Fractional Order Ship Tracking Correlation Algorithm

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***Abstract*—Aiming at the radar and AIS sensor's fuzzy association to ship tracking which caused by different error, this article provided fractional order ship tracking correlation model. From the mathematical point of view, the model used in this thesis extended the integer-order correlation measurement to the fractional-order correlation measurement; from the correlation of view, elongated the non-process correlation of the point information to the process correlation of the line information. Example shows that, fractional-order association algorithm can provide much more related information; and enhance the ship tracking correlative accuracy.**

***Index Terms*—fractional order, ship tracking association, process association, association.**

I. Introduction

In recent years, the rapid economic development in various regions and countries in the world and the global economic integration have paved the way for the prosperous development of shipping industry. With the thriving of water transportation and the increasing of maritime navigation density, ships encounter more frequently and offshore traffic accidents happen inevitably on the increase. Consequently the accurate tracking and detecting for ships has become one of the research subjects. Currently radar and automatic identification system (AIS) are the main means for ship tracking detection, nevertheless, the information provided by radar is subject to the influences of sea conditions and topography while the non-autonomous detection of AIS and the fact that not all ships are installed with AIS also make AIS application under limitations. Therefore, in order to integrate the complementary radar information and AIS information, first of all AIS information and radar information needs to be correlated, namely to establish tracking correlation. Tracking correlation is the process of comparing the degree of similarity between two tracking and judging whether the tracking from different sensors with different errors is of the same target.

Manuscript received January 1, 2011; revised June 1, 2011; accepted July 1, 2011.

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II. Review

A. Tracking-related Review

Tracking-related issues are essentially time series correlation[1,2] which were first put forward by Singer and Kanyuck. At present, the major algorithms include the weighted statistical distance test, the revised weighted statistical distance test, the nearest neighbor(NN), the classic distribution method[3], the likelihood ratio test, the maximum likelihood method, K neighbor, multi-variant hypothesis test, generalized correlation method, interacting multi-model method[4], grey correlation algorithm[5-8] and various other fuzzy methods[9].

Due to the fact that targets are more concentrated in the port, target tracking is usually intersected and there are much mobile tracking, as well as the fact that the data are of great grayscale and without typical regularity of distribution, the application of the algorithm above will produce lots of wrong or missing related tracking, thus failing to meet the accuracy requirement of the tracking correlation. Nevertheless, the method of gray correlation analysis which is based on grey system will fill in this gap. Gray correlation analysis to analyze the correlation degree between various factors of the system by comparing the geometric relations of system data sequences.

In recent years, gray correlation algorithm obtained a significant development, and many scholars have made great contributions. From the relational degree itself, it experienced from the gray relational algorithm of no differential measurement information (such as Tang's correlation, the absolute correlation Ⅱ, the relative correlation, correlation interval Ⅰ, range correlation Ⅱ) to gray relational algorithm with first-order differential metrical information (such as absolute relational degree Ⅰ, slope correlation, and T-type correlation), and then turned to be the gray relational algorithm with second-

doi:10.4304/jsw.7.12.2894-2898

order differential metrical information (B-type correlation, C-type correlation).

The abovementioned indicates that the introduction of the high order information and the fractional information into the associated metrics of the series is the development trend of related algorithms and it is also correspond with the tracking accurate associated needs.

In the paper, the notion of fractional order is introduced into the tracking correlation model and the similarities between global shape and local shape are taken into consideration. Besides, the point identification is expanded to the line identification so as to improve spatial resolution and system reliability and to reduce the uncertainty of system information, thus enhancing the accuracy of tracking correlation.

B. Summary of Fractional Differential

Fractional calculus refers to the calculus with order of any real number order. For more than three centuries, many famous scientists did a lot of basic work on fractional calculus; however, fractional calculus really began to grow till the last 30 years. Oldham and Spanier discussed mathematical calculations of the fractional number and their application in areas like physics, engineering, finance, biology, etc. In 1993, Samko made systematic and comprehensive exposition on fractional integral and derivative related properties and their applications. Many researchers have found that, fractional derivative model can more accurately describe the nature of a memory and the genetic material and the distribution process than integer order derivative model[10]. The overall and memory characteristic of fractional are widely used in physics, chemistry, materials, fractal theory[11], image processing[12] and other fields. Currently, the analysis of fractional differential has become a new active researched area that aroused great attention of domestic and foreign scholars, and turned to be the world's leading edge and hot research field.

