Algorithm of Linear References Detection by Pulse Altimeter Signal

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***Abstract*—Algorithm of linear references detection is based on statistical processing of reflected pulse altimeter signal. In assumption, linear references formed from two underlying surfaces and differences between statistical distribution of pulse amplitude depends on type of underlying surface. Differences allows us to decide which type of surface reflects our signal. We use method of maximum posteriori probability to make a decision. In this paper it is shown how to determine position of linear reference and what is the accuracy of this process. Minimum of maximum posteriori probability accorded with linear reference position. We use this fact to detect linear reference position. This algorithm allows to realize autonomic navigation. We use Doppler sharpening to increase accuracy of detection of linear reference position and increase number of discriminated surfaces.**

Keywords—radio navigation; radar tracking; linear references; radar remote sensing.

I. Introduction

In previous paper [1] it was told about necessity of stable navigation system creation for airborne vehicles, which is independent from Sputnik Navigation System (SNS). In that exploration we used onboard pulse radar altimeter as sensor with carrier wave length 7cm, which allows us to increase robustness and accuracy of the navigation system. This algorithm is created for tracking part of trajectory, when evolutions are les than 10˚.

During solving this problem we found that properties of terrain surfaces are different and some of them may be classified. It is known that a lot of experiments are described in [1] and some other less known sources. We used this information during our exploration. And we found that backscattering diagram (BSD) accorded with statistical distribution of amplitude of reflected signal.

The base of algorithm of discrimination of two underlying surfaces was introduced in [1] too. Briefly, we collected information about typical underlying surface, which give us distribution of reflected signal. Then we compared hypotheses and found maximum of a posteriori probability. Minimum of this function corresponded with border between two types of underlying surface. In case of linear references we have two borders between underlying surfaces. Than we use this information to correct airborne vehicle position relatively to linear references, which are situated in fixed places showed on geographical maps or sputnik snapshots.

II. Main Part

A. Surfaces discrimination

As shown in [1], after quadrature detector reflected signal from most typical underlying surfaces has Rayleigh distribution, which has only one parameter. This fact allows us to discriminate surfaces by integral statistic of reflected signal by comparing accumulated distribution with etalon distribution.

As result we have probability of correct discrimination. In accordance with statistical theory when we compare two or more processes we compare two or more distributions in accordance with a priori hypotheses, at first we got these distributions from [2], in this source all types of surfaces have maximum probability about 0.9 (because they are situated between 5% and 95%, other 10% are spread very widely to use this information). And the normalized crossed square is probability of false detection (if we compare two different types of distributions) or true detection (if we compare two similar distributions).

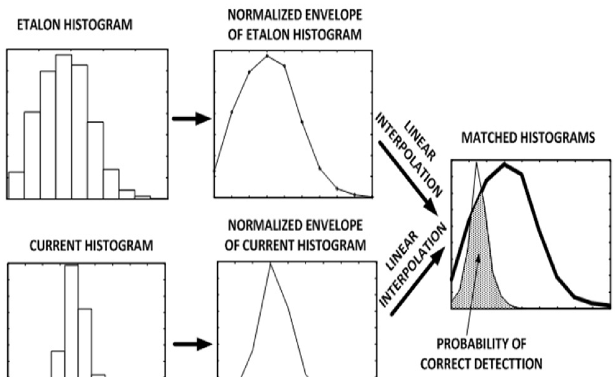

Fig. 1. Comparison process is the base of algorithm

On fig. 1 it is shown comparison process the base detection algorithm.

At first we collect amplitude of reflected signal for etalon histogram (where we know terrain type), then we do the same for unknown terrain type (amplitudes get during the flight).

Then we made necessary transformations for comparison process (they are shown on fig. 1). And at last we compute the crossed square, it is probability of correct detection (discrimination of terrains).

The result of comparing two Rayleigh distributions is shown on fig. 2.

