN algorithm for compensated signal, the detection ability of far located target is increased, but the compensation may cause another false alarm. The reason is that, the target signal is amplified by multiplying with the weighted vector, and the noise has a chance to be amplified highly. Specifically, noise can be multiplied by a greater scalar in the weighted vector, in the far field. It may exceed the target signal strength, and become a false alarm. In order to reduce these false alarms, the threshold must be designed adaptively with the range of target. In this paper, we introduce a different criterion to eliminate false alarms.

As state in previous section, because the target is extended target, the signals reflected from target have multipath components. Nevertheless, some multipath components belong to one target, thus they locate closely in the captured frame. Figure 12 (a) shows the signal strength after compensation of a captured frame where two targets locate around 1 m and 3 m, in front of the radar. The target signal consists of multiple pulses which are reflected from different parts of target, thus, they appear nearly. Whereas, the false alarms are located diversely in the same frame. Based on this feature, a jumping window is applied to eliminate false alarms as below. A window has a size covering the target appearance and jumps along the frame. After that, the number of nonzero samples inside the window is examined. If it exceeds a defined threshold, there is target presence; otherwise, there is false and the nonzero samples inside the window are deleted. This method is called 1-D jumping window.

Although 1-D jumping window method can eliminate a major of false alarms, but the false alarms sometimes appear closely in a certain range. This method cannot sufficiently provide good quality. In this case, we extended 1-D jumping window method in which concerns with the property of the neighbors of current examining frame. Normally, the movement of target is not too fast while the frame rate is quite high (e.g. 30 frames per second). Therefore, there is a slight difference in target location between two consecutive frames. Figure 12 (b) presents 200 continuous frames which are aligned horizontally. In this figure, the blue patterns indicate estimated target position. It is clear that the difference of target location between two frames is very small. By taking account into the above property, the extension of 1-D jumping window is described as follows. A 2-D window which the number of row m is related to the number of frames and the number of column n is related to the number of samples is proposed. The window jumps along the frame and between these frames, respectively. Similar to the 1-D jumping widow, the total number of nonzero samples inside the window is compared with a threshold in order to decide if the target is present or absent. The target is considered to be present if the number of nonzero samples inside the window is higher than the threshold and vice versa. This method is called 2-D jumping window.

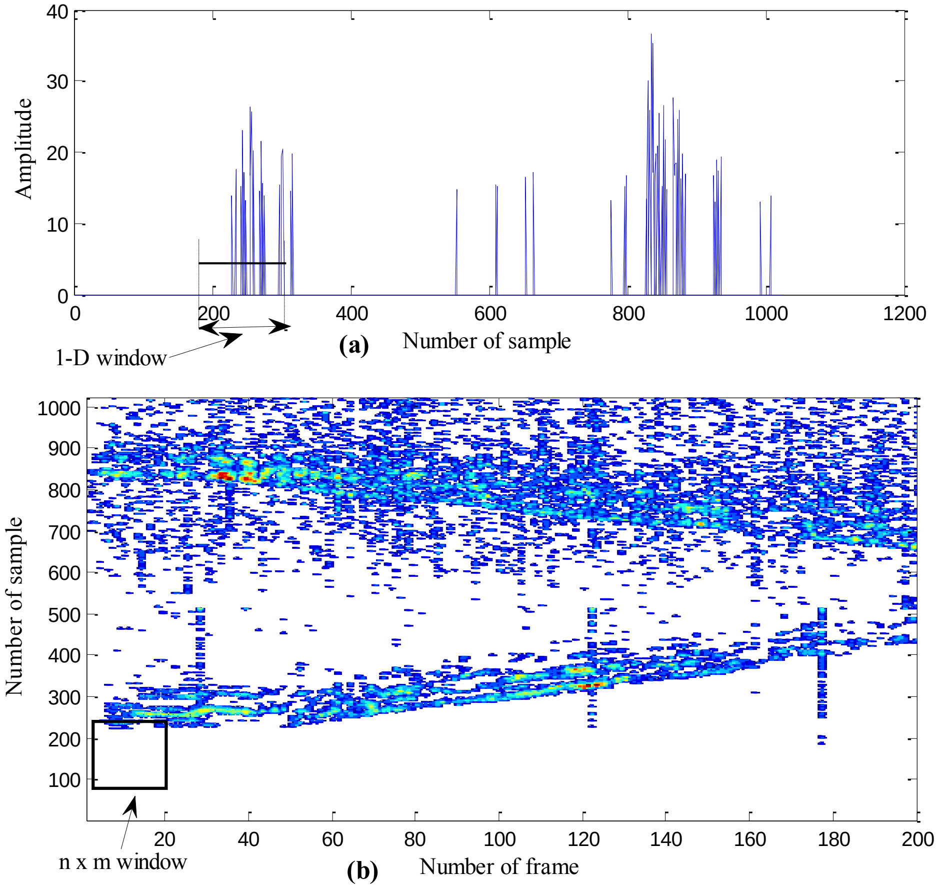


Figure 12: Jumping window method for eliminating false alarm: (a) 1-D window, (b) 2-D window

