Indoor Real-time Multiple Moving Targets Detection and Tracking Using UWB Antenna Arrays

Shengchang Lan, Caitian Yang, Beijia Liu, Jinghui Qiu, Alexander Denisov
Department of Microwave Engineering,
Harbin Institute of Technology
Harbin, Heilongjiang, China
lansc1015@hit.edu.cn;yangcaitian@hit.edu.cn; liubeijia@hit.edu.cn;qiujh@hit.edu.cn;alex_denisov2009@ukr.net

***Abstract*—The paper describes an approach of indoor multiple moving target detection and tracking using Ultra Wideband(UWB) signals. The approach utilizes estimating the time of arrival(TOA) of the UWB pulses through a linear antenna array, providing a real-time computation of moving targets position in X-Y plane. The results of the proposed approach show a reliable and responsive performance in monitoring the indoor multiple targets motions.**

***Index Terms*—indoor multiple moving target, detection and tracking, UWB, linear antenna array**

I. Introduction

In the application of Ultra Wideband(UWB) radar systems, detecting and tracking moving target are essential parts of through-wall radars, indoor monitoring and surveillance systems for industry and civil utilizations. For these purposes, time of arrival(TOA) is traditionally used to show the target positions due to the fact that TOA indicates the distance that the pulses spread over from being transmitted, reflected and received[1-2]. This principle is also included in the radar signal processing procedure. However, due to the complexity of indoor environment, the spreading pulses are scattered not only by the targets, but also scattered by the objects in the scenario such as furniture, walls and gates. Hence, multi-path effect is considered as the primary disturbance when moving targets are detected and tracked. Accurate detection and tracking approaches require eliminating the unnecessary multi-path effect. In addition, each target should be clearly identified from the echoes in the different receiving channels. Whereas in the case of multiple targets, reflections only from the one situated close to the receiving antenna is seen[3]. Detectors are frequently so insensitive with the weak reflections from the distant targets that some targets in this case are possibly disposed.

To solve these problems, this paper presents an approach of using UWB antenna arrays to detect and track the indoor multiple moving targets. The paper is organized as follows. Firstly, a 0.8 GHz to 2.4 GHz UWB radar system with linear antenna array is introduced in Section II. Section III shows the signal processing procedures of the echoes and TOA estimations. Section IV describes how to detect and localized potential targets based on the estimations which come from the anternna array. In Section 4, performance of the proposed strategy is evaluated by using the UWB radar system to detect and track two persons walking indoors with the area of $5m \times 5m$. Finally, Section V provides the concluding remarks.

II. UWB Radar and Antenna array

This section is to briefly introduce the UWB antenna array and the signals for detecting and tracking the targets. The system yielded a linear antenna array composed of 1 transmitting antenna and 8 receiving antenna[4]. The transmitting antenna was located in the center with 4 receiving antenna uniformly placed aside. The distance between each receiving antenna is $20cm$. As the core part, a digital sampling converter is used to control the periodical signal transmissions and receptions and meanwhile to measure the time delay over the path. The digital sampling converter generates a narrow pulse once two micro seconds, the width of which is only $300ps$. This feature can provide such a wide band signal with the frequency band as high as 3 GHz. Fig. 1 and Fig. 2 respectively show the system configuration and the device photo. Fig. 3 describes the profile of one UWB pulse transmitted from the antenna.

III. Radar signal processing procedures

In the application of this system, moving targets some distance away can be detected and tracked, even if the targets are blocked by the wall or furniture. Given such an indoor environment, when a single pulse is transmitted, the received signal is generally composed of echoes scattered by the desirable targets, echoes reflected by the stationary backgrounds and noise. If we define the pulse transmitted as $p(t)$, the received signal from receiving channel $m, m \in [1, 8]$ is expressed as the summation of all types of echoes and noise,

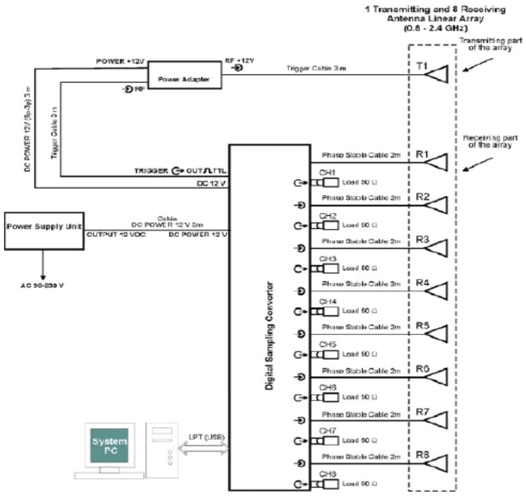

Fig. 1. The profile of the pulse transmitted.

