The Application of the Pulse Radar Signal for the Terrain's Type and the Lengthened Objects Identification

A.K. Sorokin, V.G. Vazhenin, L.L.Lesnaya
Institute of Radioelectronics and Information Technologies,
Ural Federal University, Yekaterinburg, Russian Federation.
sorokinak@urfu.ru

***Abstract*—This paper concentrated on radar signals, which are reflected from the terrain. We designed the algorithm that allows for some properties of the underlying terrain to be determined. A comparison process of two or more distributions was conducted, in which one of the distributions presented the distribution of the signal, reflected from typical terrain. Another distribution corresponded to the unidentified terrain. After the algorithms application, a decision on the most suitable terrain for the unidentified distribution was made. We then identified which type of the lengthened object crossed if the type of terrain changed.**

***Index Terms*—Autonomous Navigation, Statistical Distributions, Pulse Radar Signal, Terrain's Type Identification.**

I. Introduction

Autonomous navigation of an unmanned airborne vehicle (UAV) is a complex challenge for researchers [1]. One of the most important problems is correcting the process of inertial navigation system because the inertial navigation system has a growing shift in error during the flight and in many applications of UAVs, leading to the prohibition to use satellite navigation system for this purpose.

At first, we decided to explore the objects of the terrain, which could be applied as the reference objects. We found that the lengthened objects are well suited for this purpose. The lengthened objects are some kind of terrain combinations, which consist of two common types of the terrains. The border between them can be introduced like the part of line, in which the length is greater than the diameter of the exposure spot of the pulse radar altimeter. There are a lot of objects that can be used as the lengthened objects although not all of them should be detected by the altimeter. Further, the first step devoted to this choice process and the process of obtaining the signal parameters, which could be applied to the discrimination.

The next point is to obtain the distributions of the reflected signal [2]. It is necessary to have reference distributions although we need to obtain the tested distribution. The process of obtaining approximate distributions could be divided into the following steps. First, we collected the reflected amplitude signal from the identified homogenous terrain and build the etalon for this type of the terrain. This is a process that we need to make for all types of terrain. Then, we collected similar information for unidentified terrain. After all, we compared the identified distributions with the unidentified distribution and the most suitable distribution linked to the type of unidentified terrain. The unidentified distribution was obtained during the flight after the collection of the reflected signals amplitude. If the type of the exploring distribution changes during the flight, we detect the border and its position between two typical terrains.

The next point is to decide the type of the lengthened object. We divided the lengthened objects into two categories: the border and the stripe. And if the width of the lengthened object is less than the width of the exposure spot, we make a decision that this is a stripe object. Otherwise, we detect border of the object. Obviously, we need to know the approximate position of the UAV and choose the corrected parts of the track, which has homogenous terrains area with the approximate linear border detected by the algorithm.

As the result, we detected the border position and identified the type of terrains combination. We also classified the type of the lengthened object. After some crossed objects, we can make a decision about the real UAVs position and made a correction of the inertial navigation system (for more information see [1]).

The following explanation shows the realization of our algorithm.

II. The Preparation process

It is necessary to build a classification of the terrains, which allows for the determination of the changing the terrain using the algorithm. The analyses of different sources of information [3] showed that pulse radar with wide antennas pattern could be applied as terrain discriminator if the terrains have different backscattering patterns width and the difference between values of reflection coefficients (for fixed scattering angle) are greater than 5 dB, which is consistent with the criterion of discrimination for dispersion.

Figure 1 shows an example for the terrains combination "water/forest" [4]. The variation for the "forest" terrain (confidence interval 95%) is marked as short pieces of lines. The θ is a scattering angle (from the normal direction). Therefore, we can suggest that for θ less 15 degrees, it is possible to discriminate "forest" and "water": We called this angle as θmax that is the "maximum scattering angle for discrimination water and forest terrains".

The dispersion is smaller and the space between variances limits of backscattering diagrams is larger than ability of discrimination is wide. The homogenous terrains were grouped in combinations of the terrains. We divided them into four categories based on the backscattering pattern and the reflection coefficient. In the first category, the combinations are well discriminated, such as “water/forest”, “asphalt/meadow” and so on (maximum scattering angle more than 3 degrees). In the second category, the terrains (such as “meadow/forest”) could be discriminated in many cases (the scattering angle more than 1 degree). In the other two categories, there are combinations such as “bushes/grass” or “meadow/grass”, which could be discriminated but with some difficulties or could not be discriminated at all. Now, we have some combinations, which could be discriminated.

