Improved N-Best Multiple Hypothesis Tracking Algorithm

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Abstract
In the tracking process of the multi-hypothesis tracking algorithm, many hypothesis are made about the correlation between the track and the measured values. Although its tracking performance is better than other tracking algorithms, it needs a lot of computation time and memory resources when tracking multiple targets or in environments with large clutter due to exponential growth of hypothesis. In view of this situation, an improved N-Best algorithm is proposed to be applied to MHT. The simulation results show that this method can reduce the computation time and realize the track correlation, so it has certain practicability.

1. Introduction
Data association is an important part of multi-sensor multi-target tracking. Classical measuring-track correlation methods mainly include the nearest neighbor method, joint probability data association, neural network method, fuzzy logic method and multiple hypothesis[1] method. More and more researchers attach importance to the multi-hypothesis tracking algorithm because of its simple principle. Multiple hypothesis tracking is established through a finite length time sliding window, and the techniques of hypothesis evaluation and hypothesis management (deleting, merging, clustering, etc.) are used to achieve multi-target tracking.

In recent years, the research of MHT technology focuses on the effective implementation of hypothesis management technology. Although effective hypothesis management can alleviate the rapid increase of computation and storage caused by hypothesis splitting to a certain extent, when the number of targets and clutter is large, the splitting process of high-dimensional poly matrix still needs a long computation time, which makes the splitting process very complicated. In view of this situation, this paper studies how to further optimize the high-dimensional poly matrix before the hypothesis management process to reduce the computational load, and proposes an improved N-Best MHT technique.

2. Measurement and track association
In the process of multi-target tracking, the measure-track correlation as shown in Fig. 1 is often encountered. In Fig. 1, the sensor receives 6 measurements simultaneously in the detection area and needs to update the 3 known tracks. The purpose of the measure-track correlation is to determine the correspondence between the six measurement information and the three tracks. Since the measurements received may come not only from the three known tracks, but also from clutter and, in the case of an uncertain number of current targets, from new targets. When several measurements fall into the tracking gate of one or several targets, there will be many different combinations of measurements and tracks,
which will make the track updating process very complicated.

Fig. 1 Schematic diagram of measure-track association

3. N-Best MHT

The common MHT implementation algorithms include N-Best MHT algorithm, path-oriented MHT and its improved algorithm, multi-dimensional allocation algorithm and Bayesian MHT algorithm, etc[3]. This paper mainly studies the improvement of MHT algorithm based on N-Best.

The core idea of N-Best MHT algorithm is to suppress the exponential growth trend of the hypothesis number with time by deleting the low probability hypothesis at each moment and retaining the optimal hypothesis. Given n(t-1) hypotheses at time t, the number of hypotheses at time t can be limited to n(t). Wherein, n(t-1) and n(t) represent the number of hypotheses retained at the time of t-1 and t, respectively; N is a variable parameter, which can be given in advance or selected adaptively. The structure of N-Best MHT algorithm is shown in Figure 2.

Fig. 2 N-Best MHT algorithm structure diagram

The algorithm mainly includes 7 key steps: (1) preprocessing and initialization of the priori target, and generating initial hypothesis. (2) Receive new measurement data sets. It includes target measurement data and interference data. (3) Target data update. (4) A new cluster is formed, which contains possible tracks and the measurements associated with these tracks. (5) To form a new hypothesis set of data association and calculate the probability of each hypothesis. (6) N-Best algorithm is used to delete the generated correlation hypothesis, delete the low probability hypothesis, and retain
N optimal hypothesis. The N-Best hypothesis is formed as shown in Figure 3. (7) Simplify the hypothesis matrix in each cluster, convert the possible target with probability of 1 into certain target, and create new cluster for target.

4. Improved N-Best MHT

At present, most of the research on MHT algorithm focuses on the effective hypothesis management (hypothesis deletion and merger), that is, step(6). However, when the number of targets and clutter is large, step (4) will produce a polymer matrix with a higher dimension, which makes the meter-track correlation appear many different combinations, making the subsequent steps more complicated. Therefore, the higher the dimension of poly matrix generated by step (4) is, the more hypotheses are generated and the longer the execution time of the algorithm is. On the contrary, the algorithm execution time is shorter. In view of the above situation, this section studies how to reduce the dimension of poly matrix when the number of targets and clutter is large, so as to reduce the splitting time of poly matrix and the number of hypothesis matrix, and proposes the improvement of N-Best MHT technology in the course of track maintenance, so as to pave the way for simplifying the following steps.

N-Best MHT algorithm not only solves the problem of data association in the course of track maintenance, but also considers the start and end of the new target's track in the course. As a result, the dimension of row vector of the poly matrix after the introduction of Barshalom poly matrix becomes higher due to the addition of new targets. This situation is particularly evident when there are a large number of targets and measures. If the initial process of the new target formed in the course of track maintenance is calculated separately, then the poly matrix formed in the course of target tracking can be simplified to n*(i +2) matrix, that is, all the new targets formed are placed in a column of the matrix. Taking the correlation situation shown in Fig. 1 as an example, according to the N-Best MHT algorithm, a poly matrix N(t) is formed, as shown in Equation (1):

\[
N(t) = \begin{bmatrix}
1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
\end{bmatrix}
\]  

The improved poly matrix N'(t) is shown in Equation (2):

\[
N'(t) = \begin{bmatrix}
1 & 1 & 0 & 0 & 1 \\
1 & 1 & 0 & 0 & 1 \\
1 & 0 & 1 & 1 & 1 \\
1 & 0 & 1 & 0 & 1 \\
1 & 0 & 1 & 0 & 1 \\
1 & 1 & 0 & 1 & 1 \\
\end{bmatrix}
\]

Compared with the single column representation of each new target in N(t),N'(t) is only represented by a column with all 1, and there is no need to store the new target information in such a large space as
N(t). In fact, the number of hypothesis matrices split by N(t) and N'(t) is the same, but in the process of program execution, the search time for N(t) is $10^6/5^6 = 2^6$ times longer than that for N'(t), and it increases exponentially with the increase of the number of measurements.

