The Detection of Lengthened Objects by Pulse Altimeter

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Abstract

The algorithm of lengthened objects detection is based on statistical processing of reflected pulse altimeter signal. The method of maximum posteriori probability is applied to make a decision. Minimum of maximum posteriori probability is accorded with lengthened objects position. This fact is taken into account to detect the objects' position. This algorithm allows autonomic navigation to be implemented. Two cases of the algorithm implementation are shown in this article. The first method is based on the unsharpened beam regime of radar altimeter and the second is based on the application of the Doppler's filtration. The results of flight experiments proving the correctness of the created algorithm are introduced in this article.

1 Introduction

The necessity of robustness navigation system design for the unmanned airborne vehicles (UVA) is demonstrated in the article [1]. It is applicable for the relief navigation system supplement, if the relief of the terrain is mild. While examining this fact, the onboard pulse radar altimeter [2] with wave length of the carrier frequency in C-band as the sensor was applied. This algorithm was designed for a nearby horizontal flight where the evolutions are absent.

While solving the problem of lengthened objects (LO) detection, the properties of different terrain types were explored and the patterns of the reflected signals amplitude distributions were obtained. The terrains were classified by the width of the backscattering diagram and the module of the reflection coefficient so that allows to their identification to be done, as it is made in [1]. On the base of [1, 2, 4] the amplitude distributions of the reflected signals, related to the known terrains were obtained. The term "the pattern" was introduced. The given distributions allow us to estimate the compliance rate between patterns and current distributions if they are compared during the flight and model experiments. The comparison is corresponded to the estimation of the pattern's crossed square and current distribution (see Fig. 1). As the result of the square computation, it is possible to obtain the probability of the correct detection and the minimum of the maximum posteriori probability function corresponding to the border between two changing types of the terrain.

While modeling, a facet phenomenological model of the reflected signal was applied. It was described in [1].
In this paper the points from [1] are enlarged and applied to LO of the stripe type, the accuracy of the border (between two typical terrains) detection is also evaluated.

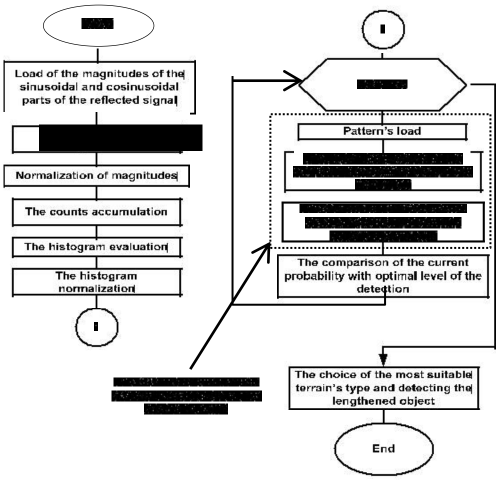

Figure 1: The algorithm of lengthened objects (LO) detection

2 The Typical Regime of Radar Altimeter

The model experiment is organized according to the Fig. 2. as follows: UVA is moving from the “terrain I” across the “terrain II” to the “terrain I”, here the “terrain II” is LO. In Fig. 2 it is marked the next: D – the LO width, L – the exposure spot width, Θ – the LO’s orientation angle. As the result of signal accumulation for each, the UVA’s position is identified (there were more than 10 000 envelope counts per the UVA’s position), used for the probability estimation evaluation.

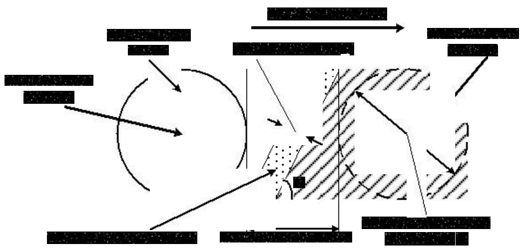

Figure 2: The Model experiment of linear reference (LO) detection

The combinations of typical terrains, which are applicable for LO detection are described in [1].

The results of the model experiment in the case of “forest/asphalt” are shown in Fig. 3.

According to the Fig. 3, the real borders are shifted symmetrically to the borders detected by the algorithm. It is explained by the minimum shift of posteriori probability function to the side of the less reflective terrain. The minima of the posterior probability detect the border between typical terrains which can be evaluated by the shift error (in Fig. 3 the shift error is about 15% of the exposure spot width), and the minimum probability of the correct detection is 0,8.

The results of the model experiments for LO detection are introduced in the Table 1 for the case with Θ=[30˚;90˚] and different signal/noise ratio.

