Bayesian recognition of a moving object information-measuring system state: a priori information weight correction

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Abstract. Within the framework of the Bayesian approach, a method has been developed for recognizing signal-interference situations that arise during the operation of the information-measuring system of a moving object. The corresponding algorithms are presented. A method for correcting the weight of a priori information in the case of its significant difference from a posteriori information is proposed. One of the possible correction options using the so-called indicators of signals and interference accompanying signs is presented.

1. Introduction

Information-measuring systems are used in the control of moving objects [1]. In this case, the measured components of the moving objects coordinates vector vary over a wide range and can be functionally related. Functionally related are, for example, the range and speed of approach to an external object. The information-measuring system of a moving object is subject to interference, which generates measurement errors. To increase the accuracy of determining moving objects phase coordinates, their information-measuring systems should be developed in the class of systems with a random change in structure in the phase space [2].

Structures are developed in advance, taking into account possible signal-interference situations [3]. To control the change in the structure, it is necessary to recognize the current signal-interference situation, which can be performed in accordance with the Bayesian approach to testing statistical hypotheses [4, 5].

In the paper, within the framework of the Bayesian approach, in addition to measuring the phase coordinates and a priori information about changes in interference situations, indicators of accompanying signs of signals and interference are used [2]. They provide prompt correction of the weight of a priori information in the Bayesian decision-making procedure in cases of its discrepancy with the actual. It is known that if the prior probability of one of the hypotheses is much greater than the prior probabilities of other hypotheses, then with a small number of observations the posterior probability of such a hypothesis will be much higher than the posterior probabilities of other hypotheses. This can lead to erroneous decisions.
2. Formulation of the problem
Let us assume that the vector of phase coordinates of the moving object \( \mathbf{x} \) and the vector of measurement signals \( \mathbf{z} \) in discrete time have the form:

\[
\mathbf{x}_{k+1} = \mathbf{f}^{(s)}(\mathbf{x}_k, \mathbf{u}_k, \xi_k);
\]
\[
\mathbf{z}_k = \mathbf{h}^{(s)}(\mathbf{x}_k, \zeta_k),
\]
where \( \mathbf{u} \) is the vector of controls; \( \xi, \zeta \) are the object and measurement noise vectors, respectively; \( \mathbf{f}, \mathbf{h} \) — known vector functions of vector arguments; \( s \) is the number of the structure (state) of the moving object and its information-measuring system, \( s = 1, 2, \ldots, S \); \( S \) is the number of structures, \( k \) is the index of the discrete moment in time.

Based on the results of the preliminary analysis, the following is determined: a list of interferences; a list of possible signal and noise situations that make up a complete group of incompatible events; a priori intensities of the transition \( \tilde{\gamma}^{(\text{ls})} \) from the \( s \)-th to the \( l \)-th and \( \tilde{\gamma}^{(\text{a})} \) from the \( l \)-th to the \( s \)-th signal-noise situations; accompanying signs of interference impact on the information-measuring system. To detect accompanying signs, the output signals of the corresponding channels of the information-measuring system are used.

The process of changing a concomitant feature is a degenerate conditional Markov chain having two states (\( \Pr = 1 \) or \( \Pr = 0 \)), which is determined for fixed values of \( s_k \) and \( x_k \) by the probability:

\[
q_n(\Pr, k | S_k^T, x_k, k),
\]
where \( n = 1, N \) — feature number; \( N \) — is the number of features; \( \Pr \) — is the value of the feature indicator, \( \Pr = 0, 1 \); \( S_k^T = [S_{1,k}, \ldots, S_k] \) — is the vector of the set of scalar indices of possible interference situations \( s = 1, S \); \( x_k^T = [x_{1,k}, \ldots, x_{i,k}] \) — is the vector of the set of scalar values of the \( i \)-th phase coordinate of the moving object, \( i = 1, 1, 1 \); \( 1 \) is the number of measured phase coordinates. This is a degenerate case of a Markov chain, when the probability of transition to the state \( \Pr = 0 \) or to the state \( \Pr = 1 \) is equal to the steady-state value of the probability of this state. In the case when the probability of the appearance of a sign of interference does not depend on the phase coordinate, expression (3), called the input indicator function \( J \), takes the form:

\[
J_{n,k} = q_n(\Pr, k | S_k^T, x_k, k), \quad n = 1, N, \quad \Pr = 0, 1, \quad s = 1, S.
\]

The functioning of the feature indicator is described by the conditional probability of transition from \( r_{k-1} \) to \( r_k \) state [3]:

\[
\pi_n(J, \Pr) = \pi_n(r_k, k | J_{n,k-1}, \Pr, r_{k-1}, k - 1), \quad n = 1, N, \quad r_k = 0, 1.
\]

Obviously, the 0 and 1 states of the indicator of the \( \Pr \) feature correspond to the absence and presence of the accompanying noise feature.

If the interference leads to the appearance of several accompanying signs, then the probability \( \pi(J, \Pr) \) of the presence of the interference according to the values of the indicators can be represented as:

\[
\pi(J, \Pr) = \prod_{n=1}^{N} \pi_n(J, \Pr), \quad n = 1, N, \quad \Pr = 0, 1.
\]

It is required, based on (1)–(6) and accounting for \( \tilde{\gamma}^{(\text{ls})}, \tilde{\gamma}^{(\text{a})} \), to determine the current signal-interference situation and the corresponding structure number of the information-measuring system of the moving object. It is also required to propose a rational option for correcting the weight of a priori information in cases of its inconsistency with the actual one.