Fig. 2. The profile of the pulse transmitted.

shown as Eq. (1).

$$r_m(t) = a_d p(\omega_d(t-\tau_{(m,d)}))+\sum_{n=1}^{L} a_n p(\omega_n(t-\tau_{(m,n)}))+n(t) \quad (1)$$

where τ_d, ω_d and a_d are the arrival time, frequency gain and amplitude gain of the signal scattered by the desirable targets, and similarly, τ_n ,ω_n and a_n are those scattered by the nth stationary objects in the background such as sofas, tables and walls, L denotes the number of these stationary objects existed in the scenario, $n(t)$ is assumed as additive white Gaussian noise. Here, to be noticed, Eq. (1) presents that both the frequency band and amplitude of the original pulse are altered after being scattered. Focusing on the moving targets, we mainly are interested with $a_d p(\omega_d(t-\tau_{(m,d)}))$ in Eq. (1), as $\tau_{(m,d)}$ contains the potential positions of the moving targets at time t. On the contrary, echoes by the stationary objects are considered as the interference of multi-path effects. To eliminate the multi-path effects, $r_m(t)$ is

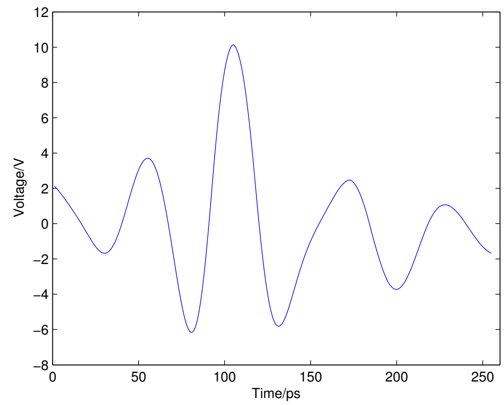

Fig. 3. The profile of the pulse transmitted.

filtered by multiplying a time window of size T. According to the potential target position, this time window can intercept a period of data from $r_m(t)$ to ignore the data outside the window. T determines the observable motion area of the targets. Assuming the time window as $w(\tau_d, T)$, Eq. (1) is further derived as,

$$\begin{aligned} r_{(m,w)}(t) &= r_m(t) \times w(\tau_{(m,d)}, T) \\ &= a_d p(\omega_d(t-\tau_{(m,d)})) + \sum_{n=1}^{\hat{L}} a_n p(\omega_n(t-\tau_{(m,n)})) + n(t) \end{aligned} \quad (2)$$

where $\hat{L}$ is the number of the remaining stationary objects.

From Eq. (2), it is known that adding time window is helpless when the block objects are placed in the motion area. However, by means of subtracting $r_d(t)$ at two neighbour time instances, the effect of the block objects are greatly minimized as they are stationary. To benefit the echoes, square-law detections can be yielded. Fig. 4 shows the profile of signals captured by the eight receiving antenna after subtraction and square law detections.

$$\begin{aligned} R_{(m)}(t) &= [(r_{(m,w)}(t) - r_{(m,w)}(t-\Delta t)) \times w(\tau_{(m,d)}, T)]^2 \\ &= [a_d(p(\omega_d(t-\tau_{(m,d)})) - p(\omega_d(t-\Delta t-\tau_{(m,d)}))]^2 + n(t) \end{aligned} \quad (3)$$

From Fig. 4, it is believed that the peaks in the echoes are corresponding to the moving targets. When a moving target appears in the scenario, the echoes should change violently because of the varying τ_d. By measuring the peak positions, TOAs of potential targets e can be obtained.

IV. Moving Target Detection and Localization

As mentioned in the section above, the basic principle of TOA measurements is to search the pulses in the echoes, which represents the existence of the targets in the scenario.

A. Target Detection

For detecting the moving targets, a Constant False-Alarm Rate(CFAR) detector is designed. The detector is applied on

