



APPLICATION OF ANT SYSTEM AND NEAREST NEIGHBOR KALMAN FILTER FOR MULTI TARGET TRACKING IN MULTI SENSOR RADAR SYSTEM

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ABSTRACT

In multi-sensor radar system, some of the sensor measurements may be incorrect, due to the occurrence of false alarm and miss detection. So the number of targets and which the results of measurements derived from the target is not known for certain. The problem becomes how to determine the number of targets, which in the measurement results are mixed between the correct measurements (derived from the target) and the incorrect (false alarm). This problem is known as a multidimensional assignment problem. To solve this problem required a heuristic method. In this paper the Ant System method is offered to solve the multidimensional assignment problem and the Nearest Neighbor Kalman filter to estimate the target state. Three different target trajectories were used in the simulation using three identical radar. It is found that the Ant system algorithm is able to separate between true and false alarm. Furthermore, the process of estimating the target using the nearest neighbor Kalman filter.

Keywords: multi target tracking, ant system, nn-kalman filter.

INTRODUCTION

The integration or data fusion from multiple sensors has been known to improve accuracy in target tracking, territorial surveillance, or non-defense applications such as industrial process monitoring and medical diagnosis. [1] In a radar system consisting of several sensors, each sensor in one scan will produce information in the form of a plot of objects (e.g. airplanes) passing through the area of the sensor coverage. To pair the points corresponding to the same object in each scan the tracking process is required. The result of the tracking process is the trajectories of objects that in principle the position and velocity of the point. Then the trajectories of the objects generated by the tracking process will be forwarded to a system monitor.

The problem that exists in every sensor is sometimes the noise in a sensor exceeds the detection threshold. If this happens, the noise will be indicated as a target. This is called a false alarm. Conversely, if the signal of the target is less than the detection threshold, the sensor can not detect the target. This is called miss detection. The appearance of false alarms is shown in Figure-1. [2], as well as the miss-detection events shown in Figure-2. [2]

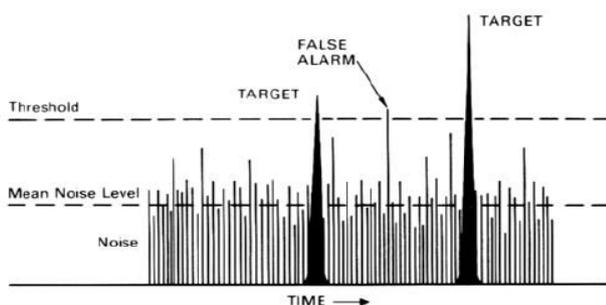


Figure-1. False alarm.

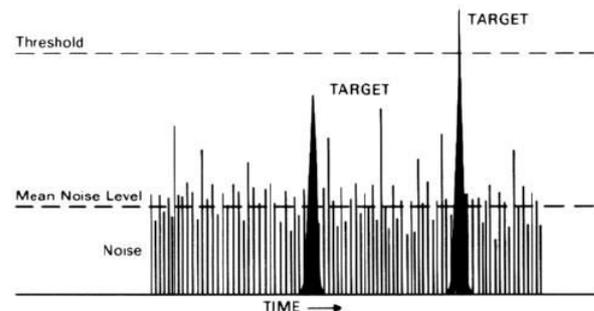


Figure-2. Miss detection.

Therefore, the problem that arises in a multi-sensor radar system is how to determine the correct number of targets, which in the measurement results are mixed between the correct measurements (derived from the target) and false alarms. This problem is known as a multidimensional assignment problem, and to solve this problem requires a heuristic approach algorithm. Several researches for multi targets based on a search methodology to solve multidimensional assignment problems have been made. In these studies using genetic algorithm [3], and tabu search [4]. In some studies applying search methodology, i.e. genetic algorithm (GA), simulated annealing (SA), and ant colony optimization (ACO), for travelling salesman problems show that ACO produces a better solution than other algorithms. [5] Ant Colony Optimization is a new concept in artificial intelligence, which is a model of ant behavior that is known to find the shortest distance between the nest and their food source.