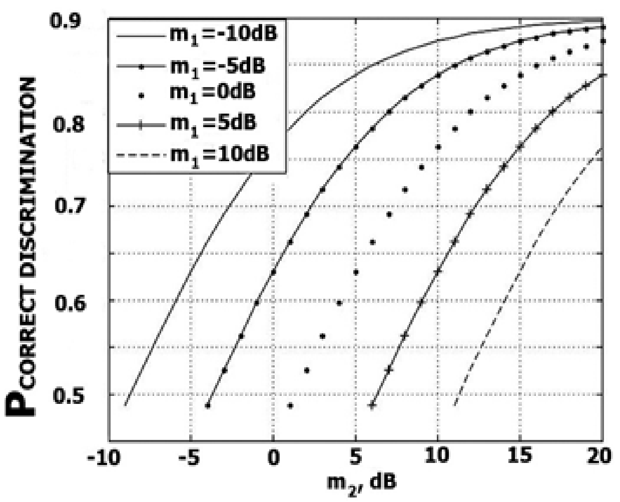

Fig. 2. Probability of discrimination of two different rayleigh distributions

Using fig. 2 allow to choose combinations of surfaces by parameter of Rayleigh distribution, that should be used as linear references (LR).

B. Classification of underlying surfaces

The main source of terrains combination is [2] and we used some other unofficial sources to fill the terrain base. Information analyze in [1] give us the table I of typical terrains combinations with qualitative characteristic.

It was shown, that backscattering diagram is the most important parameter influences on the ability of terrains discrimination. This information allows us to group terrains by ability of discrimination into table I.

TABLE I. TERRAINS COMPARISION.

Qualitative Characteristic	**Easy to discriminate**	**Discrimi-nated**	**Hard to discrimi-nate**	**Impossible to discriminate**
Angles, °	0–10 and more	0–3	0–3	0–30
Backscattering coefficient, dB	>10	about 10	1–7	More than half of std
Combination of terrains	Forest–water, grass–water, meadow–water, bushes–water	Asphalt–forest, asphalt–bushes, asphalt–meadow, concrete–forest	Asphalt–snow, grass–concrete, bushes–concrete, snow–concrete	Forest–bushes, forest–ground, grass–ground and etc.

Using this table allows us to choose some interesting cases for further exploration: well discriminated surfaces are combinations of terrains: the first terrain with large width of backscattering diagram, such as water (in some cases little width of backscattering diagram, such as asphalt) and large backscattering coefficient and the second surface with large width of backscattering diagram and little backscattering coefficient.

C. Model of reflected signal

In [1] it was described mathematical model for exploring algorithm of border detection, it can be used for exploring linear references (LR). In this part we will shortly describe main features of model and then we will introduce main features for LR exploration.

This model is based on phenomenological model, which is described in [3], and it is referred to the facet model, where each facet is an elementary reflector with next parameters: normal of facet orientation, effective backscattering coefficient and bias for average level. At first step values of main parameters (vehicle position, parameters of signal and underlying surface, Doppler filter and etc.) are set. The next step is creating the surface with LR. Then we in cycle compute signal from each facet and accumulated signal with proper delays for current position, and make vehicle moving over generated surface. Reflected signal for each facet is evaluated from the radar equation [3]. For our algorithm we need in envelope, which is introduced as accumulated signal.

Then in [1] we made some model experiments which we will show there briefly.

At first, we explored dependence of possible level dispersion from type of underlying surface. For range of possible level we used edge values of probability of correct discrimination of 0.5. This dependence looks like Rayleigh distribution but raised on fixed level on ordinates axis.

Then we explored dependence of correct probability form height of flight. And it was shown that amplitude is proportional to height. Then we normalized optimal level to height and result is shown on fig. 3.