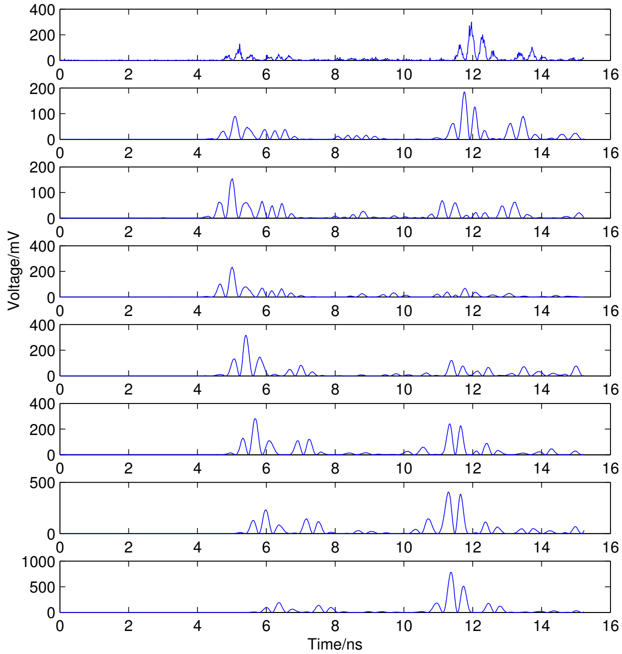

Fig. 4. the profile of signals captured by the eight receiving antenna after substraction and square law detections.

the echoes chopped by the window in the time domain. If a moving target is present in the monitored area, the detector binary output for channel m, $C_m(t)$, should be set as values "1", otherwise as "0"[5]. Fig. 5 describes the CFAR output of all the receiving channels. Shown as Fig. 5, the detection result by CFAR is non-continuous set of value "1". But it is believed that one moving target like a middle size person can have a scattering area of $1m \times 2m$. This scattering area means that all the peaks in the time domain caused by the target motions should be within $3ns$.

Owing to $C_m(t)$, we can determine the presence of the moving target at channel m. The criterion can be summarized in Tab. 1. For the time instance t_0, if the condition in Tab. 1 is satisfied, the number of potential moving targets j increases once. The final value of j is the number of the moving targets detected by the channel used. Here the resolution of the time sequence $t_0 - 1$, t_0, $t_0 + 1$ is dependent on the number of the sampling points and time window length. In addition, the spatial resolution in the desired area is related to this time resolution. Hereby we believed that the number of the sampling points within this time window determines the spatial resolution.

B. Target Localization

Target association is to find the desirable target and its corresponding peaks from the CFAR ouput of all the channels. As seen in Fig. 4, the CFAR output clutter in the time domain of all the channels. For a certain target, due to the different relative distance towards the receiving antenna array, the TOAs of all the channels are not the same. In order to acquire the position that contains two dimension coordinates (x, y), two $R_{(m)}(t)$ are at least required. Let us construct such a X-Y plane, all the receiving antenna labelled as $R1 \cdots, R8$ are linearly placed at X axis and targets are present at the area of $y > 0$. Transmitting antenna is defined as $(0, 0)$. L_i represents the distance from target 1 to the receiving antenna i. c is light speed. We take target i and receiving antenna pair R4, R5 as the example.

$$x = \frac{c^2(TOA_{5,i}^2 + TOA_{4,i}^2) - 0.5 \times D^2)}{2 \times c \times (TOA_{5,i} + TOA_{4,i})} \quad (4)$$

$$y = \frac{c^2 \times \text{TOA}_{(5,1)} - Dx - \frac{D^2}{4}}{2 \times \text{c} \times \text{TOA}_{(5,1)}} \quad (5)$$

However, CFAR output can not be directly applied to confirm the moving targets presence. The reason is that the false detected TOA at one channel might not find the associated TOAs at the paired channel. The drawback stems from the minor peaks, which can also be recognized as the

TABLE I
THE DETERMINISTIC CRITERION OF MOVING TARGET PRESENCE.

for $t_0 = 0$ to T **do**
  if $C_m(t_0 - 1) == 0$ and $C_m(t_0 + 1) == 0$ and $C_m(t_0) == 1$ **then**
    $TOA_{m,j} = t_0 k$
    $j = j + 1$
  end if
end for

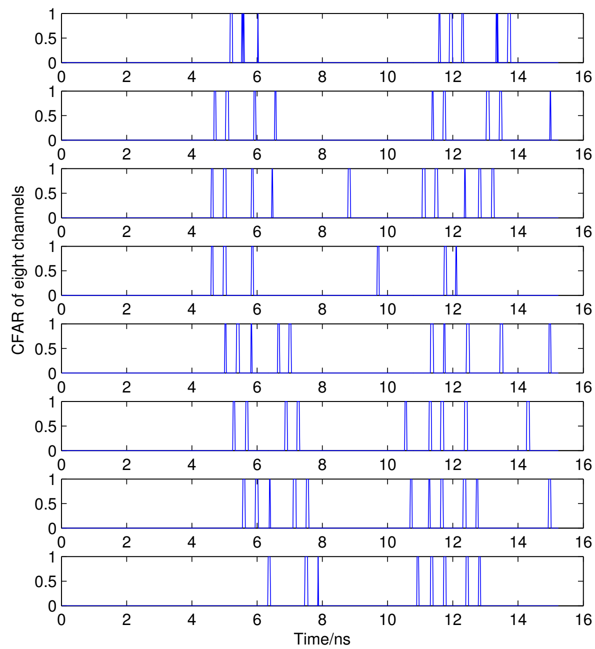

Fig. 5. CFAR output of Fig. 3.

