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The monitoring channel of the random process parameters with the simplified structure in discontinuous conditions variation

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The monitoring channel of the random process parameters with the simplified structure in discontinuous conditions variation

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Abstract. The modern requests of movement trajectory monitoring of any devices like a car or an aircraft as well as e.g. power facility parameters make one solve the task of measuring devices development which can stable operate at the extremal unexpected both coordinates variation and their derivatives. Such task can be solved by monitoring measuring devices synthesis with changeable characteristics and structures depended on the situation mainly based on variable combination of the state models. Both the functioning and simplified algorithm of the measuring system based on the synthesis technique was developed. The algorithm system consists of two simple linear filters, residual comparing scheme and estimate choice one. The both algorithms formed by the system theory technique and simplified with selection mode give the concurrent assessments.

1. Introduction

Aimed at coordinates monitoring effectiveness of moving objects including both accuracy and immunity improving, the radio-electronic sensor (RES) system constructed on several subsystems with different structures (parameters set) is reasonable providing the system capability at the changing modes with variating signal-noise situation as well as monitoring process breaking or signal values discontinuous variation due to unpredictable reasons [1–3].

The movement trajectory monitoring necessity of a carrier vehicle make one solve the task of reliable measurement with small error bar values including interference attacks. Such task can be solved by RES synthesis with changeable characteristics and structures depended on the situation.

2. Theory

In general, the potential errors are tracing using analytical methods as the first step of RES operating analysis, the second step – the actual ones locating by the simulation modeling (as a rule). At the first stage the both system and stand-alone devices potential accuracy are defined aimed at theoretical determination of a possible error value. Moreover, it is one of the most valuable indications of the RES acceptability: if the potential accuracy value less than the demanded one, the next step is the divergence source definition.

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The potential accuracy of optimal RES is determined by a posteriori filtration error analysis using typical equations calculation [4-6]. It should be noted this dispersion value depends on application condition defined in RES filter models both statistical transient response data and observation noises. The equations can be quite easy solved by analytical methods only in case of system with small equations number (two or three ones).

Providing that the potential errors are suited to the requirements, the accuracy closeness in estimation at the near actual conditions (the actual accuracy, thereafter) is analysed. The basic analysis method of the actual accuracy is the simulation modelling ended with the final result determination including both fluctuation and dynamic errors throughout the full area of possible conditions. The extremal moment of the errors increasing (the estimation process divergence) is also considered. The structural scheme of the algorithm for two parameters type is presented in figure 1.

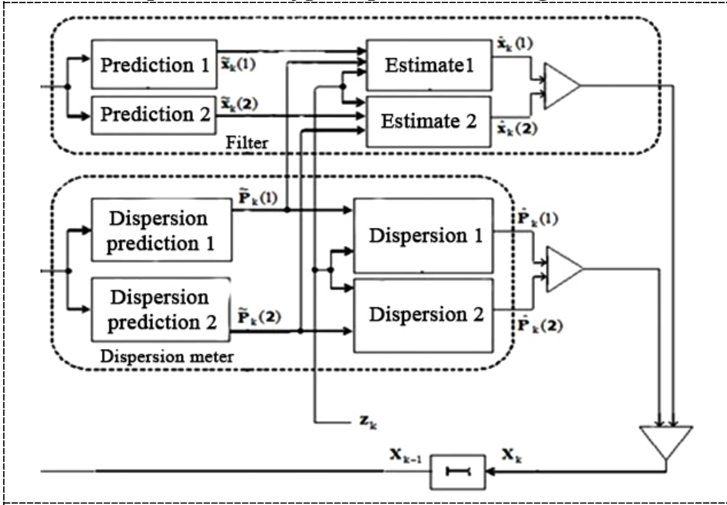

Figure 1. The algorithm operating scheme

As is clear from figure 1 the calculation consists of two stages – prediction and correction [4–6]. For each step k and the model index (number) s_k the estimation result at the correction stage depends on both the observation z_k and calculated prediction based on the previous step estimation result [7]. Despite the probable linearity (it is often in the reality) of the both object model and the measuring device, the filtration algorithm is non-linear due to “phase coordinates vector estimation - random structure variation” dependence presence. However, the offered algorithm is realizable using modern computational software.