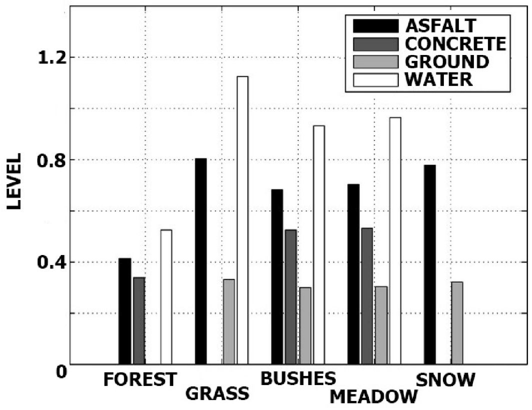

Fig. 3. Normalized level of discrimination for different types of underlying surfaces

For example, we have normalized level of 0,4 for "forest-asphalt" combination, it means that for combination of "asphalt" and "forest" underlying surfaces we have value 0,4 (it may be volts) accurate to constant (which we measure in real experiment). Now we can discriminate surfaces, based on this numbers (if more –"asphalt", less – "forest").

Then we explored dependence of correct probability discrimination from parameters of Doppler filter: they are angle from nadir direction (α) and width of Doppler filter (*d*). And we found that optimal $\alpha = 0^{\circ}$ and d is minimal, but it depends from necessary accuracy and number of accumulated pulses.

This experiments allows us to choose optimal parameters of algorithm and flight.

D. Linear references detection

This experiment we made in next sequence. At first we modeled situation to collect necessary statistic for each position. In fig. 4 is shown the way to collect dataset.

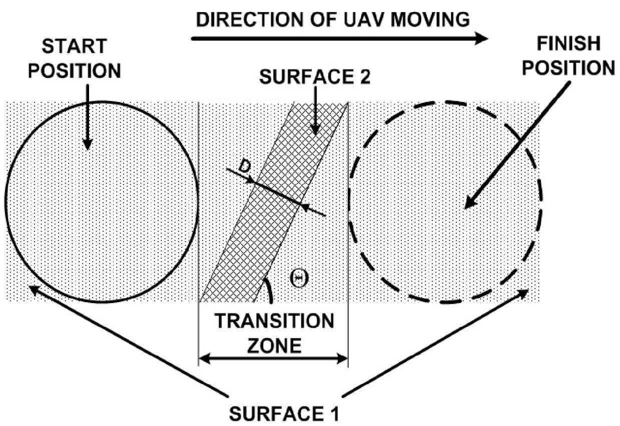

Fig. 4. To definition of model experiment

In this figures we should see that airborne vehicle trajectory is from "surface1", where is only one surface in exposure spot, throw linear reference formed by "surface2" to "surface1" at finish position. For each position we collected dataset to create the probability distribution for each position.

Then we compared etalon distribution with current distribution, as the result we get current probability of correct discrimination in assumption that we have hypothesis that we have "asphalt", for example. And we have another hypothesis that we have "forest".

Then on whole trajectory we built curve for each hypothesis for two possible situations and found maximum of posteriori probability. The result is shown in fig. 5.

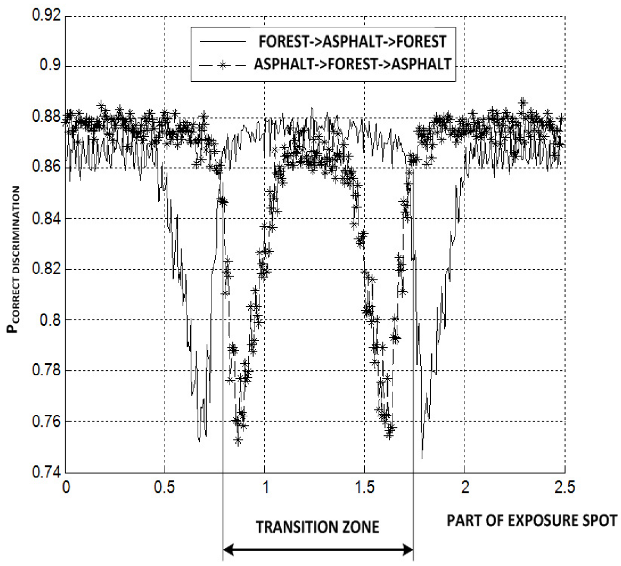

Fig. 5. Detection of LR position with width of LR=0.8 parts of exposure spot

Minimum of function in fig. 5 (maximum of posteriori probability) corresponded with borders position. Some of terrain combinations cannot be detected, and in table II it is shown those of terrain combinations, which can be detected by this algorithm in case Θ=30–90.

