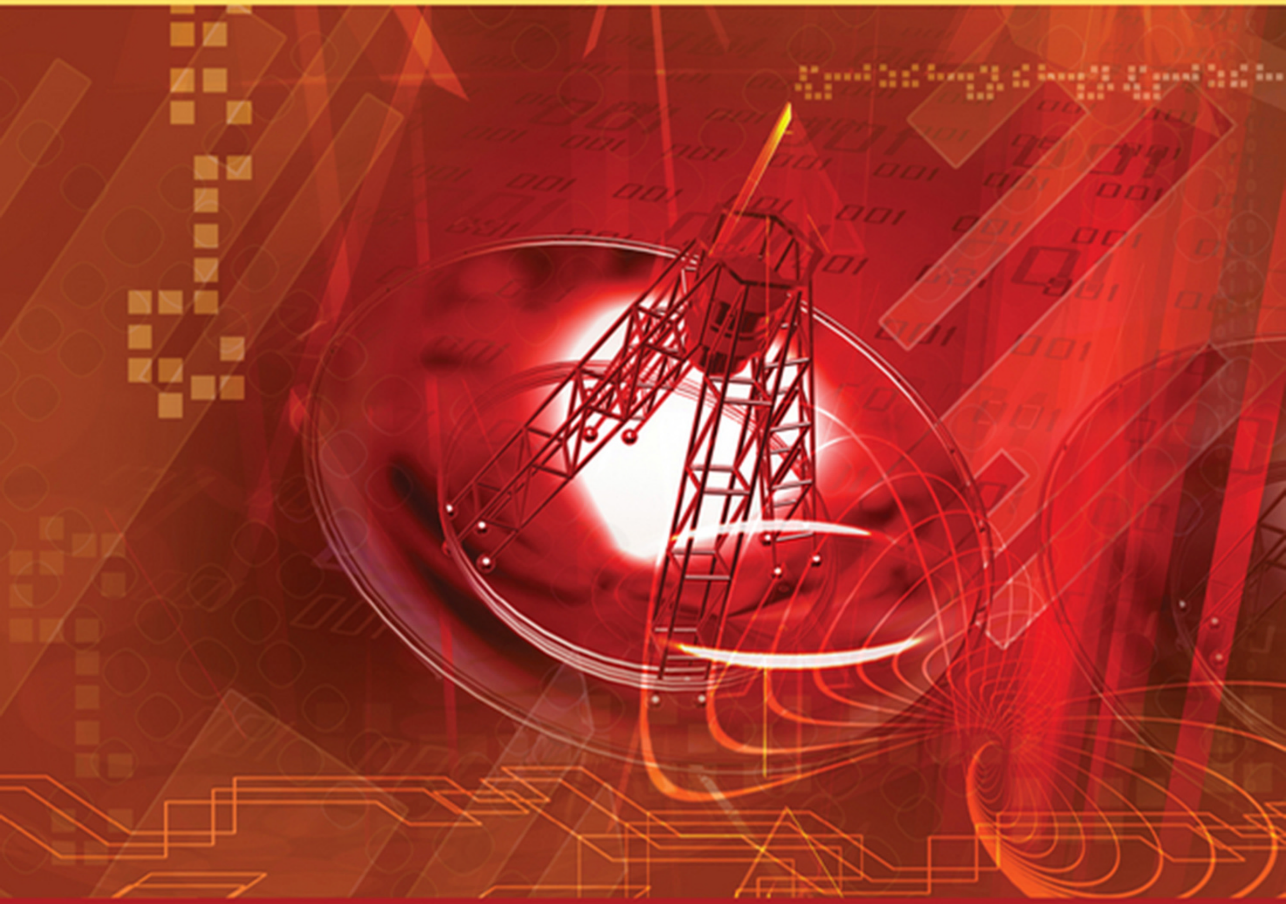
Radar Data Processing with Applications

He You • Xiu Jianjuan • Guan Xin



電子工業出版社
PUBLISHING HOUSE OF ELECTRONICS INDUSTRY

WILEY

RADAR DATA PROCESSING WITH APPLICATIONS

RADAR DATA PROCESSING WITH APPLICATIONS

He You
Xiu Jianjuan
Guan Xin

電子工業出版社
PUBLISHING HOUSE OF ELECTRONICS INDUSTRY

WILEY

This edition first published 2016

Published by John Wiley & Sons Singapore Pte. Ltd., 1 Fusionopolis Walk, #07-01 Solaris South Tower, Singapore 138628, under exclusive license granted by [copub] for all media and languages excluding Simplified and Traditional Chinese and throughout the world excluding Mainland China, and with non-exclusive license for electronic versions in Mainland China.