3. Experimental results

In order to demonstrate the detection algorithm, the experiment is made in a class room in which is occupied with tables, chairs, and white board. Two people, target A and target B, move in the range of the IR-UWB radar. Target A moves from 1 m to 4 m in front of the radar and target B moves inversely, from 4 m to 1 m. In this case, the FS parameter is set as 2 to increase the frame range. Thus, a frame consists of 1024 samples. Then the data taken by the IR-UWB radar are processed by two above detection methods.

All the thresholds using in both methods are set up manually until the false alarms are eliminated. The window size in the modified CLEAN algorithm is 10×10. The results are shown in Figure 13 in which the blue patterns indicate the detected target. It can be seen that the closer located target – i.e. located in sample number 200 to 600, is detected well by both methods. However the farther located targets are missed when the conventional CLEAN algorithm is applied (i.e. the targets located in sample number 600 to 1024). However, by using modified CLEAN method, the far targets are detected well.

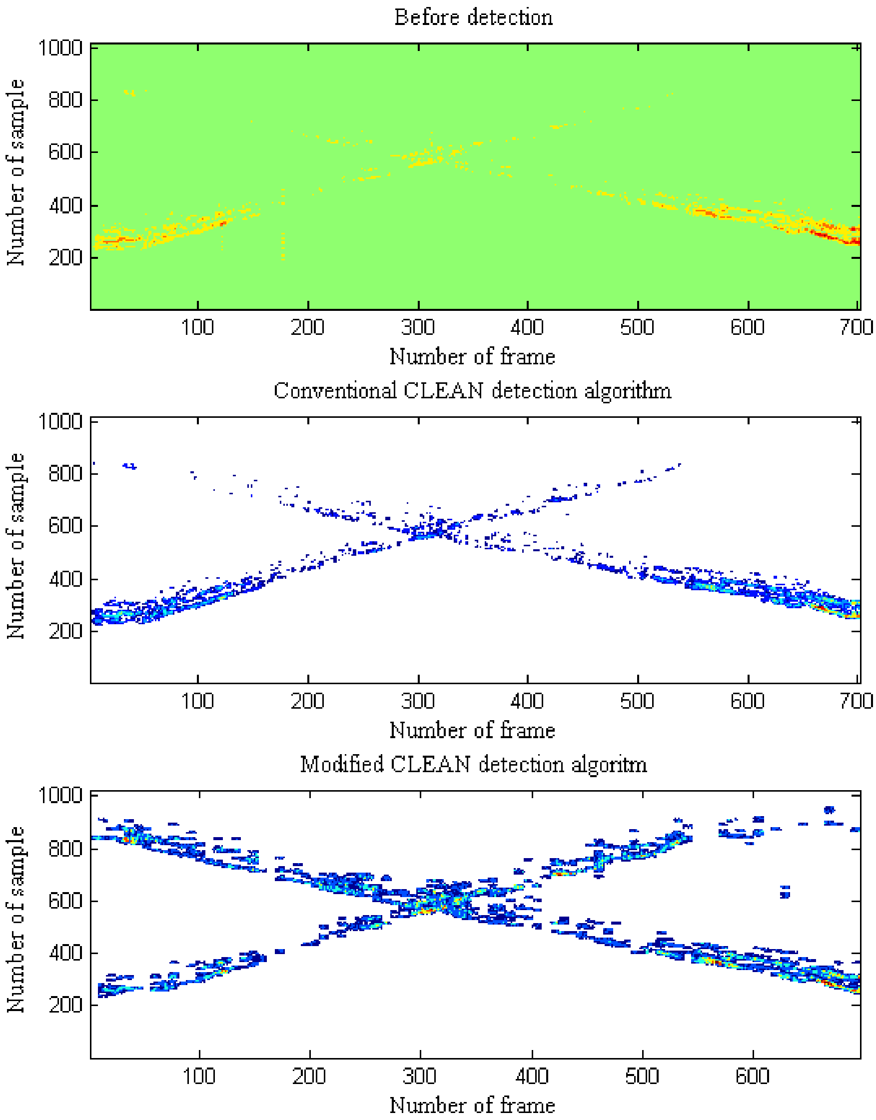


Figure 13: Detection of moving targets by different detection methods

Then, the results are analyzed further. We count the number of frames in which the targets are detected during the observed time. It is shown in Table 3.2 that, the detection rate of target A and target B using conventional CLEAN detection algorithm are 45 % and 55 %, respectively. However, by using the modified CLEAN detection algorithm, the detection rate of target A and target B increase to 73 % and 87 %, respectively. It is clear that, the modified CLEAN detection algorithm improved the detection probability.