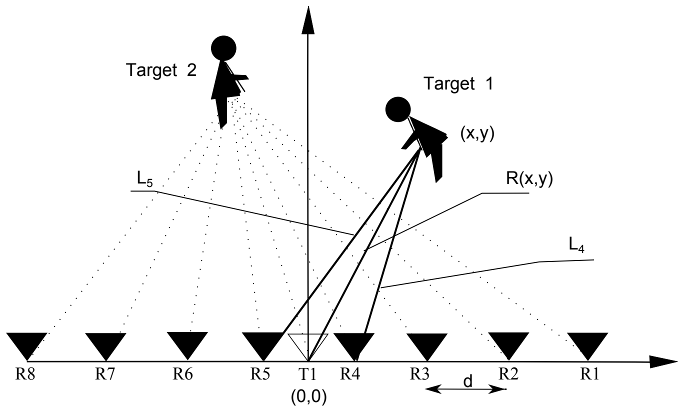

Fig. 6. Localization of moving targets.

presence of the moving target due to the noise. Considering the interference, we propose that TOAs from two channels are less than the multiplication of the distance between two receiving antenna and light speed c.

C. Anternna Array Association

According to the analysis above, each pair of antenna in the array can figure out the position of jth target. Using an array of eight receiving antenna provides the redundancy of the position measured. If we select $(R1, R8), (R2, R7), (R3, R6), (R4, R5)$ as the receiving antenna pairs, then each pair can give the position of jth target. It is theoretical that each target will have 4 groups of position estimation results. However, only one result is enough for tracking the position of the targets. Redundant estimation results actually increase the measurement accuracy. The simplest way is to average to estimated positions. Also it is suggested that using Kalman-filters helps to refine the coarse estimations for better results.

V. Performance Evaluations

The performance of the proposed approach is demonstrated by using the UWB antenna array introduced in Section 2. Based on the approach, the experiment is to evaluate the performance of detecting and tracking two walking persons in the indoor area of $5m \times 5m$. All the receiving antennas are divided into 4 pairs, e.g.,$(R1, R8), (R2, R7), (R3, R6), (R4, R5)$. Once all the pairs process the receiving signals, estimate the TOAs of the potential targets, and compute the average of the positions related to each potential targets. In this scenario, two targets are moving independently. One target is moving straightly from center of the area to left bottom corner, marked as $(-2, 1)$; the other target is showing up in the scenario at right bottom corner, marked as (3,1), and then continues walking straightly to cross the area and disappears at the middle of the border furthest to the antenna array. Following the motions, the UWB antenna array gives the real time detecting and tracking results, shown in Fig. 7. On the one hand, two walking persons can be identified. Also the tracks

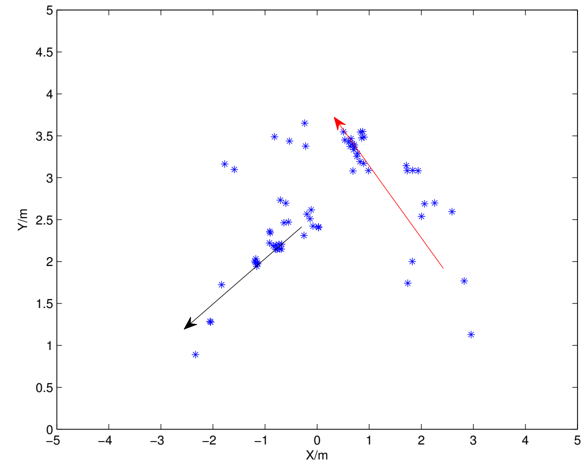

Fig. 7. Performance Evaluation result of real-time detecting and tracking two walking persons indoors.

of the motions can be clearly recorded and matches the real motions well.

VI. Conclusion

In this paper, a novel approach of detecting and tracking multiple moving targets has been introduced by using UWB antenna array. The major benefits are identifying multiple targets and real-time locating the targets. This approach is only based on time-domain measurement, which also accelerate the computation speed. The presented experimental results have illustrated the performance of the approach in the indoor scenario of two walking persons. The comparison of the real and estimated motions has confirmed the effectiveness of the approach.

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