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

Library of Congress Cataloging-in-Publication Data

Names: You, He, 1956– author. | Jianjuan, Xiu, 1971– author. | Xin, Guan, 1978– author.
Title: Radar data processing with applications / He You, Xiu Jianjuan, Guan Xin.
Description: Singapore : John Wiley & Sons, Inc., [2016] | Includes bibliographical references and index.
Identifiers: LCCN 2016010486 | ISBN 9781118956861 (cloth) | ISBN 9781118956885 (epub) | ISBN 9781118956892 (Adobe PDF)
Subjects: LCSH: Radar–Mathematics. | Radar–Data processing.
Classification: LCC TK6578 .H425 2016 | DDC 621.38480285–dc23
LC record available at https://lccn.loc.gov/2016010486

Set in 10/12pt Times by SPi Global, Pondicherry, India

1 2016

Contents

About the Authors

He You (Fellow of IET, Academician of Chinese Academy of Engineering) was born in Jilin Province, People's Republic of China, in 1956. He received a Ph.D. from the Department of Electronic Engineering of Tsinghua University, Beijing, People's Republic of China, in 1997. Then, he won a National Outstanding Doctoral Dissertation Award in 2000.

From October 1991 to November 1992, he was with the Institute of Communication at the Technical University of Braunschweig, Germany, as a senior visiting scholar researching automatic radar detection theory and constant false alarm rate processing. In December 1994, he joined the Naval Aeronautical and Astronautical University (NAAU) in Yantai, People's Republic of China, as a Professor in the Department of Electronic Engineering, and engaged in research on signal processing and information fusion with applications. Now, he is Director of the Ministerial-level Laboratory of Information Sensing and Fusion Technology, and Chief of the Information Fusion Research Institute, NAUU, as well. He has acquired over 20 authorized National Invention Patents, and is co-author of more than 200 peer-reviewed technical articles. Moreover, he is first author of the books *Radar Target Detection and CFAR Processing* (Tsinghua University Press, 1st edition 1999 and 2nd edition 2011), *Multi-sensor Information Fusion with Applications* (Publishing House of Electronics Industry, 1st edition 2000 and 2nd edition 2007), *Radar Data Processing with Application* (Publishing House of Electronics Industry, 1st edition 2006, 2nd edition 2009, 3rd edition 2013, and translated into English), *Information Fusion Theory with Application* (Publishing House of Electronics Industry, 2010). These published books and papers have been cited more than 7000 times by other scholars. He has provided leadership in many research projects and gained significant scientific research achievements including three 2nd Awards of National Science and Technology Progress, one 1st Award and one 2nd Award of National Teaching Achievements. He is leader of the Information Fusion Team, which has been ranked as Ministerial-level Innovation Team of Science and Technology, as well as Excellence Innovation Team of Shandong Province.

Dr. He has served as a Fellow of IET, Committee Member of National "863" Experts, Member of National Radar Detection Technology Group, Standing Director of Chinese Society of Aeronautics and Astronautics (CSAA), Founder and Chairman of Information Fusion Branch in CSAA, Standing Director of Chinese Society of Command and Control, Fellow of Chinese Institute of Electronics (CIE), Vice Chairman of Radio Positioning Technology Branch in CIE, and so on. He is a Vice Chairman on the Editorial Boards of *Ship Electronic Engineering*, *Radar Science* *and Technology*, and *Fire Control & Command Control*. He has also been appointed a Member on the Editorial Boards of *Chinese Journal of Aeronautics* (in English), *Acta Aeronautica et Astronautica Sinica*, *Signal Processing (China)*, *Journal of Radars*, *Journal of Data Acquisition & Processing*, and so on.

Xiu Jianjuan was born in Shandong Province, People's Republic of China, in April 1971. She received her master and Ph.D. degree from Naval Aeronautical and Astronautical University, Yantai, People's Republic of China, in 2000 and 2004. She is now a professor in Research Institute of Information Fusion of Naval Aeronautical and Astronautical University. His research interests include radar data processing and passive location.

Guan Xin was born in Jinzhou, Liaoning province, People's Republic of China, in 1978. She received her bachelor degree in communication engineering from Liaoning University, Liaoning, People's Republic of China, in 1999 and received master and PhD degree from Naval Aeronautical and Astronautical University in 2002 and 2006, respectively. She is now a professor and doctor tutor in Department of Electronics and Communication of Naval Aeronautical and Astronautical University. She also serves as a director of Chinese institute of command and control and a senior member of Chinese Aviation Society. She is major in target identification and evidence reasoning, and has published over 80 papers and 3 academic monographs.