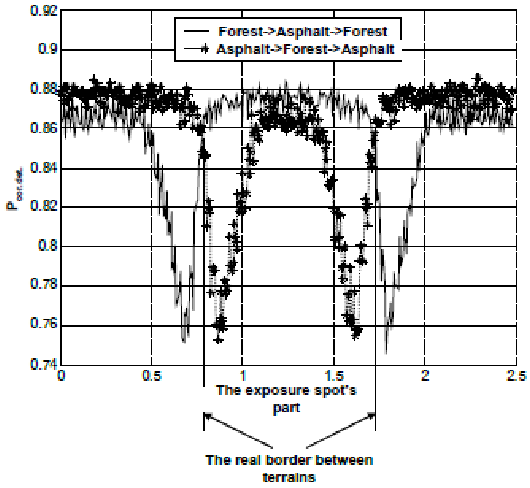

Figure 3: The results of model experiment for LO, with its width 0,8 of the exposure spot, terrain combination "asphalt/forest"

The Table 1 makes it possible to choose the terrain's combinations which could be distinguished during the flight by the pulse altimeter. As the result, the best LO for the algorithm is the "water" surface with the background of the scattering terrains such as "meadow" or "forest". This result is similar to the point in [1]. In addition, the real width of the LO is closely connected to the flight's height and the narrow objects can be detected at low altitude.

Table 1: The ability of the lengthened objects detection under the additive noise influence

SN=0дБ		SN=10dB		SN=20dB		SN=30dB	
D=0,1L	D=0,8L	D=0,1L	D=0,8L	D=0,1L	D=0,8L	D=0,1L	D=0,8L
FAF	FAF	FAF	FAF	FAF	FAF	FAF	FAF
FWF	FWF	FWF	FWF	FWF	FWF	FWF	FWF
GWG	GWG		GWG		GWG		GWG
BAB	BAB		BAB				
BWB		BWB	BWB	BWB	BWB	BWB	BWB
MAM	MAM		MAM		MAM		MAM
MWM	MWM	MWM	MWM	MWM	MWM	MWM	MWM
SWS	SWS		SWS		SWS		SWS
	ABA						
	WGW		WGW		WGW		WGW
	WMW		WMW		WMW		WMW
	WSW		WSW		WSW		WSW
			AFA		AFA		AFA
			WFW		WFW		WFW
					AGA		
			AMA		AMA		AMA
			GAG		GAG		GAG

In the Table 1 following abbreviations are used: SN – signal/noise ratio, A – asphalt, B – bushes, C – concrete, F – forest, G – grass, M – meadow, N – ground, S – snow, W – water. For example, the abbreviation FAF is equivalent to the combination "Forest-Asphalt-Forest". Shadowed combinations with high false detection probability of the LO are also presented in the table. It can happen because of signal and noise nature, being not the matter of importance for the algorithm it does not matter. These cases have to be excluded from the study.

Table 1 can be used to choose the LO, for designing recommendations and while choosing the UVA route.

3 The Doppler Filtration

The application of the Doppler filtration (DF) as the method of increasing the algorithm's spatial resolution for solving the problem of LO detection is shown in this part of the reserch.

According to [2], we can observe the curves of equivalent Doppler frequencies on the terrain, which appearance can be explained by equivalent radial velocities of the UVA in relation to the terrain. We need to find the conditions of DF application which are necessary for supplying the maximum posteriori probability.

Three series of experiments were conducted for the test. In the first range of the experiments, the orientation of the Doppler filter (see fig. 4) was changed and the probability of the correct discrimination of the terrain was estimated [1].

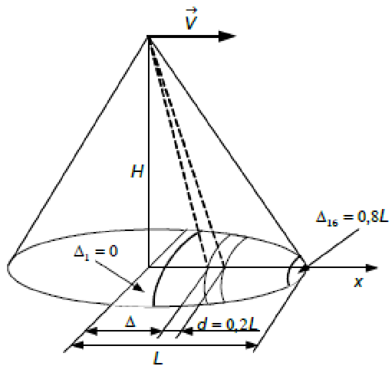

Figure 4: Model experiment to find the best conditions of Doppler filtration application

In Fig. 5 the results of the model experiments are shown. It was obtained that the maximum posteriori probability could be gained according to the position in Fig. 4, which is marked with Δ1.

Similarly, the other experiment was conducted. The width of the Doppler's filter's stripe was changed to the optimal angle, which was obtained in the previous experiment. As the result, it was achieved that the minimal d (0,2L) provides the maximum posteriori probability. Here is d – the Doppler stripe width; L – the exposure spot width.