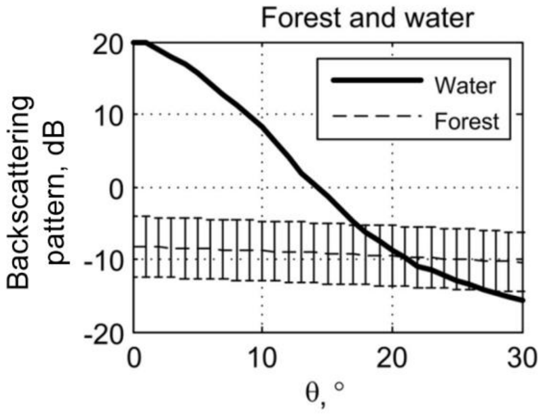

Figure 1: The terrains combination “water/forest”

III. The Algorithm

At this moment, we limited the number of potential terrains combinations. As mentioned earlier, we need to find the lengthened objects of two types: the border and the stripe. We divided the algorithm into the three stages:

1. The terrain identification by the comparison of the etalon and the unidentified distribution;
2. The fixation moment of the etalons change along the track (during the flight); and
3. The identification of the lengthened object during the flight.

Before the first stage, we need to make some definitions.

The functions set $f_{1,...N}(u)$ presents the amplitude distributions of the signal reflected from the homogenous terrains. We choose the pairs of these functions $f_{j,l}(u)$, which could be discriminated (as described in the previous paragraph).

N is the number of functions $f(u)$.

The 1st stage: In accordance with the criterion of the ideal observer, the maximum of a posteriori probability γ can be evaluated in accordance with the criterion Λ (Figure 2). Here, *u* is an amplitude.

The criterion is (1):

$$\Lambda = \max\left[\Phi_{1..N}\right] \tag{1}$$

where the decision rule is (2):

$$\Phi_{1..N} = \sum_{i=0}^{\infty} \max\left(f_j(u); f_l(u)\right) \tag{2}$$

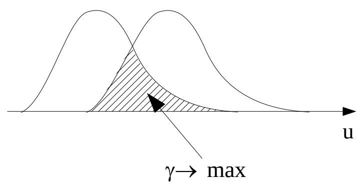

Figure 2: The common error of the functions $f_{j,l}(u)$ discrimination

As the result, we tried to find the most suitable etalon distribution for the unidentified distribution (for other methods see [5]). In other words, we need to compute the square of intersection between the two distributions for all known etalons and decide which one is the largest. We did not use other typical criterions because of the large uncertainty of the incoming counts (For example, we can obtain the distribution with nonsmooth envelope and the variation could be very large to make a decision. Another reason is an ability of the algorithm to work with undefined distribution type).

The 2nd stage: In the next step, we need to fix time (or distance) when we crossed the border between the two typical terrains. So, we need to add new parameter *t* (time), and our decision rule will be modified like this $\Phi_k(t)$. Here, the k-index shows the previous decision. To obtain this real-time decision, we need to collect the reflected amplitude in a window, in which the width is defined through the terrain correlation interval and the width of the LO, as shown in Figure 3.

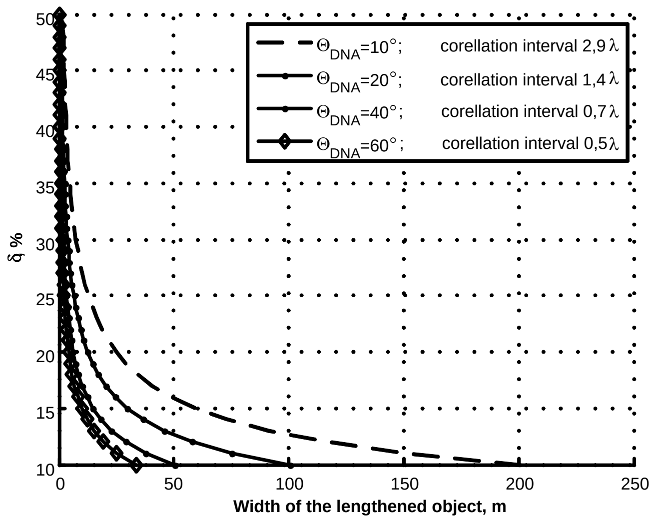

Figure 3: The detection fluctuation error (δ) dependence from LO width

As it is known, the antenna’s aperture (r) is connected with the possible discrimination ability by the simple formula [3]: $r = \frac{\lambda}{\theta_{DNA}}$ and correlation interval $I \geq \frac{r}{2}$. Figure 3 shows how correlation interval connected with the antenna’s pattern width, width of lengthened objects and fluctuation error.