Table 7: Detection comparison of two moving targets during observed time

Detection method	Detection rate	
	Target A	Target B
Conventional CLEAN method	45 %	55 %
Modified CLEAN method	73 %	87 %

In conclusion, this section presented the problem of detection of multiple moving targets when IR-UWB radar is applied. The conventional CLEAN algorithm is modified by adding two extra processes based on weak signal compensation and jumping window. The experimental results validate that the modified method can detect the moving targets much better than the conventional CLEAN algorithm. Therefore, it is chosen as the signal processing in detection step. Its outputs are provided for the next step: localization and tracking.

D. Localization and tracking

Localization and tracking are important functions of radar. That is the association of consecutive radar observations of the same target in to its location and track [8]. In this application using IR-UWB radar, the radar observation is the distance from target to radar. Because the input of localization and tracking step is the output of detection step which is considered to be the target signal, it must be converted into target distance. After that, the target distance is provided for localization and tracking. This section consists of the following parts:

- Target distance conversion: The target distance is computed from target signal after detection.
- Tracking of target distance: The target distance provided by one radar is tracked
- Localization: By using two radars, the position of a target is determined in 2-dimension coordinates.
- Tracking: Track the target trajectory in 2-dimension coordinates by the observations from two radars.

1. Distance conversion

After the detection step, the target signals are determined. As the target is extended target, a target signals is a set of pulses located in several consecutive samples. For simplicity to compute target distance, a target resolution is defined as the smallest distance between two targets that the radar can separate. We set up the experiment to determine the target resolution as follow. Two people move closely until the radar cannot distinguish them. After that, we measure the distance between two people that is the target resolution. By doing the experiment, the target resolution is $R_t = 0.3$ m, equivalent to number of sample is 75 (i.e. $R_t / R = 0.3/0.004 = 75$). The procedure for computing the target distance is shown in Figure 14. First of all, target sample index of a frame after detection is stored in a vector denoted as $In[n]$. If $In[n]$ is an empty vector, there will be no targets. Otherwise, there is target. The criteria to decide a target is whenever the distance between two consecutive samples is bigger than the target resolution.