In this paper we will describe how a multi-sensor system combines observational data from multiple sensors and a suggested method for separating between measurements derived from targets and false alarms.



MULTI SENSOR FOR MULTI TARGET TRACKING

Suppose there are N sensors used to find targets in a region. Suppose there are a number of t targets (t unknown) in the observation area, and the position of the target t is $\theta_t = (x_t, y_t, z_t)$. The detection probability of the sensor s is P_{ds} . Suppose that the number of measurements of sensor s is $n_s, s=1,2,3,\dots,N$. The result of the sensor measurement s expressed as $z_{si_s}, i_s=1,2,3,\dots,n_s$; and it is assumed that the measurement is came from the true target plus Gaussian noise $N(0, \sigma_s^2)$.

A target may be undetectable or appear false alarm on every scan. To simplify the notation in describing false alarms and also for incomplete target measurement associations caused by the miss detection, a dummy measurement $z_{s0} (i_s=0)$ is added to each measurement set of each sensor. False alarms of a set of data $Z(k)$ is expressed as Z_{γ_i} with $\gamma_i = (0,0, \dots, 0, i_k, 0, \dots, 0, 0)$, and miss detection is expressed as Z_{γ_i} where $\gamma_i = (i_1, i_2, \dots, i_{k-1}, 0, i_{k+1}, \dots, i_{N-1}, i_N)$.

The cost function to associate N -tuple measurement with a target t is given by

$$c_{i_1, i_2, \dots, i_N} = \sum_{s=1}^N \{u(i_s) [\frac{1}{2} [Z_{i_s} - \hat{\theta}]^T \sigma^{-2} [Z_{i_s} - \hat{\theta}] + \ln \frac{\sqrt{2\pi}\sigma}{P_{ds} \cdot \Psi_s}] - (1 - u(i_s)) \ln [1 - P_{ds}]\} \tag{1}$$

where $u(i_s)$ is the indicator function, which indicates that if $i_s \neq 0$, that the sensor s detects the target t , then $u(i_s) = 1$, otherwise if $i_s = 0$, the sensor s does not detect the target t , then $u(i_s) = 0$. $\hat{\theta}$ is the measurement average, Ψ_s is the field of view of sensor s .

The goal is that a measurement declares as a target or declares as a false alarm, and each measurement is assigned only to one target. This problem can be formulated into the following multidimensional assignment problem [6] minimize:

$$\sum_{i_1=0}^{n_1} \sum_{i_2=0}^{n_2} \dots \sum_{i_N=0}^{n_N} c_{i_1, i_2, \dots, i_N} \chi_{i_1, i_2, \dots, i_N} \tag{2}$$

dengan kendala:

$$\begin{aligned} \sum_{i_2=0}^{n_2} \dots \sum_{i_N=0}^{n_N} \chi_{i_1, i_2, \dots, i_N} &= 1, & i_1 &= 1, \dots, n_1 \\ \sum_{i_1=0}^{n_1} \dots \sum_{i_{k-1}=0}^{n_{k-1}} \sum_{i_{k+1}=0}^{n_{k+1}} \dots \sum_{i_N=0}^{n_N} \chi_{i_1, i_2, \dots, i_N} &= 1, \\ \text{for } i_k &= 1, \dots, n_k \text{ and } k = 2, 3, \dots, N-1 \\ \sum_{i_2=0}^{n_2} \dots \sum_{i_{N-1}=0}^{n_{N-1}} \chi_{i_1, i_2, \dots, i_N} &= 1, & i_N &= 1, \dots, n_N \\ \chi_{i_1, i_2, \dots, i_N} &\in \{0, 1\} & \text{for all } i_1, \dots, i_N \end{aligned}$$

where $\chi_{i_1, i_2, \dots, i_N}$ is a binary association variable, such that $\chi_{i_1, i_2, \dots, i_N} = 1$ if the N -tuple measurement is

associated as a target candidate. Conversely, if N -tuple is not a target candidate $\chi_{i_1, i_2, \dots, i_N} = 0$.