It should be stressed the partial aposterior covariance matrixes of the filtration errors, e.g. for the first filter $\widetilde{P_k}(1)$, calculated by the algorithm (figure 1) allow to define the estimate accuracy of the linear model status. Therefore, they can be used at the optimal filter functionality estimation in the precise correspondence to the actual condition only. The accuracy will be estimated by the matrix diagonal elements $\widetilde{P_k}(1)$ characterized the aposterior errors of the status vector filtration: $\widetilde{P_k}(1)_{11}$ – estimate error dispersion of the current coordinate; $\widetilde{P_k}(1)_{22}$ – estimate error dispersion of the first order derivative coordinate; $\widetilde{P_k}(1)_{33}$– estimate error dispersion of the second order derivative coordinate. For example, it can be the distance to the tracking object, the closing speed V_r and slewing rate V_r.

The potential standard deviations value (PSD) of the phase coordinates estimation can be defined only by computer modeling due to random variation type of both parameters and the synthesized filter structure. As was already mentioned the aposterior covariance matrixes of the filtration errors $\widetilde{P_k}(1)$ depends on the application condition only.

3. The task solution

The partial PSD of the phase angular coordinates estimate at the stable mode for RES based on three partial models as three RES parts are presented in table 1; FAF – fast-acting filter, BF – basic filter, WF – wave-trend filter [5, 6].

Table 1. PSD of the phase angular coordinates estimate

Expected tracking noise power, mW	PSD of the phase angular coordinates estimate ($\sigma_\varphi \cdot 10^{-4}$ radian)		
	FAF	BF	WF
0.001	2.2	0.45	1.4
0.01	7.3	2.7	7.9
0.1	22.4	21.4	44.7

According to table 1, the BF has the minimum PSD value at the stable conditions due to the narrowest transmittance line. However, in case of the tracking noise raising the PSD values of both FAF and WF are close to each other.

Aimed at the actual signal estimation of the RES partial filter the surge characteristic building of the tracking system does out of necessity: the signal – discontinuous changing of the true radio bearing of the target φ at the varied tracking noise background ξ_φ – is given to the system input. Such text signal application allows to provide the synthesized algorithm estimation independently from both random angular target coordinates variation and the subjectiveness selection of the actual target manoeuvre realization.

It should be stressed out the filtration algorithm suggests the partial covariance matrixes application only. The data presented in table 2 are PSD for each partial model. The summarized PSD matrix is not calculated here but taking into account the weight criteria summarizing, the total angle error is very slight less the minimum partial filters one. The partial PSD (FAF, BF, WF) and the total PSD of the tracking system (TF) at the both stable and surge modes are presented.

Table 2. PSD for partial model

Function mode	PSD of the phase coordinates estimate ($\sigma_\varphi \cdot 10^{-4}$ radian)			
	FAF	BF	WF	TF
Surge	26.0	380.0	210.0	26.3
Stable	10.8	5.2	7.2	6.2

Both the surge process time t and PSD of tracking noise dispersion value (power) for each partial filter are shown in table 3.

Table 3. Surge process time and PSD at the stable mode

Expected tracking noise power, mW	Surge process time t, s			PSD at the stable mode ($\sigma_\varphi \cdot 10^{-4}$), grad		
	FAF	BF	WF	FAF	BF	WF
0.001	0.06	0.72	0.28	43.8	1.1	4.4
0.01	0.1	1.22	0.52	80	6.3	23
0.1	0.3	2.62	0.8	200	40	120

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Since the minimum time of the surge process is typical for FAF, the highest accuracy – at the stable BF mode.

It should be stressed out again both such small surge process time and high accuracy are caused the potential errors estimate not consider a lot of real function features such as both quantization and discretization errors, round-off error and limited number of digits and etc.

We can conclude that quite fast all filtration PSD are convergently decreased from initial values (1-3s) wherein the quickest changes are fixed for FAF as well as the both angle and angular rate PSD at the stable mode are constant.