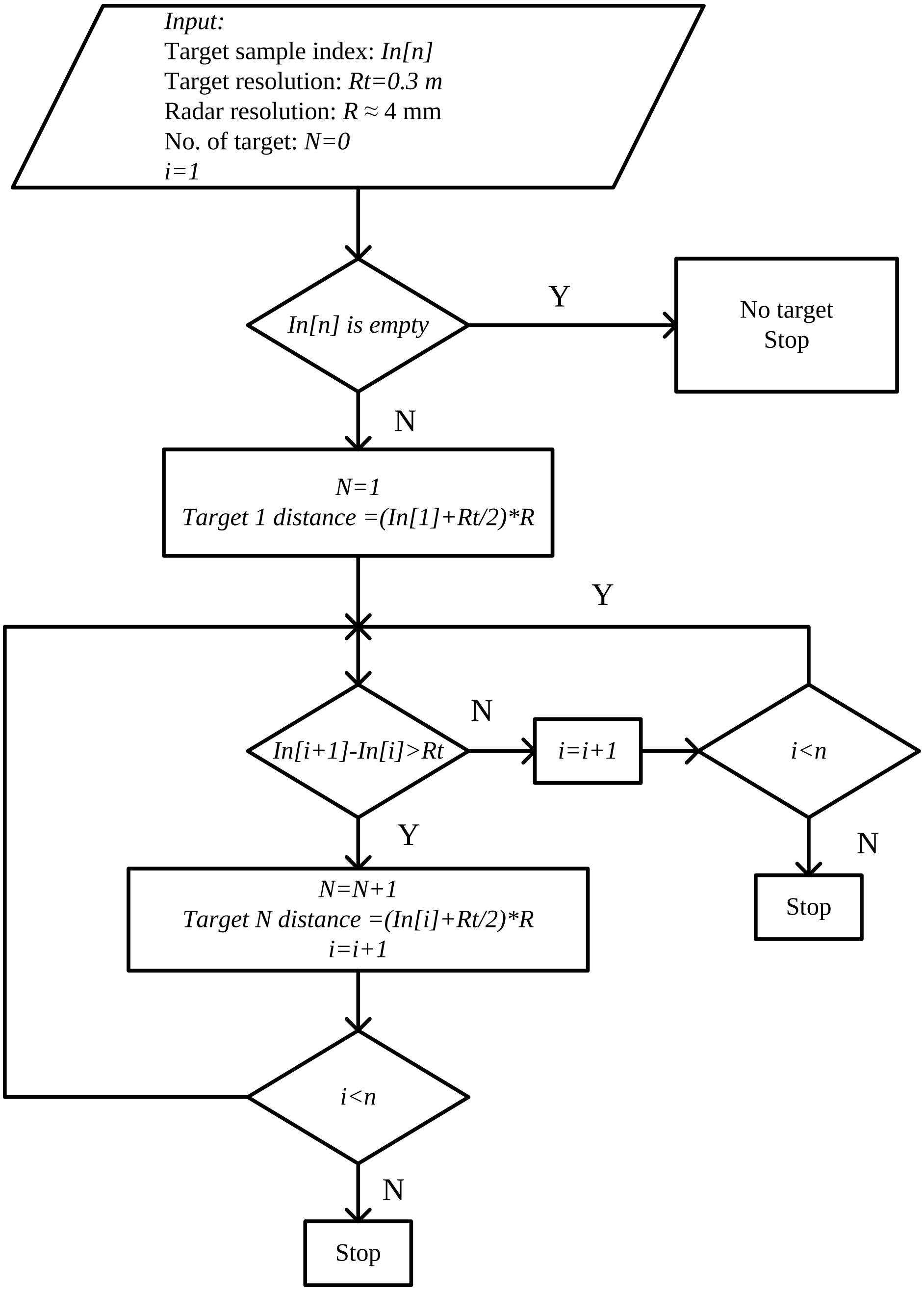


Figure 14: Procedure for computing the target distance

2. Tracking of target distance

In this part, the target distance observed by the radar is tracked. The most common tracking method based on Kalman filter is applied in this situation [21]. In this section, the tracking of distance of one target is considered.

Assume the target moves according to the kinetic mechanism. Hence, its state is characterized by distance and velocity (i.e. $x_k = [d_k, v_k]$). The state transition equation is:

$$x_k = \begin{bmatrix} d_k \\ v_k \end{bmatrix} = \begin{bmatrix} d_{k-1} + v_{k-1}t + a\dfrac{t^2}{2} \\ v_{k-1} + at \end{bmatrix} + w_{k-1} = Ax_{k-1} + Bu_{k-1} + w_{k-1}, \tag{3.12}$$

where: $A = \begin{bmatrix} 1 & t \\ 0 & 1 \end{bmatrix}$, $B = \begin{bmatrix} \dfrac{t^2}{2} \\ t \end{bmatrix}$, $u_k = a$ is acceleration, and $\mathrm{w_k} = \aleph(0, \mathrm{Q})$ is the process noise with covariance matrix Q.

The radar can observe only the target distance (i.e. $z_k = d_k$). Therefore, the measurement equation is:

$$z_k = d_k = \begin{bmatrix} 1 & 0 \end{bmatrix} x_k + v_k = Hx_k + v_k, \tag{3.13}$$

where $H = [1 \quad 0]$ and $v_k = \aleph(0, R)$ is the measurement noise with the covariance R. The measurement noise includes the radar resolution noise and target resolution noise.

The state of the target is estimated optimally by the KF algorithm as follow:

- Time update:

  (1) Initial state and error covariance: $\tilde{x}_{k-1}$, P_{k-1}

  (2) Project the state ahead: $\hat{x}_k = A\tilde{x}_{k-1} + Bu_{k-1}$

  (3) Project the error covariance ahead: $\hat{P}_k = AP_{k-1}A^T + Q$

- Measurement update:

(1) Compute the Kalman gain: $K_k = P_k^{\wedge} H^T \left(H P_k^{\wedge} H^T + R \right)^{-1}$

(2) Update estimate with measurement z_k: $x_k^{\sim} = x_k^{\wedge} + K\left(z_k - H x_k^{\wedge} \right)$

(3) Update the error covariance: $P_k = \left(I - K_k H \right) P_k^{\wedge}$.

