Kalman-based Moving Object Tracking Using Nonuniform Pulse Transmission Scheme

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Abstract - **This paper presents a radio-based real-time moving object tracking method based on Kalman filtering using phase-difference compensation technique and nonuniform pulse transmission scheme. Conventional methods often require time, amplitude, phase information and their derivatives for each receiver antenna, however its location estimation accuracy does not become good even with many transmitting pulses. The present method employs relative phase-difference information and nonuniform pulse generation scheme, which can greatly reduce the number of transmitting pulses while preserving the tracking accuracy. Performance of the proposed method is evaluated in comparison with that of the conventional method.**

1. Introduction

Moving object tracking is a significant technique in wireless communication applications like mobile terminal position detection, and now is also applied to many different kind of applications. Sports is one of such applications where the players can be regarded as moving objects, and has nowadays become an immense branch of business especially in football game. Important incidents during a game often cannot be recognized neither by human eye nor with state-of-the-art camera techniques. Therefore the accurate tracking of moving players becomes important for football game analysis.

In this paper, we present a novel, accurate and radio-based moving object tracking method based on Kalman filtering, using phase-difference compensation technique and nonuniform pulse transmission scheme. Performance of the proposed method is evaluated in comparison with that of some conventional methods.

2. Conventional Approach

The system [1] consists of a set of small and lightweight transmitters (objects to be located) and a receiving infrastructure that is set up around the area of interest, which may be the inner part of a football stadium. The miniature transmitters make use of this bandwidth by generating short but broadband signal bursts of pulse-shaped sequences with the time interval *dt* as in Fig. 1(a).

Suppose that we have L receiver antennas. The conventional system [1] tracks the moving objects based on Kalman filtering with its state vector at the time $t = kdt$:

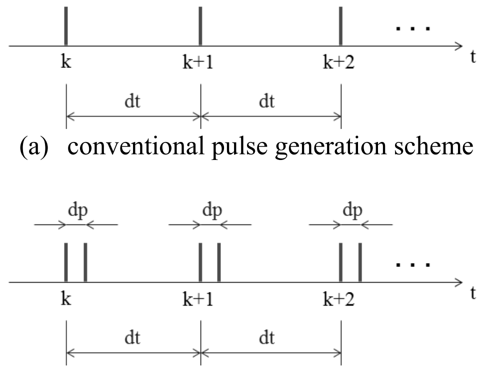


Fig. 1. Pulse generation scheme.

$$\boldsymbol{x}_{i,k} = \left[t_{i,k}, M_{i,k}, \phi_{i,k}, \dot{t}_{i,k}, \dot{\phi}_{i,k} \right]^T, i = 1, 2, ..., L \quad (1)$$

where $t_{i,k}, M_{i,k}, \phi_{i,k}$ respectively denote the delay time, amplitude and carrier phase, with the two derivatives for delay time $\dot{t}_{i,k}$ and for carrier phase $\dot{\phi}_{i,k}$ at the *i*-th receiver antenna element. The magnitude and phase terms in (1) are used to suppress multipath components as mentioned in [1].

3. Proposed Approach.

In this section, we describe the proposed tracking method: first the state vector formulation in Kalman filtering, and then the nonuniform pulse generation scheme for phase-difference compensation.

(1) State Vector with Phase-Difference

We newly introduce the phase-difference information into the state vector in Kalman filtering, instead of the absolute phase characteristics of each antenna used in (1). Here we employ the relative phase-difference between antenna elements, and also the delay time index is replaced by the TDOA (time difference of arrival) between antenna elements.

Let $t_{mn,k}$ $(m, n = 1, 2, ..., L, m < n)$ denote the TDOA between the antennas #*m* and #*n*. Then we replace the derivative $\dot{t}_{mn,k}$ by the relative phase-difference information. To estimate $t_{mn,k}$, the state vector in (1) can be modified into

$$\boldsymbol{x}_{mn,k} = \left[t_{mn,k}, \Delta\phi_{mn,k}, \Delta\dot{\phi}_{mn,k} \right]^T \quad (2)$$

where $\Delta\phi_{mn,k}$ is the relative phase-difference between the *m*-th and *n*-th antenna elements during the time from $(k-1)dt$ to kdt.

(2) Nonuniform Pulse Generation

The proposed state vector (2) still has a problem that we cannot specify the phase-differences which are out of the range $[-\pi, \pi]$. It happens when we use large carrier frequency f_0 or small number of samples N per a second.

To correctly estimate the phase-difference out of $[-\pi, \pi]$, we employ the nonuniform pulse configuration which is generated and transmitted from the miniature moving objects as illustrated in Fig. 1(b) instead of the uniform pulse configuration in Fig. 1(a), where dp denotes the fine pulse interval. The additional pulses at the time $t = kdt+dp$, $(k+1)dt+dp$, … in Fig. 1(b) are used to correctly estimate the phase-difference out of $[-\pi, \pi]$.