ANT SYSTEM FOR FINDING TRUE TARGETS

Ant system is one of the algorithms of the ACO method that is inspired by the behavior of ant colonies to find the shortest distance between the nest and their food source. Several studies of the application of ACO have been conducted, among others, to solve vehicle route problems [7], tuning the PI controller on three-phase induction motors [8], harmonic compensation [9], and for mobile ad-hoc networks [10]. In this paper the ACO method is offered to find the true target. Here is the ant system algorithm to find the true target.

On the problem of multidimensional assignments in equations (1) and (2), the goal is to find the largest possibility that each measurement is assigned to a one target or the measurement is a false alarm. The largest possibility that a measurement is a target is expressed by a small cost. The minimum amount of cost specifies that the points are target candidates or false alarms. Thus, the data association problem can be represented by the set of cost points, where each of these points represents a possible target. Therefore, the ant will move toward the allowed points (subject to equation (2)) so as to achieve the minimum amount of cost. The following will explain the search process by the ant:

In the first cycle, the initial step is the ants (the number of ants determined arbitrarily) are placed randomly at different points. Next, until the end of the first cycle, the ant will move from point i to point j (which allowed) to consider the visibility,

$$\eta_j = \frac{1}{C_j} \tag{3}$$

where C_j is the cost of point j . Ants will go to the point that have greatest visibility values. The points are not allowed to be stored in the tabu list. After one cycle, the contents of the tabu list are reset. Each one cycle finished, the ant will leave a pheromone trail on every point it visited. After completing one cycle, the ants will die and be replaced by the same number of new ants. In the second cycle and furthermore, the new ants are placed on one of the points visited by the ant in the previous cycle, and will move from point i to point j (which allowed) based on a probability function, named as status transition rule,

$$p_j(t) = \begin{cases} \frac{[\tau_j(t)]^\alpha [\eta_j]^\beta}{\sum_{j \in allowed} [\tau_j(t)]^\alpha [\eta_j]^\beta}; & \text{if } j \in allowed \\ 0; & \text{otherwise} \end{cases} \tag{4}$$

where $\tau_j(t)$ is amount of pheromone of the ant on point j at time t . The parameters α and β used to control relative importance of pheromone and visibility. Thus, after an ant finish its tour in one cycle, the amount of pheromone will be update becomes:

$$\tau_j(t + N) = \rho \tau_j(t) + \Delta \tau_j(t, t + N) \tag{5}$$



where ρ is a coefficient with a value between 0 to 1, such as $(1 - \rho)$ indicates the evaporation of pheromone, and

$$\Delta\tau_j(t, t + N) = \sum_{k=1}^m \Delta\tau_j^k(t, t + N), \tag{6}$$

where $\Delta\tau_j^k(t, t + N)$ is the pheromone left by ant k on point j , by the time between t to $(t+N)$, which is defined as follows:

$$\Delta\tau_j^k(t, t + N) = \begin{cases} \frac{1}{L^k}; & \text{if } j \in \text{tour } k \\ 0; & \text{otherwise} \end{cases} \tag{7}$$

where L^k is the total cost of the tour by the ant k . N is the number of points visited by each ant in a cycle. Total points visited by each ant in one cycle $(N) = 1 + \sum_{i=1}^s n_i$. Where n_i is the number of measurements on the i -th sensor and s is the number of sensors.

The amount of pheromone $at t=0$ for every point that is $\tau_j(0)$, determined equal to the value of its visibility.

Algorithm will stop when all the ants have the same route.

NEAREST NEIGHBOR KALMAN FILTER

The integration of Kalman filter and nearest neighbor (NN) methods is a way of adaptation Kalman filter to track targets based on the uncertainty of the origin of measurement. The NN algorithm needs to know the predictions and innovations of covariance as calculated by the Kalman filter. Thus, the data association unit using the NN algorithm should be integrated after the covariance innovation given.