4. The simplified algorithm

The developed algorithm is quite complex due to high number of crossed connections even for two models [8]. As it known the measuring residual value is based on action of the measurement background and measurement prediction inaccuracy for the next step. Providing for the described situation the total signal of the primary device is given to the system input, the measurement residual variation with respect to background will be similar for the both models subsystems. The residual mismatches will mainly appear due to different prediction models. It allows to simplify the developed algorithm at the same foundation.

As it clear from figure 2 the structural system consists of two typical linear filters (F1, F2), the residual comparing scheme and estimate choice one. To the filter input the RES signals are given (RES is the primerary measuring device) then the output signal from F1 and F2 are given to the only output that is supported by the residual comparing scheme.

On the condition the F1 residual value less F2 one or in contrast the F1 residual more F2 one at the residual comparing system output (A<B or A>B relatively) the high degree signal will appeared, which will switch the estimation scheme input, resulted to the only signal (either F1 or F2) giving to the estimation scheme input. At the radio interferences presence, the both residuals are increased the same.

Different residuals are based on movement variation of the tracing object (manoeuvring e.g.). We will use the input signal with the minimum residual value as more preferable due to minimum signal deviation. Then the received residual values redirected to the comparing system input by the comparator which is switched the sig al to the input. This technique allows to determine coordinates as well as to detect the aircraft manoeuvre.

In figure 3 both the true coordinate behaviour *x(k)* (curve 1) and resulting estimate $\hat{x}(k)$ (curves 2 and 3) of the synthesized and simplified algorithms obtained at the same conditions are presented.

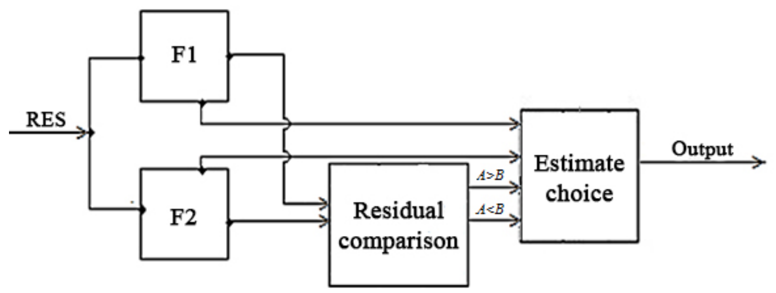

Figure 2. The simplified algorithm structure of coordinate estimation

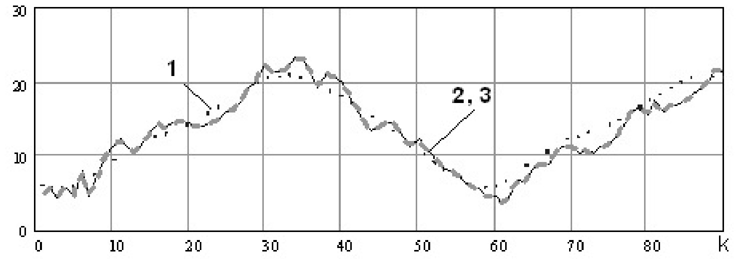

Figure 3. The true coordinate and its estimate variation

5. The modelling results

Through this process estimations carried out using the developed algorithm based on two state models by the system theory techniques with random structure as well as the simplified one are just congruent. This is due to the fact the models, which are characterized by different parameters at the detection of the estimated factors variation as well as just accurate tracing of the signal deviations either the first or the second model, were used. In general, the statistical modelling results demonstrate the developed algorithm effectiveness. Also, such method of tracing system construction allows to use several filters each of them is adjusted on own working area without drastic full system complication.

Let us to describe one more feature of the simplified estimation system: assuming the true coordinate value is varied as it shown in figure 4 (curve 1). Since 0 to 20 steps time the coordinate is constant. There is a very slight coordinate variation with the zero-order expectation. At the 20…45 steps interval the target snatch is happened with the next return to the initial position after that (46…100 steps) there is small random coordinate variation with the zero-order expectation again.