Preface

Advances in radar technology and application demands have promoted the fast development of radar signal processing and data processing technology. In recent years, with the continual emergence of new types of radar, significant progress has been made in related hardware, algorithms, and computer performance, and the signal processing capacity has been constantly improved, which demands the application of new algorithms in related radar data processing equipment to implement the simultaneous processing of multiple targets in the cluttered environments and allow the data association and tracking of multiple targets and information fusion of multiple radars in complex environments. That is why we decided to publish *Radar Data Processing with Applications*.

This book begins with the basic linear and nonlinear filtering approaches, and introduces the development and latest research findings on radar data processing technology thoroughly and systematically. Its main contents are as follows.

1. The initial discussion deals with the static and dynamic parameter estimation for linear and nonlinear discrete-time systems, providing such classical filtering algorithms as the Kalman filter, the extended Kalman filter, the unscented Kalman filter, and the particle filter.
2. Measurement preprocessing techniques are discussed, including time and space registration, radar error correction, and data compression.
3. Such practical issues as multi-target track initiation, data association, and tracking are introduced, of which multi-target data association is divided into the maximum likelihood and Bayesian approach. Maneuvering target tracking, group target tracking, and track termination are also discussed.
4. The final analysis is the practical application of radar data processing, including passive radar data processing, pulse Doppler radar data processing, phased array radar data processing, radar network error registration, radar network data processing, radar data processing performance evaluation, and simulation techniques.

Acknowledgments

The authors gratefully acknowledge the contributions of those colleagues from the English Department who have been involved in the translation work: Associate Prof. Chen Li, Associate Prof.

Yang An-liang, Associate Prof. Liu Hong-ying, Lecturer Liu Hui, Lecturer Qu Lei, Lecturer Wang Xue-sheng, Lecturer Xu Xiao-juan, Lecturer Zhang Dong-li, Lecturer Zhu Zi-jian, and Lecturer Guan Hui-jie. The authors would like to express their appreciation to Dr. Dong Kai, Dr. Wang Hai-peng, Dr. Cui Ya-qi, and postgraduates Miao Xu-bin, Wang Wang-song, and Sun Shun for their participation in proofreading and revision. Special thanks go to the Electronic Industry Publishing House, especially to Editor Qu Xin, for support in the publication of this book.

It is expected that the publication of this book will not only provide a very readable reference for those engaged in information engineering, pattern recognition, military command, etc., but also lay a theoretical foundation for their work and further study.

Any advice and suggestions from readers of this book are most welcome.

1

Introduction

1.1 Aim and Significance of Radar Data Processing

Generally, a modern radar system consists of two important components: a signal processor and a data processor. The signal processor is used for target detection (i.e., the suppression of undesirable signals produced by ground or sea surface clutter, meteorological factors, radio frequency interference, noise sources, and man-made interference) [1–3]. When the video output signal, after signal processing and constant false alarm rate (CFAR) detection fusion, exceeds a certain detection threshold, it can be determined that a target has been discovered. Then, the discovered target signal will be transmitted to the data recording device, where the space position, amplitude value, radial velocity, and other characteristic parameters of the target are recorded, usually by computers. The measurement output from the data recording device needs to be processed in the data processor, which associates, tracks, filters, smooths, and predicts the obtained measurement data – such as the target position (radial distance, azimuth, and pitch angle) and the motion parameters [4–6] – for the effective suppression of random errors occurring during the measurement, estimation of the trajectory and related motion parameters (velocity and acceleration, etc.) of the target in the control area, prediction of the target's position at the next moment, and formation of a steady target track, so that highly accurate real-time tracking is realized [7–9].

In terms of the level at which radar echo signals are processed, radar signal processing is usually viewed as the primary processing of the information detected by the radar unit. It is done at each radar station, with information obtained from the same radar and the same scanning period and distance unit, with the aim of extracting useful target information from clutter, noise, and various active and passive jamming backgrounds. Radar data processing is usually viewed as secondary processing of the radar information [10–13]. Making use of information from the same radar, but with different scanning periods and distance units, it can be done both at each independent radar station and at the information processing center or system command center of the radar network. Data fusion of multiple radars can be viewed as a third or tertiary processing of the radar information, which is usually done at the information processing center. Specifically, the information the processing

Radar Data Processing with Applications, First Edition. He You, Xiu Jianjuan, and Guan Xin.

center receives is the measurement from the primary processing or the track from the secondary processing (usually called the local track) by multiple radars, and the track after fusion (called the global track or system track). The function of the secondary processing of radar information, based on the primary processing, is to filter and track several targets, and estimate the targets' motion parameters and characteristic parameters. Secondary processing is done strictly after primary processing, while there is no strict time limit between secondary and tertiary processing. The third level of processing is the expansion and extension of secondary processing, which is mainly reflected in space and dimension.