3. Recognition of signal-interference situations
Recognition of the signal-interference situation that has developed at the current time can be performed in accordance with the Bayes formula:
\[ \hat{P}_k^{(s)} = \left[ \frac{P_k^{(s)}(Pr, z|s)}{\sum_{s=1}^{S} P_k^{(s)}(Pr, z|s)} \right]_k, \]  

where \( P_k^{(s)} \) are the a posteriori and a priori probabilities of the s-th signal-interference situation, respectively; \( P(Pr, z|s) \) is the probability of a joint change in the states of indicators of accompanying signs of signals and interferences of a moving object when the s-th signal-interference situation occurs at the k-th moment.

In cases where there is no information about the predominant effect on the information-measuring system of certain interferences, the prior probabilities \( P_k^{(s)} \) at the initial moment of time will be equal to 1/S. As the prior probability \( P_k^{(s)} \) at the next step, its value from the previous step can be used. Under the assumption of a normal distribution of signals and noise, expression (7) can be represented as

\[ \hat{P}_k^{(s)} = \left[ \frac{P_k^{(s)}(Pr, z|s)}{\sum_{s=1}^{S} P_k^{(s)}(Pr, z|s)} \right]_k, \]  

where

\[ g^{(s)}(z) = \sum_{i=1}^{I} g^{(s)(i)}(z^{(i)}), \quad s = 1, S, \quad i = 1, I; \]  

\[ g^{(s)(i)}(z^{(i)}) = \left( \frac{z^{(i)} - \mu^{(s)(i)}}{\sigma^{(i)}} \right)^2, \]  

\( z^{(i)} \), \( \sigma^{(i)} \) — respectively the output signal of the i-th meter and its standard deviation; \( \mu^{(s)(i)} \) is the average value of the i-th phase coordinate in the s-th signal-interference situation.

The decision about the current signal-interference situation and, accordingly, the number of the structure of the information-measuring system of the moving object is made according to the criterion

\[ \hat{s} = \text{argmax}_S (\hat{P}_k^{(s)}). \]  

In the case when the a priori intensities \( \tilde{P}^{(Is)}, \tilde{P}^{(sl)} \) of the change in signal-noise situations are known, expression (8) can be represented as

\[ \hat{P}_k^{(s)} = \left[ \frac{P_k^{(s)}(Pr, z|s)}{\sum_{s=1}^{S} P_k^{(s)}(Pr, z|s)} \right]_k, \]  

where

\[ \tilde{P}_k^{(s)} = [\hat{P}_k^{(s)} - \Delta t(\tilde{P}^{(s)} \sum_{s=1}^{S} \tilde{P}^{(s)} - \sum_{i=1}^{S} \frac{\tilde{P}^{(Is)}}{\tilde{P}^{(l)}})]_{k-1}, \Delta t = \text{tk-tr-1} \]  

Thus the algorithm for recognizing signal-interference situations will consist of (12), (13), (6), (9)–(11). In this case, in the process of a moving object functioning, it is advisable to record the facts and duration of the effect of interference on the information-measuring system to correct the values \( \tilde{P}^{(Is)}, \tilde{P}^{(sl)} \) used in (13).

Preliminary studies of the algorithm (12), (13), (6), (9)–(11) showed that when a priori and actual intensities of the change in signal-noise situations coincide, the probabilities of making a correct decision about \( \hat{s} \) are close to 1 and decrease as the mismatch grows.

Algorithms (8), (6), (9)–(11) and (12), (13), (6), (9)–(11) are quasi-optimal and depend on the accuracy of the used a priori data, which is typical for Bayesian approaches.

To improve the proposed algorithms, the opportunity of correcting the weight of a priori information in algorithm (12), (13), (6), (9)–(11) is considered in cases of its inconsistency with the actual data. The correction option consists in using a priori information about \( \tilde{P}^{(Is)}, \tilde{P}^{(sl)} \) in expression (13) at the next step with a weight coefficient \( D \) depending on \( \Delta t \)

\[ \tilde{P}_k^{(s)} = [\hat{P}_k^{(s)} - \Delta t(\tilde{P}^{(s)} \sum_{s=1}^{S} \tilde{P}^{(s)} - \sum_{i=1}^{S} \frac{\tilde{P}^{(Is)}}{\tilde{P}^{(l)}})]_{k-1}, \Delta t = \text{tk-tr-1}. \]
where \( D = \frac{1}{d \Delta \tau + 1} \); \( d \) — coefficient determined heuristically. The start of integration of time \( \Delta \tau \), in addition to indicators, can be carried out when a predetermined threshold is reached for any phase coordinate of a moving object, selected when classifying signal-interference situations. To determine the correction parameters, it is necessary to perform statistical simulation of a specific moving object, its information-measuring system and signal-interference situations. Preliminary studies have shown that correction (14) can significantly improve the accuracy of algorithms (8), (6), (9)–(11) and (12), (13), (6), (9)–(11).

4. Conclusion
The paper proposes Bayesian algorithms for assessing the current state of a moving object and its information-measuring system, which make it possible to recognize various signal-interference situations from an a priori formed list. An approach to the correction of a priori data during operation is proposed. The algorithms are formulated in a very general form, which allows them to be applied to objects of various classes.

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