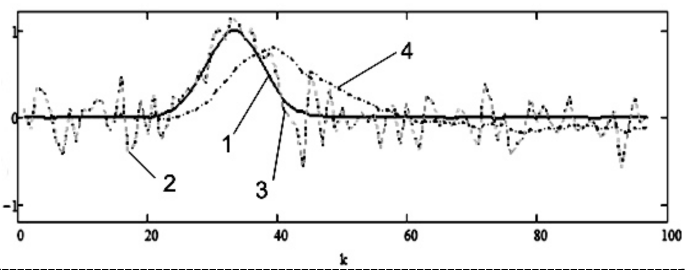

Figure 4. The coordinate variation

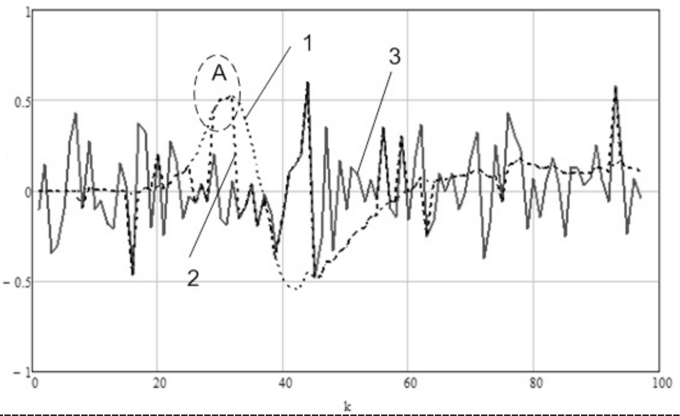

Figure 5. The F1 (1), F2 (2) errors and the error at the united filter output (3)

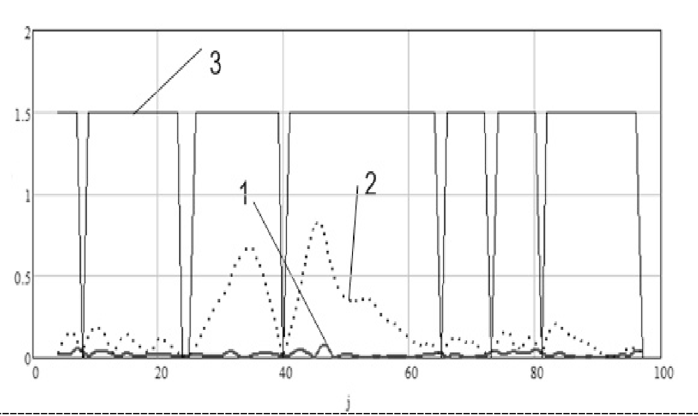

Figure 6. The F1 (1), F (2) residual and the multiplexor operation

Moreover, in figure 4 the coordinate value measured using the primary device (curve 2) as well as its estimation at the both F1(wide-band) (curve 3) and F2 (narrow-band) (curve 4) inputs are presented. As we can suggest at the angle snatch (200.45 steps) the high dynamic F2 error is appeared but herein there is no noticeable F2 reaction to the tracing background (noise). At the same time the dynamic error of the wide-band filter is absence but the filter reaction on the noise component is significant. The F1 (curve 1) and F2 (curve 2) filters errors and the multiplexor output error of the united filter (curve 3) are presented in figure 5. As it clear that at some moments (A area) the multiplexor sends to the output the estimate not with the minimum error but maximum one due to residual and error values disagreement despite their dependence. Aimed at residual value snatch minimization the smoothing methods can be applied.
The listed factors operation modelling with residual smoothing by different low frequency was carried out, in particular, using the tertiary Butterworth digital low frequency filter. In addition to F1 (curve 1) and F2 (curve 2) residual the multiplexor action (curve 3) is present in figure 6: at the high value the F1 estimate is given to the multiplexor output, at the low one – the F2 estimate. At this stage filter switching is less frequent as the result of the dynamic component error variation. The standard deviation decreases by 10-15% for the typical operating condition.

Table 4. Output filters errors

№	Output filter signal	Standard deviation, radian
1	Wide-band filter	0.032
2	Narrow-band filter	0.046
3	United filter	0.024
4	Primary measuring device	0.056

Conclusion

The developed simplified algorithm accuracy is close to the synthesized one which is basen on the system theory using with random discontinuous structure variation. The simplified algorithm structure is more compact than at three or four analysis models. In general, the simulation modelling results shows the offered technique effectiveness.

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