III. Algorithm Principle

In this paper, the notion of fractional order is introduced into the tracking correlation model, both the similarities of overall shape and partial shape are considered so that the original point recognition is expanded to the line recognition, thus to reduce the uncertainty of information system and improve the accuracy of tracking correlation.[13,14]

A. Fractional Order Differential

Differential operations can enhance the high-frequency and weaken low-frequency of the signals. Fractional differential operation can nonlinearly improve more high-frequency and weaken less low-frequency of the signals with the growth of the order. From the perspective of the information extraction, the order of integer order operations is discrete whereas fractional one is continuous, and can provide more tracking correlation information to help the identification of the target tracking.

Each observed value on the tracking is the common result of variety of subjective and objective factors and the development of all previous observations; therefore tracking is of overall and memory characteristics. Fractional differential operator is intended differential operator with overall and memory characteristics whereas integral order doesn’t have this feature. Therefore, from the description of the tracking it can conclude that, fractional differential could more accurately describe the memory nature of tracking comparing with the integral order one, and was imported to calculate the relevancy of the tracking.

B. Fractional Differential Difference Form

Since time series is discrete, when using the fractional differentials in it's associate calculation, the definition pattern of fractional differential algorithms must be change into the difference form. Then, we derive the fractional differential difference formula via Grümwald-Letnikov definition.

Known, v order fractional differential Grümwald-Letnikov definition is

$$ {}_{a}^{G}D_t^{v}s(t)=\lim_{h\to 0}s_t^{v}(t)=\lim_{\substack{h\to 0\\ nh\to t-a}}h^{-v}\sum_{r=0}^{n}C_r^{-v}s(t-rh) \tag{1}$$

Where in

$$C_r^{-v}=\frac{(-v)(-v+1)...(-v+r-1)}{r!}$$

According to Expression(1), if the persistent period of s(t) is: t ∈ [a ,t], divide [a ,t] into equal parts corresponding to one unit interval h=1, it can be got that

$$n=\left[\frac{t-a}{h}\right]^{h=1}=[t-a]$$

Then, v order fractional differential difference expression to unitary signal s(t) can be get

$$\frac{d^v s(t)}{dt^v}\approx s(t)+(-v)s(t-1)+\frac{(-v)(-v+1)}{2}s(t-2)+\frac{(-v)(-v+1)(-v+2)}{6}s(t-3)+...+\frac{\Gamma(-v+1)}{n!\Gamma(-v+n+1)}s(t-n)$$

From this differential expression, the difference coefficient of the fractional is

$$a_0=1,a_1=-v,a_2=\frac{(-v)(-v+1)}{2},$$
$$a_3=\frac{(-v)(-v+1)(-v+2)}{6},...,a_n=\frac{\Gamma(-v+1)}{n!\Gamma(-v+n+1)} \tag{2}$$

C. The Nature of Fractional Differential

Fractional differential operator can meet the exchange rate and the overlay standard

$$D^{v_1}D^{v_2}s(t)=D^{v_2}D^{v_1}s(t)=D^{v_1+v_2}s(t).$$

(0, 1) differential order measures the overall situation of the sequence, other differential order results can all be acquired through the iterate integer-order differential on it. First-order differential reflects the slope of the tracking, second-order differential reflects the curvature of the tracking, and they all response to the partial trends of the tracking. To give consideration to the measurements of both global and local trends, non-integral order emphasis on (0, 1) order, integer order taking into account of the first, second order, therefore, this paper is only analysis the (0, 3)-order differential related information.

IV. Algorithm Model

Based on the time series of tracking in x, y and z directions, figure out the respective correlation curve and analyze the degree of correlation of each curve at each differential so as to confirm tracking correlation.

Based on the t tracking are acquired $s_{11}, s_{12}, ..., s_{1m}$, $s_{21}, s_{22}, ..., s_{2m}$, ..., $s_{t1}, s_{t2}, ..., s_{tm}$, where $S_{ij} = (x_{ij}, y_{ij}), i = 1, 2, ..., t;\ j = 1, 2, ..., m$, (x_{ij}, y_{ij}) is the spatial three-dimensional coordinate of S_{ij}. Set $s_{11}, s_{12}, ..., s_{1m}$ as reference vector sequence, and figure out the correlation degree between $s_{i1}, s_{i2}, ..., s_{im}, i = 2, 3, ..., t$ and reference vector sequence. Then find out the sequence correlated with the reference sequence, so as to discover correlation tracking.