TABLE II. ABILITY OF LR DETECTION.

D=0.1	**D=0.2**	**D=0.4**	**D=0.8**
FAF, FWF, GWG, NGN, BWB, MWM, SWS	FAF, FWF, GWG, NGN, BWB, MWM, SWS	FAF, FWF, GWG, NGN, BWB, MWM, SWS, WGW, WBW, WMW, WSW, SNS	FAF, FWF, GWG, NGN, BWB, MWM, SWS, WGrsW, WBW, WMW, WSW, SNS, CFC, FCF, WFW, GNG

In this table we used this abbreviations: A – asphalt, B – bushes, C – concrete, F – forest, G – grass, M – meadow, N – ground, S – snow, W – water.

This table gives us information about combinations of surfaces, which should be detected during the flight. And, as it was shown in [1], the best linear reference is “water” on some spreading terrains, like “forest” or “meadow”. It is important to notice, that real width of LR strongly depends from height of flight, and thin LR should be detected on less height.

On fig. 5 the real borders of LR a bit differ from detected. It’s because backscattering coefficient of “asphalt” is larger than this coefficient for “forest”, and we should see this effect in shift from real border. This error depends from factors: width of BSD (backscattering diagram) and backscattering coefficient. In all cases error shifted to surface with low backscattering coefficient.

Then we explored robustness to additive noise and in table III is shown ability of LR detection.

TABLE III. ABILITY OF LR DETECTION WITH ADDITIVE NOISE.

SN=0dB		**SN=10dB**		**SN=20dB**		**SN=30dB**	
D=0.1	***D=0.8***	***D=0.1***	***D=0.8***	***D=0.1***	***D=0.8***	***D=0.1***	***D=0.8***
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 this table SN – means signal noise ratio. Also in this table gray colored fields’ means that in these cases we can detect LR, but this is unstable detections, because noise masking real LR, and we should see LR where it doesn’t exist. This situation is usual, because noise and signal have similar distributions.

Table III useful for choosing linear references for real experiment, and recommendation, given in this table were used for real experiment.

We made two flights over flat terrain with different types of underlying surfaces. The routes were similar, but weather conditions were different: in first flight it was dry, and in second flight it was wet and rainy.

During the flight we collected dataset of amplitude in receiver, parameters of flight, GPS coordinates and video stream of underlying surface.

Then we processed dataset with introduced algorithm and as result found that “water” should be detected in “forest” with probability of correct detection more than 0.7 for D~0.8 and with probability more than 0.5 for D~0.2. Other terrains like “forest”, “meadow” and “ground” also should be detected with $P_{cor.\ det.}$>0.5 at D>0.4. We couldn’t analyze “asphalt” terrain, because we have no good etalon, but further experiments should give us necessary information.

Thus we described application of algorithm in [1] to linear references detection, and results of experiment shows, that this algorithm works with LR correctly.

III. CONCLUSION

In this paper we’ve got next results.

We described base of linear references detection algorithm. Then we introduced previous results from [1], applied to linear references. Two main parameters influence on discrimination ability: width of BSD and backscattering coefficient. We classified these surfaces in table I. And we briefly described mathematical model as instrument for exploration. It is necessary for further understanding.

Then we made some necessary experiments to understand which types of linear references should be detected, and we found, that “water” is very good LR and it should be detected with D>0.1 and Θ=30–90, main results introduced in table III.

Then we made similar experiment that shows ability of linear references detection with additive noise. And we found some false detections that conditioned with similar nature signal and noise. But mostly we can use this table for choosing LR in real experiment.

After that we tested this algorithm with two flight experiments over flat terrain with different types of underlying surfaces. The routes were similar, but weather conditions were different.

As a result we applied algorithm of surfaces discrimination to linear references and found that it is works correctly in flight experiments. That’s why we should evolve this algorithm to increase number of detected LR and its probability of correct detections.

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