The above improvement is carried out without changing the number of split matrix, and the size of poly matrix is modified by reducing the row vector dimension of poly matrix, so as to reduce the number of program search and search time in the split process. However, when the number of equivalent measurements is large, the process still generates thousands of feasible correlation hypotheses, so the computation is still quite large. To solve this problem, we reduce the complexity of splitting the matrix by reducing the dimension of the column vector. Since each row of the poly matrix represents the correlation information of each measurement, reducing the dimension of the column vector of the poly matrix means the loss of measurement data and will affect the accuracy of the correlation. Therefore, in the case of no loss of measurement data, all measurements at a certain time can be grouped according to some rules before the formation of aggregation matrix, and then N-Best MHT algorithm can be used for each group of measurement data respectively. This method achieves good results in the course of target tracking. The structure of the algorithm is shown in Figure 4.

The measurement group part is the key of the algorithm. According to different requirements, different grouping methods can be used for the measurement set at time t. The multi-target tracking shown in Figure 1 is taken as an example to illustrate the specific measurement grouping method. You can consider the first goal as one group and the second and third goals as another group. Thus, the 6 measurements can be divided into two groups. One group is used to update target 1, and the other group is used to update target 2 and target 3. The grouping can be achieved according to the norm of each measurement to the residual vector of each target. The specific grouping steps are as follows: (1) Calculate and sort the norm of the six measurements to the residual vector of target 1, select the measurement with the smallest norm and put it into the first group; (2) Calculate and sort the norm of the residual vector of the remaining 5 measures to target 2, select the measurement with the smallest norm and put it into the second group; (3) Calculate and sort the norm of the residual vector of the remaining 4 measurements to target 3, select the measurement with the smallest norm and put it into the second group; (4) Repeat steps (1) to (3) for the remaining 3 measurements, and finally obtain two measurement sets.

5. Results
In this paper, a typical multi-target tracking scenario is assumed, that is, three targets cross flight in the clutter environment. The correlation accuracy and tracking time of the traditional MHT algorithm and the improved N-Best MHT algorithm proposed in this paper are compared by simulation. Parameter n
is 1, detection probability PD=0.97, radar sampling interval T=4s. A nonparametric Poisson distribution clutter model is used in the simulation, and the expected number of the false measurement in the wave gate is 1. Assuming that the pruning uses a zero-scan method, Barshalom's joint data interconnection filtering algorithm is used to find the probability of each event and then estimate the state of each target.

In this simulation, we tried a variety of scenarios and compared the average and maximum computation times for processing one sample (scan) data. Especially when the calculation time is the longest, the improvement effect is obvious.

| Table 1 Average and maximum calculation time of each sample |
|------------------------------------------------------------|
|                | N-Best MHT | Traditional MHT | Correlation accuracy |
| Ave(s)          | 0.07122    | 0.3484          | 99%                  |
| Max(s)          | 0.4123     | 348.9           | 99%                  |

![Fig. 5 Comparison of computation time in one case](image)

![Fig. 6 Comparison of the number of temporary hypothesis in one case](image)

We show in Figure 5 a comparison of calculation times in one case and a comparison of the number of temporary hypothesis in the same case in Figure 6. The computation time of a conventional MHT is almost proportional to the number of provisional hypothesis. In the sample, the processing time of traditional MHT is about 0.1 seconds, and there is not much difference between the two algorithms. The longer the processing time of traditional MHT, the greater the difference.

6. Conclusions
In view of the fact that the computation amount of N-Best MHT algorithm increases rapidly with the increase of measurement and target number in multi-target tracking, this paper studies how to reduce the computation amount and computation time required in matrix splitting process of N-Best MHT algorithm from the perspective of reducing the dimension of poly matrix, and proposes an improved MHT technique. The simulation results show that the proposed method not only greatly reduces the computation time of N-Best MHT algorithm, but also realizes the effective tracking of multiple targets.

It should be pointed out that in the implementation process of N-Best MHT algorithm in this paper,
the target initialization (i.e., path initiation) process is not considered, but the path initiation and maintenance process are considered separately, mainly in consideration of the complexity of long-period MHT engineering implementation. The next work will mainly consider M-optimal MHT path initiation problem. Secondly, there are many methods to measure the grouping in the MHT improvement in this paper. Different grouping will lead to different final tracking results, but this paper only verifies one of them, and there are some deficiencies in considering other grouping methods.

References
[1] D.B. Reid, “An Algorithm for Tracking Multiple Targets,” IEEE Trans. Autom. Control, vol.29, no.2, 98/108 (1984).
[2] Ingemar J C, Sunita L H. An Efficient Implementation and Evaluation of Reid’s Multiple Hypothesis Tracking Algorithm for Visual Tracking[J]. IEEE Transactions on Parrem Analysis and Machine Intelligence, 1996, 18 (2): 138-150.
[3] Blackman S S. Multiple Hypothesis Tracking For Multiple Target Tracking [J]. IEEE Transactions on Aerospace and Electronic Systems, 2008, 19(1): 5-18.
[4] J. D. Glass and W. D. Blair, “Hierarchical Track Correlation and Fusion for Multi-Target Tracking with Biased Sensors,” Proceedings of the 2017 IEEE Aerospace Conference, pp. 1-7, March 2017.