1.2 Basic Concepts in Radar Data Processing

The input to the radar data processing unit is the measurement from the front, which is the object of data processing, while the output is the track formed after data processing is conducted. Generally, functional modules of radar data processing include measurement pretreatment, track initiation and termination, and data association and tracking. A wave gate must be set up between the association and the tracking process, and their relationship is shown in the block diagram in Figure 1.1. The content and related concepts of the functional modules of radar data processing are briefly discussed as follows.

1.2.1 Measurements

Measurements, also called observations, refer to noise-corrupted observations related to the state of a target [14]. The measurements are not usually raw data points, but the output from the data recording device after signal processing. Measurements can be divided, according to whether they are associated with the known target track, into free measurements and correlated measurements. Free measurements are spots that are not correlated with the known target track, while correlated measurements are spots that are correlated with the known target track.

1.2.2 Measurement Preprocessing

Although modern radar adopts many signal processing technologies, there will always be a small proportion of clutter/interference signals left out. To relieve the computers doing the follow-up

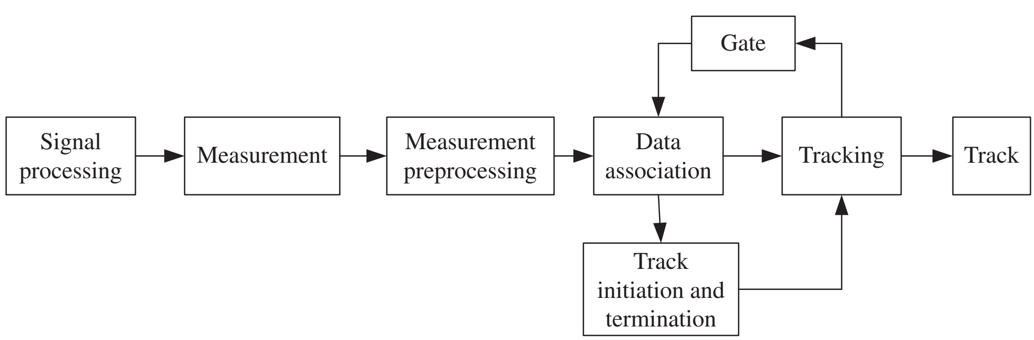


Figure 1.1 Radar data processing relation diagram

processing job from a heavy burden, prevent computers from saturation, and improve system performance, the measurement given by the primary processing needs to be preprocessed, which is called "measurement preprocessing": the preprocessing of secondary processing of radar information. The preprocessing is a precondition of correct processing of radar data, since an effective measurement data processing method can actually help yield twice the result with half the effort, with the target tracking accuracy improved while the computational complexity of the target tracking is reduced. The measurement preprocessing technology mainly involves system error registration, time synchronization, space alignment, outlier rejection, and saturation prevention.

1.2.2.1 System Error Registration

The measurement data from radars contains two types of error. One is random error, resulting from the interior noise of the measurement system. Random error may vary with each measurement, and may be eliminated to some extent by increasing the frequency of measurement and minimizing its variance in the statistical sense by means of methods like filtering. The other is system error, resulting from measurement environments, antennas, servo systems, and such non-calibration factors in the data correction process as the position error of radar stations and the zero deviation of altimeters. System error is complex, slowly varying, and non-random, and can be viewed as an unknown variable in a relatively long period of time. As indicated by the findings in Ref. [15], when the ratio of system errors to random errors is greater than or equal to 1, the effect of distributed track fusion and centralized measurement fusion deteriorates markedly, and at this point system errors must be corrected.

1.2.2.2 Time Synchronization

Owing to the possible difference in each radar's power-on time and sampling rate, the target measurement data recorded by data recording devices may be asynchronous. Therefore, these observation data must be synchronized in multiple-radar data processing. Usually, the sampling moment of a radar is set as the benchmark for the time of other radars.

1.2.2.3 Space Alignment

Space alignment is the process of unifying the coordinate origin, coordinate axis direction, etc. of the data from the radar stations in different places, so as to bring the measurement data from several radars into a unified reference framework, paving the way for the follow-up radar data processing.

1.2.2.4 Outlier Rejection

Outlier rejection is the process of removing the obviously abnormal values from radar measurement data.

1.2.2.5 Saturation Prevention

Saturation prevention mainly deals with saturation in the following two cases.

1. In the design of a data processing system, there is a limit to the number of target data. However, in a real system, saturation occurs when the data to be processed exceed the processing capacity.