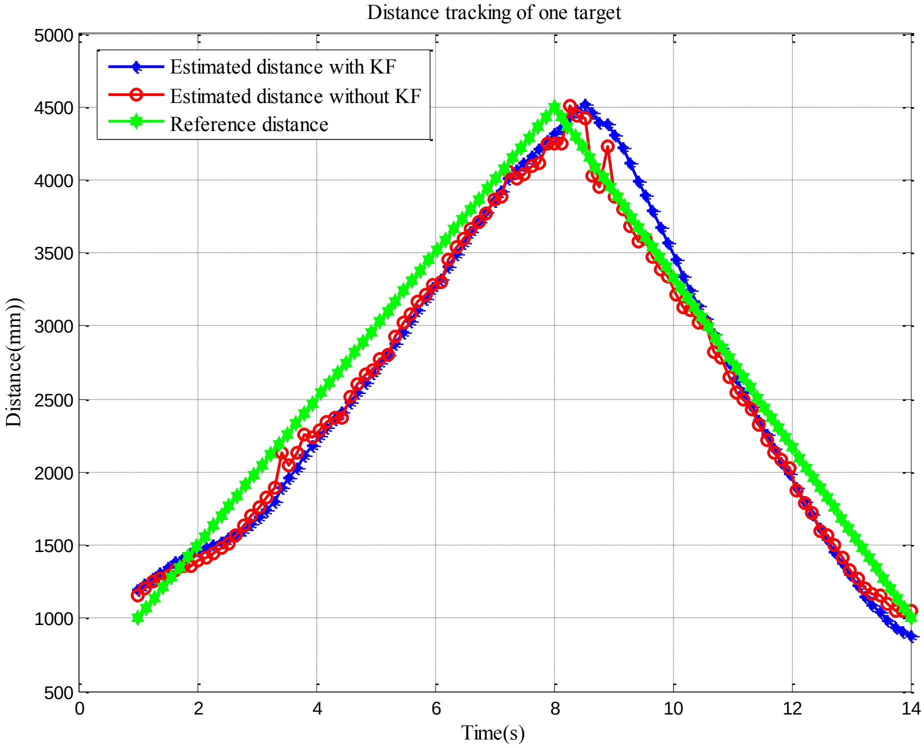


Figure 15: Distance tracking of one target

To demonstrate the target distance tracking algorithm, an experiment is set up as follow. One person considered as a target moves with constant velocity in the radar range. He moves from 1 m to 4.5 m and backs from 4.5 m to 1 m, during the captured time. The raw data are processed by KF clutter reduction, and modified CLEAN detection algorithm. After that, the target distance is calculated and fed into the tracking step. The result is shown in Figure 15, in which the blue line indicates the target distance estimated by KF, the red line indicates the estimated target distance without using KF, and the green line is the reference target distance. The reference target distance is the distance of target that assumes target moves with constant velocity from 1 m to 4.5 m, during captured time. It can be seen from the Figure 15, the estimated target distances are closed to the reference target distance.

3. Localization and tracking in 2-dimension coordinates

The localization and tracking of target in 2-dimesion coordinates are often done in a UWB sensor networks or UWB radar network. There are variety methods to solve this problem. In [22], the tracking of moving target in UWB sensor network based on Particle filter is proposed. In [23], various positioning algorithms are presented, such as: triangular, least square method, and Taylor series method. These methods have the trade off in performance and complexity. However they are suitable for a network of UWB sensor or UWB multistatic radar. In this thesis, two IR-UWB radars are cooperative in order to localize and track the target. The algorithm based on Extended Kalman Filter (EKF) is proposed for both localization and tracking purposes.

Recall the general estimation problem stated in section A of this chapter, which is characterized by equations (3.6) and (3.7):

$$x_k = f(x_{k-1}, u_{k-1}) + w_{k-1}$$
$$z_k = g(x_k) + v_k$$

If at least one of two above equations is nonlinear, in order to apply the KF algorithm, it should be linearized by using the approximation techniques. The KF with linearization is called EKF. The most common approximation technique used in EKF is Taylor series [18].

In the application of localization and tracking of target in 2-dimensons coordinates, two radars must be used. They are set up orthogonally, where the position of first radar is $R_1(X_1, Y_1)$ and the position of the second radar is $R_2(X_2, Y_2)$. The moving target state is characterized by its location and velocity in x and y coordinates (i.e. $x_k = [dx, vx, dy, vy]^T$). The state transition is governed by motion equations:

$$x_k = f(x_{k-1}, u_{k-1}) + w_{k-1} = \begin{bmatrix} dx_k \\ vx_k \\ dy_k \\ vy_k \end{bmatrix} = \begin{bmatrix} dx_{k-1} + vx_{k-1}t + a_x \dfrac{t^2}{2} \\ vx_{k-1} + a_x t \\ dy_{k-1} + vy_{k-1} + a_y \dfrac{t^2}{2} \\ vy_{k-1} + a_y t \end{bmatrix} + w_{k-1} = Ax_{k-1} + Bu_{k-1} + w_{k-1}, \qquad (3.14)$$

where d_x, d_y, v_x, v_y are the position and velocity of target in x and y coordinates, respectively.

The state transition matrix is: $A = \begin{bmatrix} 1 & t & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & t \\ 0 & 0 & 0 & 1 \end{bmatrix}$.