(3) Tuning TDOA Values by Averaging

The location estimation accuracy is further enhanced by averaging TDOA values. Using the non-uniform pulses in Fig. 1(b), we can observe multiple TDOA values $t_{mn,k}$ and $t_{mn,k+dp}$ as well as the phase difference. Then we calculate the average of the TDOA values:

$$t_{mn,k+\frac{(P-1)dp}{2}} = \frac{1}{P}\sum_{\ell=1}^{P-1} t_{mn,k+\ell dp} \qquad (3)$$

To suppress the noise effect, we hereafter use the above averaged TDOA $t_{mn,k+(P-1)dp/2}$ instead of $t_{mn,k}$. The larger P will achieve better tracking accuracy due to noise suppression effect, which is confirmed in the next section.

4. Simulation

The proposed tracking method is evaluated through simulation in comparison with the conventional method [1]. Specifications of the simulation basically follow the specifications in [1], but some are modified to clearly evaluate the effect of the proposed method as summarized in Table Ⅰ. We assume a football field of 100m×70m, where the center, top-right, bottom-left of the field are specified as (x, y)=(0, 0), (50, 35) and (−50, −35), respectively. Four receiver antennas are installed at (60, 45), (−60, 45), (60, −45) and (−60, −45).

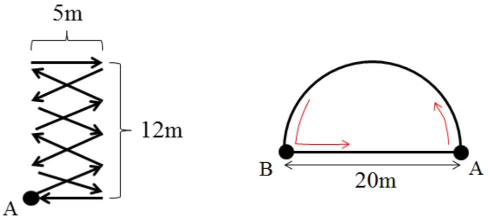
Here we evaluate the tracking accuracy of just one moving object, even the method [1] can track two or more objects. We found that the tracking of multiple objects could be done more accurately when we distinguish multiple objects by code (e.g., Gold code).

The tested motion models are illustrated in Fig. 2. In scenario #1, the object starts from 'A' and takes a second to follow each diagonal or horizontal line. In scenario #2, the object takes 5 seconds to follow the half-circle from 'A' to 'B', and then takes another 3 seconds to move straightly from 'B' to 'A'.

We compare the averaged RMSE(Root Mean Square Error) as summarized in Table Ⅱ. The Table Ⅱ shows that the proposed method achieved much better tracking accuracy than the method cited in [1] and achieved even better results for the method cited in [2]. Table Ⅱ also indicates that a larger value of P leads to smaller error for both scenarios #1 and #2.

TABLE I
Specifications of simulation.

scenario	#1	#2
tested field	100m ×70m	
no. of antennas, L	4	
no. of tags	1	
carrier frequency, f_0	2.4 GHz	
occupied bandwidth, Δf	80 MHz	
sampling frequency	400 MHz	
SNR	23	
CNR	20	
maximum velocity	10 m/sec	
time detection error	Gaussian distribution with σ_t = 0.723 nsec	
phase detection error	Gaussian distribution with σ_ϕ = 4.05 deg	
coarse time interval	0.04sec	
fine time interval	0.003 sec	
# of iteration	251 (= 10 sec)	201 (= 8sec)
modeling of moving objects	Fig. 2(a)	Fig. 2(b)
starting point of objects	(−2.5, −6)	(10, −5)



(a) scenario #1 (b) scenario #2
Fig. 2. Modeling of moving targets.

TABLE Ⅱ
Comparison of the averaged RMSEs.

	Approach			
	Ref. [1]	Ref. [2]	Proposed(P=2)	Proposed(P=3)
Scenario #1	0.2263 m (100%)	0.1030 m (45.5%)	0.0826 m (36.5%)	0.0724 m (31.9%)
Scenario #2	0.2275 m (100%)	0.0945 m (41.5%)	0.0732 m (32.2%)	0.0647 m (28.4%)

5. Conclusion

In this paper, we described our development of a radio-based moving object tracking system using non-uniform pulse transmission and phase difference compensation. We showed how we averaged the observed neighbouring TDOA values and in so doing were able to improve the tracking accuracy over that of a conventional method. Further improving tracking accuracy remains as a subject for future studies.

Acknowledgment

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References

[1] T. Von der Grun, N. Franke, D. Wolf, N. Witt, and A Eidloth, “A Real-Time Tracking System for Football Match and Training Analysis,” *Microelectronic Systems, Circuits, Systems and Applications,* pp. 199-212, Dec. 2011.

[2] K. Ichige, N. Arakawa, and O. Shibata: “Real-Time Moving Object Tracking Using Phase-difference Compensation and Nonuniform Pulse Transmission,” *to appear in International Symposium on Circuits and Systems,* May 2016, (accepted).