2. The time used to process data is limited. Saturation occurs when the number of measurements, or batches of targets, reaches a certain extent. In this case, the processing of the data from one observation has to be interrupted before the processor starts to deal with the next batch of data.

1.2.3 Data Association

In the single-target, clutter-free environment, where there is only one measurement in the target-related wave gate, only tracking is involved. Under multi-target circumstances, where a single measurement falls in the intersection area of several wave gates or several measurements fall in the related wave gate of a single target, data association is involved. For instance, suppose two target tracks have been established before the radar's *n*th scanning, and two echoes are detected in the *n*th scanning, are the echoes from two new targets or from the two established tracks at that time? If they are from the two established tracks at that time, then in what way can the echoes resulting from the two scans and the two tracks be correctly paired? The answer involves data association, the establishment of the relationship between the radar measurements at a given moment and the measurements (or tracks) at other moments, to check whether these measurements originate from the processing of the same target (or to ensure a correct process of measurement-and-track pairing).

Data association, also called "data correlation" or "measurement correlation," is a crucial issue in radar data processing. False data association could pair the target with a false velocity, which could result in the collision of aircraft with air traffic control radars, or the loss of target interception with military radars. Data association is realized through related wave gates, which exclude the true measurements of other targets and the false measurements of noise and interference.

Generally, data association can be categorized, according to what is being associated with what, into the following classes [16]:

1. measurement-to-measurement (track initiation);
2. measurement-to-track (track maintenance or track updating);
3. track-to-track, also called track correlation (track fusion).

1.2.4 Wave Gate

In the process of target track initiation and tracking, a wave gate is often used to solve data association problems. What then is a wave gate? How many categories is it divided into? A brief discussion of these questions follows.

An initial wave gate is a domain centering on free measurements, used to determine the region where the target's observations may occur. At the track initiation stage, the initial wave gate is normally bigger for better target acquisition.

A correlation wave gate (or tracking wave gate, validation gate) is a domain centering on the predicted position of the tracked target, used to determine the region where the target's observations may occur [17].

The size of the wave gate is related to the magnitude of radar measurement error, the probability of correct echo reception, etc. That is to say, when deciding the wave gate's shape and size, one should make it highly probable that the true measurement falls in the wave gate, while making sure that there are not many unrelated measurements in the correlation wave gate. The echo falling in the correlation wave gate is called a candidate echo. The size of the tracking gate reflects the error in the predicted target position and velocity, which is related to the tracking method, radar measurement error, and required correct correlation rate. The size of the correlation wave gate is not fixed in the tracking process, but adaptive adjustment should be made among small, medium, and large wave gates in accordance with the tracking conditions.

1. For a target in uniform rectilinear motion (e.g., a civil airliner flying smoothly at high altitude), a small wave gate should be set up, with its minimum size no less than three times the mean square root value of the measurement error.
2. When the target maneuver is relatively small (e.g., when the aircraft is taking off, landing, or making a slow turn), a medium wave gate should be set up, by adding one or two times the mean square root value of the measurement error to the small wave gate.
3. When the target maneuver is relatively big (e.g., when the aircraft is making a fast turn, or when the target is lost and recaptured), a large wave gate should be set up. Besides, at the track initiation stage, a large wave gate should be adopted to effectively capture the target's initial wave gate.

1.2.5 Track Initiation and Termination

Track initiation refers to the process from the entrance (and detection) of a target into the radar coverage area to the establishment of the target track. Target initiation is important in radar data processing. If the track initiation is incorrect, target tracking is impossible.

Since the target being tracked may escape the surveillance zone at any time, once it goes beyond the radar detection range, the tracker must make relevant decisions to eliminate the unwanted track files for track termination.

1.2.6 Tracking

Tracking is one of the two primary issues in radar data processing. It refers to the processing of the target's measurements for the constant estimation of the target's current state [16]. The multiple-radar and multi-target tracking system is a highly complex large-scale system, whose complexity is mainly due to the uncertainty in radar data processing.

1. From the perspective of measurement data, the received radar measurements form a random sequence, which may be obtained by non-equal interval sampling, and the observation noises are non-Gaussian. This should be considered in real measurement data processing.
2. From the perspective of multi-target tracking, the complexity of the tracking problem lies mainly in:
   a. the uncertainty of measurement origin – since there are multiple targets and false alarms, many measurements may be produced in radar environments, which will lead to the uncertainty of the measurements used for filtering;
   b. the uncertainty of the target model parameter – since targets could be on maneuvers at any time, the model parameter initially set could be incorrect. Therefore, adjustments must be made to the model parameter in accordance with the tracking conditions; hence maneuvering target tracking.
3. From the perspective of the system, the tracking system could be nonlinear, with a complex construction. On the one hand, the system tracking performance under complex circumstances depends chiefly on the filtering algorithm's capability to deal with the uncertainty of measurement origins and target model parameters, or its capability to effectively solve the problem of measurement correlation and adaptive target tracking. On the other hand, the nonlinear characteristics of the system itself should also be taken into consideration.