A. *Fractional Order Correlation*

Based on the vector sequence of $S_{ij} = (x_{ij}, y_{ij}), i = 1, 2, ..., t;\ j = 1, 2, ..., m$, generate the following sequences in the direction of x, y respectively.

$$X_i = x_{i1}, x_{i2}, ..., x_{im}; i = 1, 2, ..., t$$

$$Y_i = y_{i1}, y_{i2}, ..., y_{im}; i = 1, 2, ..., t$$

Calculate the correlation degree of the above sequences respectively and assume the correlation degree $Qi(v)$ between sequence Q_1 and sequence $Q_i, i = 2, 3, ..., t$ as:

$$Qi(v) = \frac{1}{m-7}\sum_{j=8}^{m}(Q_{1j}^{v} - Q_{ij}^{v})^2; i = 2, 3, ..., t; v \in (0, 3)$$

Where:

$$Q_{1j}^{v} = \sum_{d=j-5}^{j} q_{1d} * a_{(j-d+1)}, Q_{ij}^{v} = \sum_{d=j-5}^{j} q_{id} * a_{(j-d+1)};$$

i=2,3,…,t; Q=X,Y; $q = x, y$.

B. *Correlation Judgment*

(1) Judgment for numerical value of correlation:

The greater the value of $Qi(v)$ is, the smaller the correlation degree between sequence Qi and Q1 is; whereas, the smaller the value of $Qi(v)$ is, the greater the correlation degree between sequence Qi and Q1 is.

(2) Relation between order and correlation:

Comparing with high order differential, low order differential extract more of the low-frequency information and less high-frequency information. As for the tracking, low order differential extract more long-term-effect information while high order differential extract more short-term-effect information.

When $Qi(v) < Qj(v), i, j = 2, 3, ..., t$ and v ranges between 0 and 1, sequence Qi has a greater correlation with sequence Q1 than sequence Qj does in the long term; when v ranges between 1 and 3, sequence Qi has a greater correlation with sequence Q1 than sequence Qj does in the short term.

V. Algorithm Simulation

Based on the tracking of $S_{ij} = (x_{ij}, y_{ij}), i = 1, 2, ..., 7;\ j = 1, 2, ..., 26$, generate the following sequences in the direction of x, y respectively.