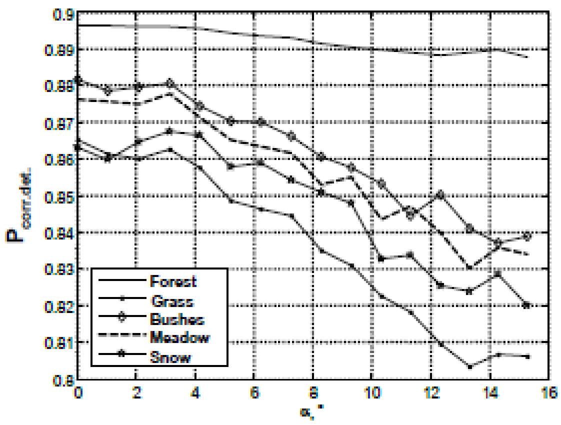

Figure 5: Dependence $P_{cor.det}.(\alpha)$ for "water" combination and some background terrains

So, during the test it was obtained that the DF provides better discrimination for terrains if the width of the Doppler stripe is small (d≤0,2L) and the direction of the exposure is corresponded to nadir direction.

The application of the Doppler filtration provides the increasing of the spatial resolution for the radar altimeter. It allows us to detect narrow LO, but simultaneously it can prevent us from the detection if the angle φ in Fig. 6 is small.

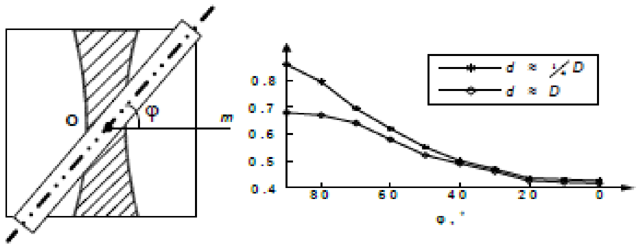

Figure 6: The model experiment m(φ) for two ratios between d and D

The third experiment was about LO's orientation. Fig. 6 shows the relative part of the LO in the Doppler's filter's stripe (m) from the angle of the LO (φ)orientation . The model experiment showed that the maximum influence in the reflected signal delivered by the LO is oriented co directional to the Doppler stripe. If the angle is φ=30˚, the part of the LO decreases by half. As the result we suggested that the advantages of the DF are applicable only if φ≥30˚. In this case maximum posteriori probability gained if φ=90˚.

The similar to [1] experiment was conducted during the exploration and the results are shown in Table 2. The results of the experiment similar to the model experiment in [1] are presented in Table II. Here are the number of discriminated terrains if the signal/noise ratio (sn) and the width of the LO are changed (D).

Table 2: The ability of lo detection if the normal noise influences are added

SN=0дБ		SN=10dB		SN=20dB		SN=30dB	
D=0,1L	D=0,8L	D=0,1L	D=0,8L	D=0,1L	D=0,8L	D=0,1L	D=0,8L
FAF, FWF, GWG, BWB, MWM, SWS	FAF, FWF, GWG, BWB, MWM, SWS, WGW, WMW, WSW, AFA	FAF, FWF, GWG, BAB, BWB, MAM, MWM, SWS, GAG	FAF, FWF, GWG, BAB, BWB, MAM, MWM, SWS, ABA, WGW, WMW, WSW, WFW, AGA, AMA, GAG, WBW	FAF, FWF, GWG, BAB, BWB, MAM, MWM, SWS, GAG	FAF, FWF, GWG, BAB, BWB, MAM, MWM, SWS, ABA, WGW, WMW, WSW, WFW, AGA, AMA, GAG, WBW, ASA	FAF, FWF, GWG, BAB, BWB, MAM, MWM, SWS, GAG, SAS	FAF, FWF, GWG, BAB, BWB, MAM, MWM, SWS, ABA, WGW, WMW, WSW, WFW, AGA, AMA, GAG, WBW, SAS, ASA

The information in the Table 2 provides the detection of LO with the probability of correct discrimination higher than 0,6 if φ is changed from 30˚ up to 90˚. As the result, it is shown that the change of the signal/noise ratio leads to the change of typical LO number which can be detected by the algorithm (decreasing leads to the increasing of the LOs), also the increasing of the LO width leads to the LOs number increasing.

4 The Flight Experiments

The information from the experiments [4] was used during investigations. Two flights were made. The flights had similar tracks in three heights: 60m, 100m and 300m. The weather conditions of flights were different, in pattern's flight it was rainy and in the second flight it was dry. The results of the experiment were processed by the created algorithm from [1].

To conduct the flight experiment, the information was obtained from pulse radar altimeter [2] synchronized with the information from satellite navigation system (GPS) and with video record (see Fig. 8). So, we had the ability to fix the change of the terrain with the accuracy of about a few meters.