For the effective tracking of the target under these complex circumstances, the following two problems need to be solved.

First, the establishment of the target motion model and the observation model. Estimation theory, which provides a foundation for radar data processing, requires the establishment of a system model describing the dynamic characteristics of target and radar measurement processes. A valuable method of describing the system model, the state variable method, is based on the system state equation and the observation equation. According to this method, the state variable, system state equation, system observation equation, system noise and observation noise, system input and output (i.e., the estimated value of the state variable) are the five essential elements of the target tracking system modeling. The five elements above reflect the basic characteristics of a system, and can be viewed as a complete expression of a dynamic system. The introduction of the state variable is the core of creating an optimum control and estimation theory, because in the state space, the state variable defined should be a batch of variables with minimum dimensions that can fully reflect the system dynamic characteristics. The state variable at any given time is expressed as a function of the state variable prior to that time, and the input/output relationship of the system is described by the state transition model and the output observation model in the time domain. The state reflects the system's "interior condition." The input can be described by the state equation, which is composed of the decided time function and the random process representing the unpredictable variable or noise. The output is a function of the state vector, usually disturbed by the random observation error, and can be described by measurement equations. In the system modeling process, the use of the system state equation and the observation equation in the description of the dynamic characteristics of the target is therefore the most successful method in common use. The relation between the state equation and the measurement equation is shown in Figure 1.2.

Second, the tracking algorithm. The tracking filtering algorithm in the state space is actually a matter of optimum estimation based on state space. The following two points are of major concern.

1. Multiple maneuvering target tracking. Maneuvers are both the basic attribute of the target and the forms of motion commonly used in attacks or escapes. Therefore, maneuvering multi-target tracking is the focus of target tracking, dealing with the problem of a maneuvering target model, testing and tracking algorithm.
2. The optimality, robustness, and rapidity of tracking algorithms. That is to say, an overall consideration is needed of the tracking timeliness, tracking accuracy, and robustness of the algorithm.

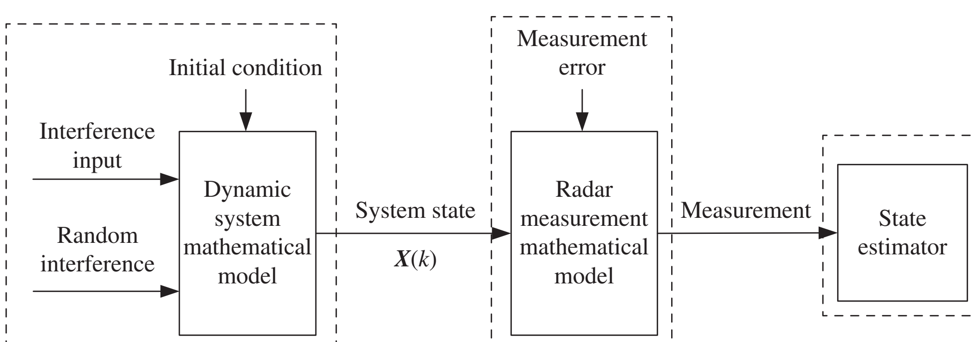


Figure 1.2 Filtering diagram

1.2.7 Track

A track is a trajectory which is formed with the states of a target estimated from a set of measurements of the same target (i.e., tracking trajectory). The radar, when conducting multi-target data processing, designates an identity (ID) for each tracking trajectory, namely the track ID, which serves as a point of reference for all the parameters related to a given track. The measurement of the track's reliability can be described by the track quality which, if properly controlled, can help both promptly and accurately initiate a track so that a new target file is set up, and cancel a track so that the redundant target files are cleared up. Tracks are the ultimate result of data processing, as shown in Figure 1.3.

The concepts related to tracks also include the following.

1. *Possible track.* The possible track is a track composed of a single measurement point.
2. *Tentative track.* Tentative tracks are tracks composed of two or more measurement points with low track quality. They could be target tracks, or random interference, namely false tracks. After initial correlation is complete, a possible track is turned into a tentative track or a canceled track. The tentative track is also called a temporary track.
3. *Confirmed track.* A confirmed track, also called a reliable track or a stable track, is a track with stable output or a track whose track quality exceeds a given value. It is the formal track set up by the data processor, and is generally considered as a true target track.
4. *Fixed track.* A fixed track is a track composed of clutter measurements, whose position does not change much with the scans of a radar set.