The control input matrix is: $B = \begin{bmatrix} \dfrac{t^2}{2} & 0 & 0 & 0 \\ 0 & t & 0 & 0 \\ 0 & 0 & \dfrac{t^2}{2} & 0 \\ 0 & 0 & 0 & t \end{bmatrix}$. The input vector is $u_k = [a_x, a_x, a_y, a_y]^T$, with

a_x and a_y are the target accelerations in x and y coordinates, respectively, and $w = \aleph(0, Q)$ is the process noise with covariance matrix Q .

The radars can only measure the distance from target to radars (i.e. $z_k = [r_1, r_2]^T$). Thus, the relationship between the target distances measured by the radars and target position is given by the measurement equation:

$$z_k = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = g(x_k) + v_k = \begin{bmatrix} \sqrt{(dx - X_1)^2 + (dy - Y_1)^2} \\ \sqrt{(dx - X_2)^2 + (dy - Y_2)^2} \end{bmatrix} + v_k, \qquad (3.15)$$

where $v_k = \aleph(0, R)$ is the measurement noise with covariance matrix R. It can be seen that, the measurement equation is non-linear. Therefore, the EKF algorithm must be applied to estimate the target state. Similar to the conventional KF algorithm, the EKF algorithm contains time update step and measurement update step, as follow:

- Time update:
  - (1) Initial state and error covariance: $x_{k-1}^{\sim}$, P_{k-1}.
  - (2) Project the state ahead: $x_k^{\wedge} = f\left(x_{k-1}^{\sim}, u_{k-1}\right)$.
  - (3) Project the error covariance ahead: $P_k^{\wedge} = AP_{k-1}A^T + Q$.
- Measurement update:
  - (1) Compute the Kalman gain: $K_k = P_k^{\wedge} H_k^T \left(H_k P_k^{\wedge} H_k^T + R\right)^{-1}$.
  - (2) Update estimate with measurement z_k: $x_k^{\sim} = x_k^{\wedge} + K\left(z_k - g\left(x_k^{\wedge}\right)\right)$.
  - (3) Update the error covariance: $P_k = (I - K_k H_k) P_k^{\wedge}$.

By using the Taylor series approximation, the measurement matrix H_k is a Jacobian matrix:

$$H_k = \begin{bmatrix} \dfrac{\partial g_1}{\partial x_k} \\ \dfrac{\partial g_2}{\partial x_k} \end{bmatrix} = \begin{bmatrix} \dfrac{dx_k - X_1}{\sqrt{(dx_k - X_1)^2 + (dy_k - Y_1)}}, 0, \dfrac{dy_k - Y_1}{\sqrt{(dx_k - X_1)^2 + (dy_k - Y_1)}}, 0 \\ \dfrac{dx_k - X_2}{\sqrt{(dx_k - X_2)^2 + (dy_k - Y_2)}}, 0, \dfrac{dx_k - Y_2}{\sqrt{(dx_k - X_2)^2 + (dy_k - Y_2)}}, 0 \end{bmatrix}. \quad (3.26)$$

4. Experimental results

To demonstrate the localization and tracking algorithms, the experiments are set up as Figure 16. Two radars are placed orthogonally. The first and second radar positions are (0 m, 1.5 m) and (1.5 m, 0 m), respectively. For localization, one person considered as a target stands at position (3 m, 3 m), in fact, the person body fluctuates slightly in order the radar does not consider it is a clutter.

For tracking, the target moves with constant velocity from position (2 m, 0.5 m) to (0.5 m, 2 m) in the range of two radars. The raw data captured by radars are processed by clutter reduction, detection, and distance conversion steps before they are fed to the localization and tracking step.

Figure 17 shows the localization result, in which the blue points indicate the estimated target positions by the EKF, the red points indicate the measured target positions without using EKF, and green points indicate the true target position. The RMSE of measured target positions without EKF and true target position, and RMSE of estimated target positions with EKF and true position, in x and y directions are provided in Table 8. It is clear that the estimated target positions by EKF are closed to the true position.