The comparison of the current model experiments' results with the typical regime for pulse radar altimeter shows that DF allows us to distinguish approximately twice typical LOs than typical regime.

Figure 7: The scheme of flight experiment

The program in MATLAB's script was also designed. The program makes it possible to accomplish the process of flight experiments according to the created algorithm.

Furthermore, the information was processed by applying the multistage scheme. At the first stage the information from the pulse altimeter was prepared (the pulse train was formed, computed quadrature with considering the amplifying and many flags). At the next stage the histograms of the reflected signals were formed (see Fig. 7). In the pattern experiment the histograms were identified according to the video record. For the processing the segments of homogenous typical terrain were chosen. There were no any significant evolutions of the UVA. These segments for different heights were normalized and after averaging, the histograms for typical terrains were build. As a result, the pattern histograms for typical terrains with the types: "water", "forest", "meadow" and "ground" were received. The patterns for the case of Doppler filtration were also obtained

In the second flight experiment the information for all tracks was processed by the designed algorithm, and we have the time dependent on the correct detection probability (for example, see Fig. 8).

The plots of the time dependence of the probability were analyzed in accordance to the video record. According to the Neumann-Pearson criteria, the optimal level, which provided the maximum probability of the correct discrimination, was evaluated, if the false detection was fixed. The information of Table 3 was obtained as the results of correct and false detection.

In the Table 3 next abbreviations were used: level – the optimal level of the correct probability detection without DF;

level – the optimal level of the correct probability detection with DF;

< > – the percentage of the objects which were detected correctly for the typical application of the radar;

< > – the percentage of the objects which were detected correctly for the case of Doppler filtration.

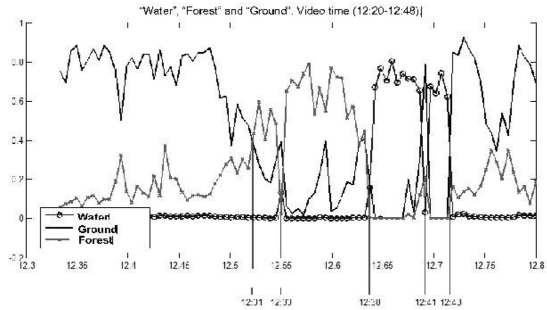

Figure 8: The probability of correct detection for different terrains during the flight

Table 3: The summary table for the results of the exploration during the flight experiments

The terrain type	Water	Forest	Ground	Meadow
Level $P_{cor.det.no.DF}$	0,4	0,6	0,6	0,6
Level $P_{cor.det.DF}$	0,4	0,5	0,6	0,5
$< N_{\%no.DF} >$	44	27	43	63
$< N_{\%DF} >$	60	31	31	54

According to the Table 3, during the flight experiments it was found out that for typical application of the pulse radar the detection of the “water” was provided in 44% cases, «forest» – 27% (because «forest» – significantly heterogeneous terrain), «meadow» – 63%, and «ground» – 43%. In addition, the application of the DF makes it possible to increase the probability detection for narrow LOs (the width is less than ¼ of the exposure spot’s width) of the “water” type at least 15%, but the probability of correct detection simultaneously and significantly decreases for “ground” and “meadow”, because of wide backscattering diagram, that leads to decreasing the contribution of these terrains into the reflected signal.

So, it is recommended to apply both types of processing: the DF and typical processing. It depends from the type of terrain which we want to detect.

In the future, the series of flights above homogenous terrains are planned to be done. The experiments will be implemented for creating more preciously pattern histograms

5 Conclusion

In this article the significant results were obtained:

1. Two cases of the created algorithm application were examined: the pulse radar altimeter with unsharpened beam and the narrowed beam by the DF. It was shown that the regime of Doppler filtration allows us to increase the number of detected terrain’s combinations at least twice. For example, if DF is used, the algorithm can detect next terrain combinations (with narrow “water”) “Bushes/water/bushes”, “Grass/water/grass” and so on.
2. The flight experiments validated the correctness of the created algorithm. It is obtained, that the combination of unsharpened beam and DF algorithms allow us to detect more than 60% of the narrow “water” objects, “meadow”, “ground” and “forest” objects can also be found
3. The results of the current investigation allow us to choose the lengthened objects which are suitable for the UVA navigation. It is shown that the terrain combinations “water/forest” and “asphalt/forest” provide the maximum of the correct discrimination probability if LO is oriented to the flight direction with the angle from 30 up to 90 degrees and the signal/noise ratio is not less than 0dB.

References

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