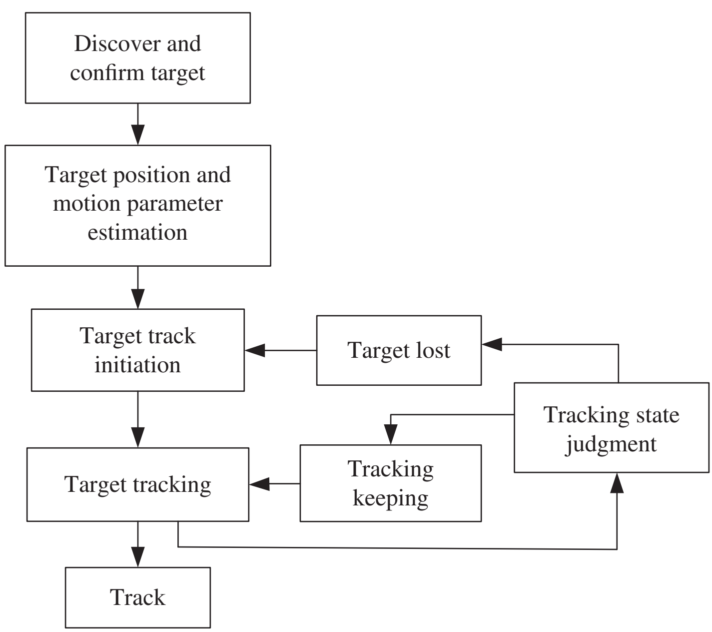


Figure 1.3 Data processing flowchart

The following sequence can be determined in the correlation process of measurements and tracks: fixed tracks first, then reliable tracks, and finally tentative tracks. That is to say, after a batch of observation measurements is obtained, the correlation of these measurements and the fixed track is done first. The measurements that can be correlated with the fixed track are deleted from the measurement file and are used to update the fixed track (i.e., to replace the old clutter points with the measurements that are correlated). If these measurements cannot be correlated with the fixed track, they should be correlated with the existing confirmed track. The successfully correlated measurements are used to update the confirmed track. The measurements that cannot be correlated with the confirmed track should be correlated with the tentative track, which finally either disappears or is turned into a confirmed track or a fixed track. The confirmed track has priority over the tentative track, which excludes the possibility that the tentative track obtains measurements from the reliable track.

5. *Canceled track.* When its quality is lower than a given value or is composed of isolated random interference points, the track is called a canceled track, and the process is called track cancellation or track termination. Track cancellation is the process of erasing the track when it does not conform to a certain rule, which means the track is not a track of a true target, or that the corresponding target has moved out of the radar coverage range. Specifically, when a certain track cannot be correlated with any measurement in a certain scan, an extrapolation should be done according to the latest velocity. Any track that does not receive a measurement in a certain number of successive scans should be canceled. The primary task of track cancellation is to promptly cancel a false track with the true one being retained.

   There are three possible instances of track cancellation.

   i. Possible tracks (with only track heads) to be canceled as long as there is no measurement in the first scanning period that follows them.
   ii. Tentative tracks (such as a newly initiated track) to be erased from the database as long as there is no measurement in the three successive scanning periods that follow them.
   iii. Confirmed tracks, whose cancellation should be done with caution. If no measurement falls in the relevant wave gates in four to six successive scanning periods, cancellation of the track can be considered. It is worth noting that extrapolation must be used several times to expand the wave gates to recapture the lost target. Of course, track quality management can also be used to cancel a track.

6. *Redundant tracks.* Two or more tracks being allocated to the same true target is called track redundancy. The unnecessary track is called a redundant track.
7. *Track interruption.* If a certain track is allocated to a true target at time t, but no track is allocated to the target at time $t+m$, then track interruption happens at time t, where m is a parameter set by the tester, usually $m=1$.
8. *Track switch.* If a certain track is allocated to a true target at time t, while another track is allocated to the target at time $t+m$, then track switch happens at time t, where m is a parameter set by the tester, usually $m=1$.
9. *Track life* (the length of a track; the times the track is successively correlated). Based on whether the terminated track is false or true, it can be divided into [18, 19]:
   a. *False track life.* The average times of radar scanning from the initiation of a false track to its deletion is called false track life. False track can sometimes last for a long time when false measurements are highly dense.

b. *True track life.* The average times of radar scanning of a true track mistaken for a false one and deleted after it is initiated.