Nearest neighbor is a non Bayesian method. The closest measurements between validated measurements and predicted measurements are chosen according to the measure of the distance given by equation (8)

$$D(z_k) = [z_k - z_{k+1}]^T Q^{-1} [z_k - z_{k+1}] \tag{8}$$

The Kalman filter model assumes that the true state at time k is composed of state at time $(k - 1)$ with the following equation

$$x_k = F_k x_{k-1} + B_k u_k + G_k w_k, \tag{9}$$

where,

- F_k is the state transition matrix used in the previous state x_{k-1} ;
- B_k is the control-input matrix used in the control vector u_k ;
- G_k is the noise excitation matrix and w_k is the noise on the process assuming zero mean with covariance Q_k . $w_k \sim N(0, Q_k)$

At time k , an observation or measurement z_k of true state x_k is modeled by equation,

$$z_k = H_k x_k + v_k \tag{10}$$

where H_k is observation model observasi that mapping true state space into the observation space and v_k is observation noise which assumed zero mean Gaussian white noise with covariance R_k . $v_k \sim N(0, R_k)$.

The initial state, and the vector noise at each step $\{x_0, w_1, \dots, w_k, v_1 \dots v_k\}$ are all assumed to be independent of each other.

SIMULATION

In radar system modeling assumed that the radar system uses three sensors to find the target. The number of measurements of each sensor is expressed as n_s , with $s=1, 2, 3$. The measurement result of each sensor is expressed as z_{s,i_s} , $i_s = 1, 2, 3, \dots, n_s$. Thus, the data association problem can be formulated as the following multidimensional assignment problem,

$$c_{i_1, i_2, i_3} = \sum_{s=1}^3 \{u(i_s) [\frac{1}{2} [Z_{i_s} - \hat{\theta}]^T \sigma^{-2} [Z_{i_s} - \hat{\theta}] + \ln \frac{\sqrt{2\pi}\sigma}{P_{ds} \Psi_s} - (1 - u(i_s)) [1 - P_{ds}]\}, \tag{11}$$

minimize:
 $\sum_{i_1=0}^{n_1} \sum_{i_2=0}^{n_2} \sum_{i_3=0}^{n_3} c_{i_1, i_2, i_3} \chi_{i_1, i_2, i_3}$ (12)

Subject to:

$$\begin{aligned} \sum_{i_2=0}^{n_2} \sum_{i_3=0}^{n_3} \chi_{i_1, i_2, i_3} &= 1, & i_1 &= 1, \dots, n_1 \\ \sum_{i_1=0}^{n_1} \sum_{i_3=0}^{n_3} \chi_{i_1, i_2, i_3} &= 1, & i_2 &= 1, \dots, n_2 \\ \sum_{i_1=0}^{n_1} \sum_{i_2=0}^{n_2} \chi_{i_1, i_2, i_3} &= 1, & i_3 &= 1, \dots, n_3 \\ \chi_{i_1, i_2, i_3} &\in \{0, 1\} & \text{for all } i_1, i_2, i_3 \end{aligned}$$

The multidimensional assignment problem above will be solved by using the ant system method to get the target number (separating between the true targets and false alarms). Figure-3 shows the results of the selected measurements after running the ant system algorithm up to 100 scans.

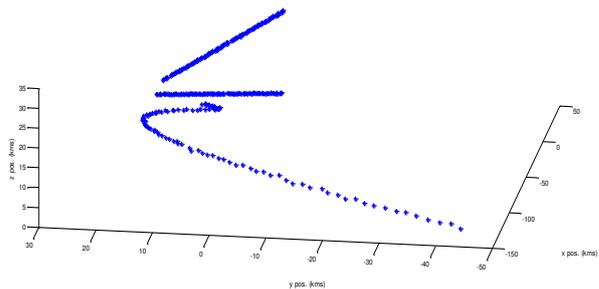


Figure-3. Selected measurements up to 100 scans.



Next, NN-Kalman Filter process to estimate the target state. Figure-4 shows the target estimation result using NN-Kalman Filter. Figure-5 shows the estimation results for target that moving with constant velocity and Figure-6 shows estimation results for target that maneuvered. It appears that for constant velocity targets the estimation results are better than the measurement results. On maneuvered targets, the estimation is more precise, but the estimated target trajectory shifts slightly from the actual target trajectory.