$$X_i = x_{i1}, x_{i2}, ..., x_{i26}, i = 2, 3, ..., 7$$

where $x_{ij} \in [0, 1000]$, see Fig.1,

$$Y_i = y_{i1}, y_{i2}, ..., y_{i26}, i = 2, 3, ..., 7$$

where $y_{ij} \in [0, 1000]$, see Fig.2,

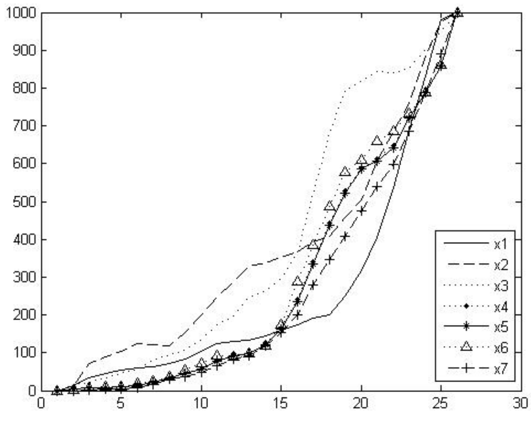

Figure 1. Tracking data in x direction

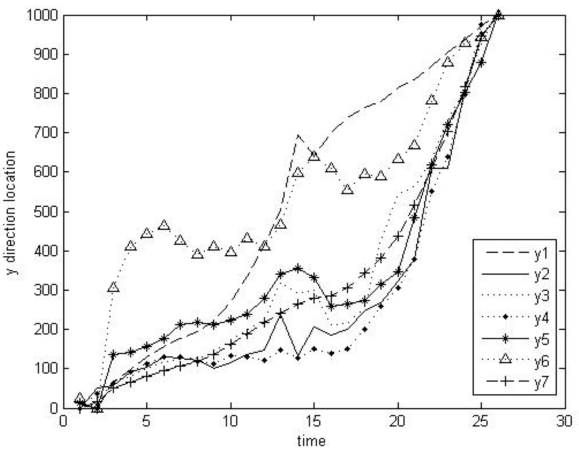

Figure 2. Tracking data in y direction

Taking Radar and AIS's detecting error into account which is about 20 meters and 2 meters respectivly, simulation experiments are structured as follows. Add noise with range of [-2, 2] into the reference sequences X_1, Y_1 to get X_{11}, Y_{11}; add noise with range of [-20, 20] into all the tracking to get X_{i2}, Y_{i2}, in which i=1， 2,..., 7. Then calculate separately the curve of correlation degree (see Fig.3,4) at the order of (0, 3) between X_{i2} and X_{11}, Y_{i2} and Y_{11}. In the figure, mqhk stands for the correlation degree between qh and qk, in which m stands for correlation degree, $q = x, y$, h and k are the subscripts of the sequences generated after adding noise.

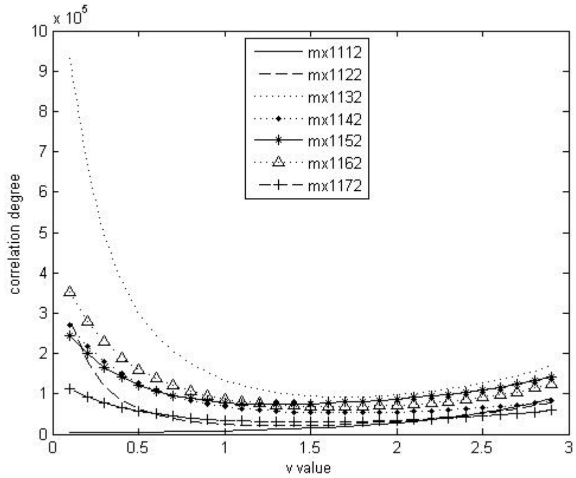

Figure 3. Curve of correlation degree at the order of (0, 3) between X_{i2} and X_{11}, i=1,2,...,7

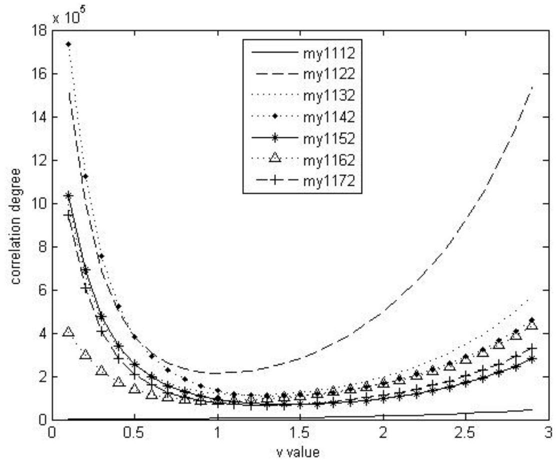

Figure 4. Curve of correlation degree at the order of (0, 3) between Y_{i2} and Y_{11}, i=1,2,...,7

In Fig.3,4, from the curves of correlation degree at the order of (0, 3) between X_{i2} and X_{11}, Y_{i2} and Y_{11}, it can be seen that all the correlation values between X_{i2} and X_{11}, Y_{i2} and Y_{11} at the order of (0,3) are far smaller than other correlation values. Therefore, it can be concluded that X_{i2} and X_{11}, Y_{i2} and Y_{11} are correlated and thus S_{11} and S_{12} are the tracking of the same target. The results agree with the experimental expectation.

VI. Conclusions

It is proved in the experiments that the addition of error will affect high-frequency information of the sequence and moreover, with the increase of the error, the influence will gradually expand from higher order to lower order. On account of the effects of errors, the order can be adjusted to calculate correlation degree. The greater the error is, the smaller the order needs to choose at. It is also proven in the experiments that when adding noises with range of [-20,20] and [-2,2] into the sequence with the threshold of [0, 1000], the required correlated accuracy can still be acquired with this algorithm.

Acknowledgment

This work was financially supported by the National Natural Science Foundation of China (Grant No. 10731050) and Ministry of Education Innovation Team of China(No. IRT00742).

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