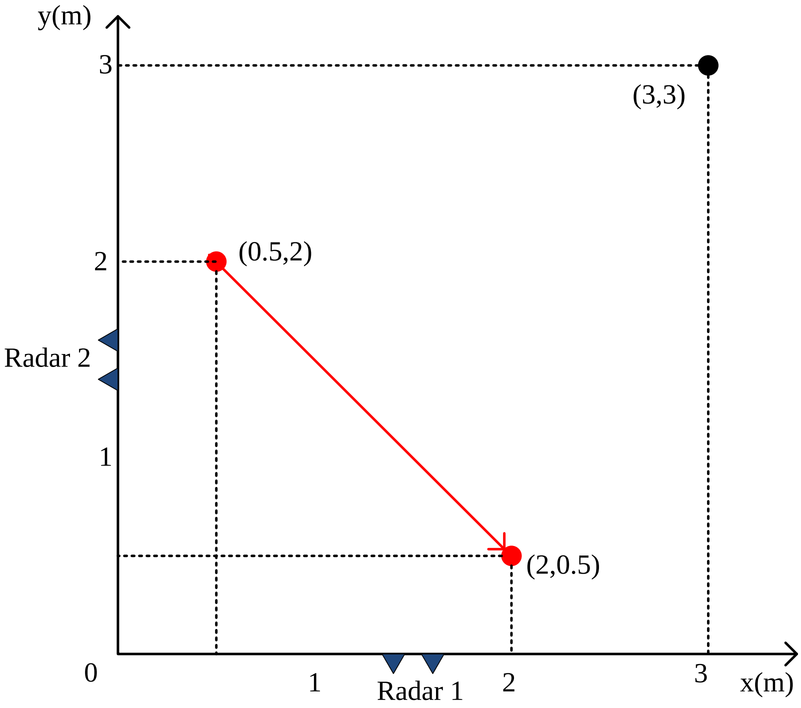


Figure 16: Experiment of localization and tracking of target in 2-dimesion coordinates

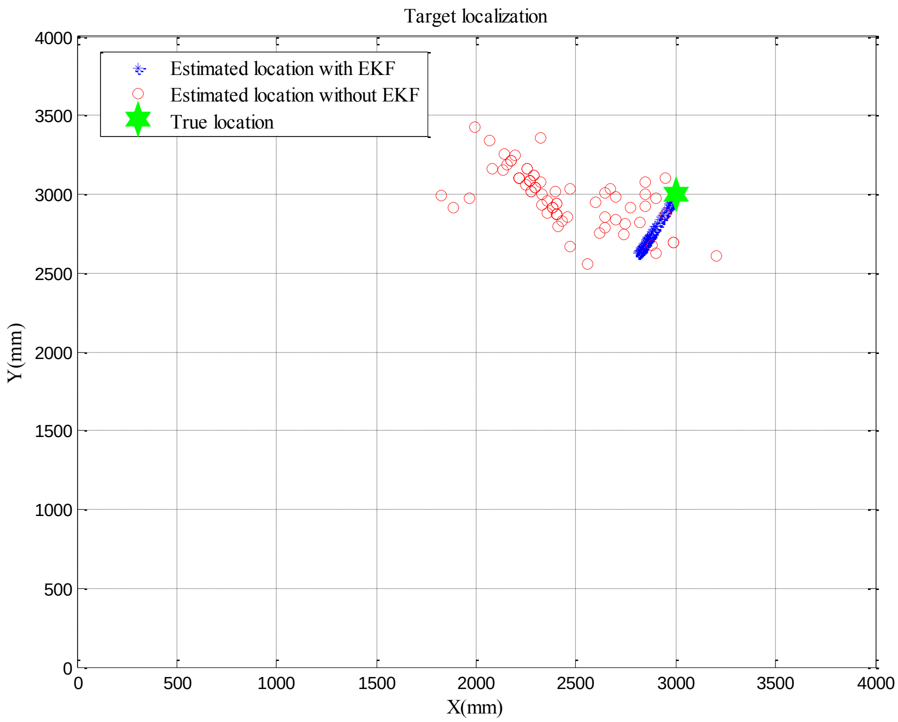


Figure 17: Localization of target in 2-dimesion coordinates

Table 8: Comparison of RMSE between estimated target location with EKF and true target location, and RMSE of measured target location without EKF and true target location

Localization	RMSE	
	x-coordinator	y-coordinator
Estimated position with EKF	142.1134	284.2269
Measured position without EKF	630.7734	175.1673

The tracking of one target is shown in Figure 18. In this Figure, the blue points present the estimated target trajectory by EKF, the red points present the measured target trajectory without EKF, and green points present the true target trajectory. It is clear that the estimated target trajectory by EKF is closed to true target trajectory.