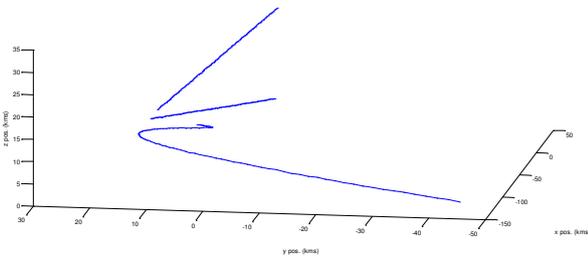


Figure-4. Estimation result using NN-Kalman filter.

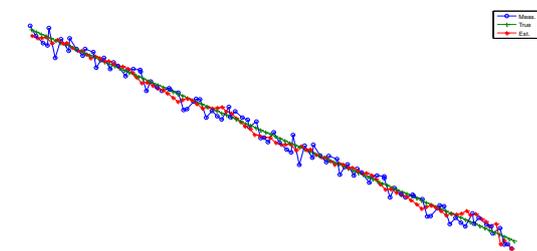


Figure-5. Target estimation with constant velocity.

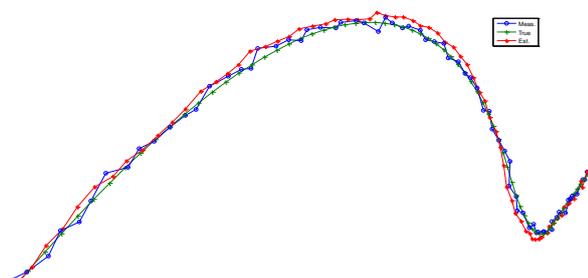


Figure-6. Estimation result for maneuvered target.

CONCLUSIONS

In this research has been successfully applied ant system algorithm to solve multidimensional assignment problem that happened in multi radar sensor system. The ant system is capable of determining which measurement results come from the target and which are the false alarms. In target state estimates for maneuvered targets, estimates are more precise than measurement results but slightly shifted from the true target trajectory.

REFERENCES

- [1] D.L. Hall and J. Llinas. 2001. Multisensor Data Fusion, Handbook of Multisensor Data Fusion, New York, CRC Press. pp. 1-10.
- [2] G.W. Stimson. 1998. Introduction to Airborne Radar. 2nd Ed., New York, Scitech Publishing Inc.
- [3] G. Chen, L. Hong. 1997. A Genetic Algorithm based Multi-dimensional Data Association Algorithm for Multi-sensor Multi-target Tracking, Pergamon, Mathl. Comput. Modelling. 26(4): 57-69.
- [4] I. Turkmen K. 2006. Guney Tabu search tracker with adaptive neuro-fuzzy inference system for multiple target tracking, Progress in Electromagnetics Research, PIER. pp. 169-185.
- [5] E. Bonabeau, M. Dorigo, G. Theraulaz. 1999. Swarm Intelligence: from natural to artificial systems, New York, Oxford University Press.
- [6] R.L. Popp, K.R. Pattipati, Y. Bar-Shalom. 2001. m-Best S-D Assignment Algorithm with Application to Multitarget Tracking, IEEE Transactions on Aerospace and Electronic Systems. 37(1): 22-39.
- [7] T. Pellonpera. 2014. Ant Colony Optimization and The Vehicle Routing Problem, University of Tampere, School of Informatics Sciences, M.Sc. Thesis.
- [8] J. Kour, S. Tiwari. 2014. Performance Comparison of Variants of Ant Colony Optimization Technique for Online Tuning of a PI Controller for a Three Phase Induction Motor Drive. International Journal of Computer Science and Information Technologies. 5(4): 5814-5820.
- [9] A.K. Tiwari, S.P. Dubey. 2016. Ant Colony Optimization Based Hybrid Active Power Filter for Harmonic Compensation. International Conference on Electrical, Electronics, and Optimization Techniques.
- [10] S. Jena, J.K. Lakra. 2009. Application of Ant Colony Optimization Technique for MANETS. National Institute of Technology Rourkela, Bachelor Thesis.