True track maintenance time is restricted by two factors:

1. The measurement track correlation error (the true measurement is measured but is correlated with other tracks, which commonly occurs in dense target environments or crossed target environments) could lower the quality of a true track, or even result in the deletion of a true track mistaken for a false one.
2. The times that measurements are successively lost reach a given threshold, so the track is deleted as a lost target, which commonly happens when the signal-to-noise ratio is low or there is strong interference.

1.3 Design Requirements and Main Technical Indexes of Radar Data Processors

1.3.1 Basic Tasks of Data Processors

As can be seen from the discussion and elaboration of the relevant basic concepts in radar data processing, the basic tasks of data processors include:

a. measurement pretreatment;
b. determination of the correlation area and correlation principle, and the distinction between true and false measurements;
c. the establishment of new tracks;
d. the correlation of measurements and existing tracks, track maintenance;
e. the correlation between and fusion of tracks;
f. track termination and track management, including quality grade determination and track quality management;
g. situation display, including the display of tracks and measurements.

1.3.2 The Engineering Design of Data Processors

The engineering design of data processors is a comprehensive design. Generally, the following three issues need to be considered.

First, the balanced relationship between tracking accuracy, robustness, and real-time performance. Target tracking algorithms are mostly obtained when the probability distribution function of the system noise and measurement noise is subject to certain assumptions, and usually the assumed system noise and observation noise are both Gaussian white noise. However, in real systems it is hardly possible to find a matrix that accords completely with Gaussian distribution because the mutation of the electromagnetic environment, the immaturity and failure of the observation equipment, etc. can result in the deviation of observations from the Gaussian distribution. When the system's actual noise distribution deviates from the assumed noise distribution, tracking algorithms can effectively exclude the interference of the uncertainty factors and abnormal values in the system, and consequently ensure that there is not much change in the estimation effect and the estimation accuracy. Simply put, the tracking algorithms can ensure the robustness of estimation algorithms in this case, so that the system can operate normally. This is robust tracking (estimation). In other words, a relatively “loose” assumption of the noise distribution mode is allowed, which may not be the optimum one for a certain specific distribution mode, but can exclude the interference of the abnormal values and help improve the anti-interference ability of the system.

Basically, research on the robust estimation theory aims to find estimation algorithms that can both exclude or resist the influence of the abnormal value (cases) and basically possess the good characteristics of traditional estimation algorithms (i.e., algorithms that incorporate considerations of optimality and robustness of estimation in a balanced manner). What optimality emphasizes is an algorithm that makes the system index function reach its minimum (or maximum), while what robustness focuses on is an algorithm that sacrifices some indices of the system to improve its anti-interference performance. Therefore, an optimal balance between robustness and optimality is what needs to be taken into consideration in the whole process of robust tracking system design. Some efficiency has to be sacrificed to robustness [10].

Common problems in the balance between tracking accuracy, robustness, and real-time performance are:

1. Excessive emphasis is put on the tracking accuracy index, while the robustness index is neglected. As a result, the accuracy of the target tracking result is high at the simulation stage, but declines markedly at the actual engineering test stage, which reduces the algorithm’s engineering value.
2. Too idealized an index design results in complexity of the algorithm structure, which badly affects its real-time performance.

As for engineering algorithms, the index of robustness is the first priority, followed by the tracking accuracy and the real-time index. However, in an engineered index design, the three indexes mentioned above are the basic technical indexes on which compromises must be made.

The second issue is one of reliability. An algorithm that is simple in structure, highly reliable, easy to realize, and mature in engineering should be used in the engineering design of radar data processing. Otherwise, the system cannot operate normally and continuously. Meanwhile, the design of the software system data processor needs to be modularized, visible, and revisable.

The third issue is that of intelligence information processing. Although the function modules contained in data processors are basically the same, different radars have different requirements for the data processor design. For example, the core of the skywave over-the-horizon radar is the ionosphere mathematical model. Specifically, the echo multipath resulting from the multipath structure of the ionosphere, and the severe attenuation of the echo signal resulting from the severe shortwave environment noise and ionosphere transmission characteristic can result in a higher probability of false alarms and missed alarms in radar measurements, leading to discontinuity of the track. However, the striking problem with the groundwave over-the-horizon radar is the rejection of false tracks and the maintenance of stable tracks. Therefore, in the design of data processors, an analysis of the data processor’s characteristics should be made first according to the system’s index requirements for data processors, including observation characteristics such as the measurements’ temporal and spatial distribution characteristics, noise distribution and statistical characteristics, the variation of the signal-to-noise ratio, the intensiveness of the targets, etc. Besides, the system’s resolution, probability of detector false alarms and discovery, accumulated time and coordinate system, etc. are also included in the analysis, to provide a basis for the assignment of data processor indexes and the emphasis of the design.