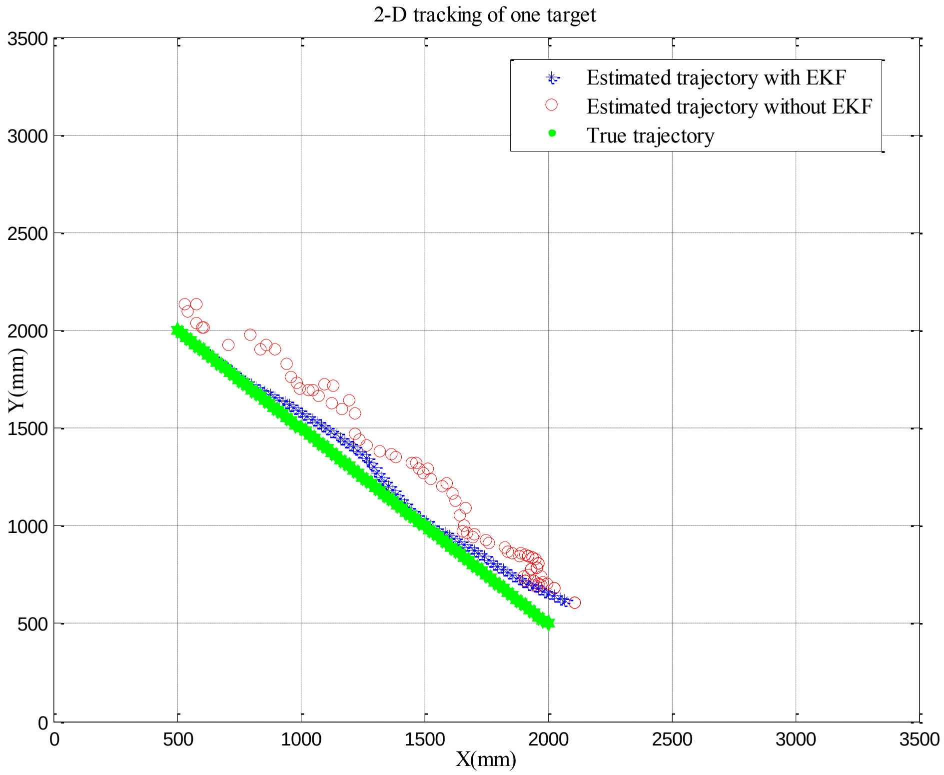


Figure 18: Tracking of target in 2-dimesion coordinates

Table 9 shows the RMSE of estimated target trajectory by EKF and true target trajectory in comparison with RMSE of measured target trajectory without using EKF and true target trajectory. The RMSE of estimated trajectory by EKF is smaller than the RMSE of the measured trajectory without using EKF. Therefore, the tracking algorithm by using EKF provides better performance in target trajectory estimation in comparison with measured target trajectory without using EKF.

Table 9: Comparison of RMSE between estimated target trajectory with EKF and true target trajectory, and RMSE of measured target trajectory without EKF and true target trajectory

Tracking	RMSE	
	x-coordinator	y-coordinator
Estimated trajectory with EKF	28.7626	54.8042
Measured trajectory without EKF	310.4183	133.3987

This section provided the last steps in the signal processing procedure which are the localization and tracking. By using the sets of KF and EKF algorithms, it can be seen that, the estimated target location and trajectory are closed to the true target location and trajectory.

IV. Conclusions

Detection, localization and tracking of moving target are important applications for many purposes, such as: rescues, emergencies, and securities. This thesis proposed the improved target detection for moving objects based on IR-UWB radar methods. In addition, it provides the tracking in 2-dimensional coordinates. The most challenge in IR-UWB radar signal processing is that the far target signal is as small as noise. The proposed method overcomes this problem by using the compensation and jumping window method. After processed by clutter reduction and detection step, the target distance is determined and fed to the localization and tracking step. Firstly, the target distance observed by one radar is tracked. Secondly, using two radars, the target position and trajectory are determined and tracked in 2-dimension coordinates. The experiment results verified that the signal processing steps give the good performances.

This thesis is limited in detection and tracking of single target. However, in practical, it is needed to detect and track of multiple targets in many scenarios. The most difficulty of multiple targets detection and tracking is the target association. That is the assignment of each target features into its own. In multiple targets detection and tracking, the target tracks can intersect and affect with others. Therefore, the future work will concern with the multiple targets detection, localization and tracking. Because UWB signal can penetrate through the wall and obstacle, it is possible for through the wall detection and imaging of object. Besides that, UWB has ultra fine spatial resolution. It makes UWB can be used to detect a small movement. Such property of UWB can be applied in healthcare applications such as: heart beat detection, heart beat counting, and imaging. All these mentioned applications have been researching around the world and would be our works in the future.

List of Publications

Nguyen Van Han, Dong-Min Kim, Goo-Rak Kwon and Jae-Young Pyun, "Clutter Reduction on Impulse Radio Ultra Wideband Signal," *the 28th International Technical Conference on Circuits/Systems, Computer and Communications (ITC-CSCC 2013)*, Yoesu, South Korea, July 2013.

Nguyen Van Han, Kang Hui Seon and Jae-Young Pyun, "Performance Comparison of Movement Detection Methods using IR-UWB Radar",proceeding of *KISM Fall Conference*, Kunsan, South Korea , Nov. 2013, pp. 55-57.

Nguyen Van Han and Jae-Young Pyun, "Improved Target Detection for Moving Object in IR-UWB Radar", *International Conference on Green and Human Information Technology 2014 (ICGHIT'14), Ho Chi Minh City*, Vietnam, Feb. 2014, pp. 69-73.

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South Korea, May 2014

Nguyen Van Han

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