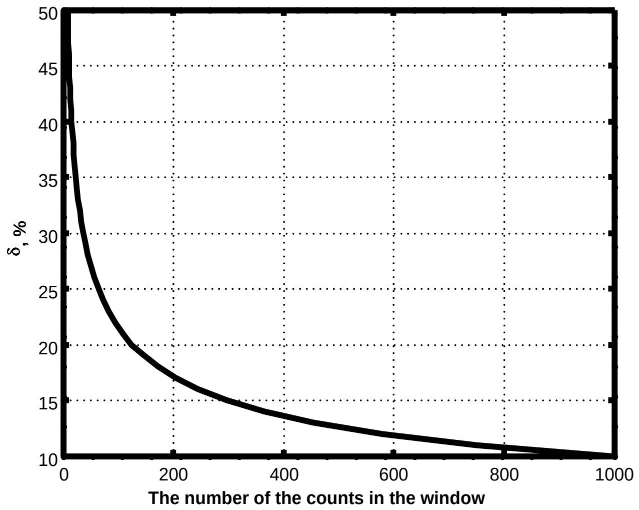

Figure 4: The detection fluctuation error (δ) dependence from the number of counts

As shown in Figure 4, the fluctuation error δ is connected to the number of amplitude counts (*N*) by the Scott's formula [2]: $\delta \sim 1/\sqrt[3]{N}$.

Therefore, we need to analyze *M* counts of *Q* count of the whole track, where $M<Q$. On the terrain changing time, we have $\hat{O}_k(t) \neq \hat{O}_m(t+t_1)$. In Figure 5, the m-index shows the current decision and the t_1 is the time-discrete of the decision.

Then, we designed the function: "The function of the minimum of a posteriori probability". It shows the moments of change of the terrain (see Figure 5).

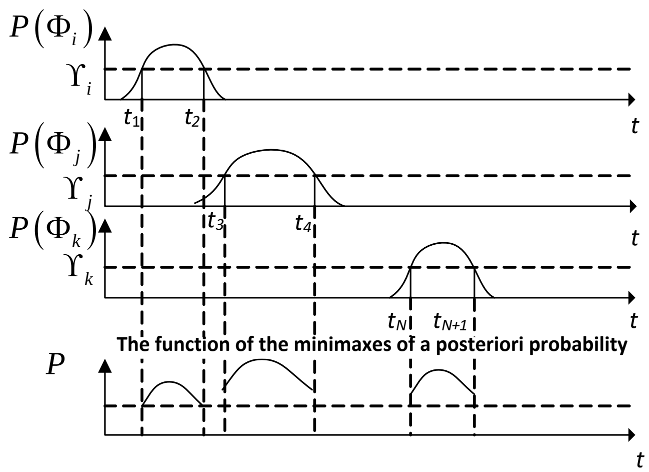

Figure 5: The time-line of the function of the minimaxes of a posteriori probability

where:

$P(\hat{O}_{i,j,k}(t))$ = the probability of the corresponding decisions;

$\Upsilon_{i,j,k}$ = the level of the probability for the corresponding decisions.

At this moment, we have enough information to define lengthened objects.

The 3rd stage. At this stage, we need to identify the sequence of the lengthened objects. As mentioned earlier, we divided the important lengthened objects into two categories: the stripes and the borders. As the criterion of the decision rule, we used the equivalent time of the flight through the distance of the exposure spots diameter. Therefore, if it is equivalent or less, we make a decision that this LO is stripe, otherwise – border. Although we cross a lot of borders during the flight, it is useful to identify the stripe objects as they were defined earlier. It is because many objects of the infrastructure could be defined as lengthened objects and their width is often less than the diameter of the exposure spot.

We have made some definitions: T_0 – the flight time through the exposure spots distance; Δt_k – the time interval for the decision Φ_k; Γ – the decision about the lengthened objects type; μ – the decision about the stripe object; η – the decision about the border object.

The criterion is shown in (3):

$$\Gamma = \begin{cases} \mu, \text{if } \Delta t \leq T_0 \\ \eta, \text{if } \Delta t > T_0 \end{cases} \quad (3)$$

After going through all these stages, we obtained the sequence of the lengthened objects and defined their types. It could be used in the challenge of the UAV's inertial navigation system correction.

Although the probability of the correct detection (identification) can be less than 0.8 for each LO, it is possible to increase the average of common probability. For example, if we try to find 5 of the 10 objects and identify each of them with the average probability 0.8, we obtain a common probability about 0.96, which is often enough for the correction.

IV. The Model Experiments Notes

The description of the model experiment with some important notes was described in [6]. The model track includes one stripe object, which has the start and stop positions on a homogenous terrain. In other words, the UVA flies from one typical terrain through the transferring zone to the same terrain. We changed the parameters of the stripe object: its orientation to the flight direction, width, type and processing (unsharpened beam and sharpened beam). We applied the low-frequency Doppler filtration for the beam sharpening. The average probability of the correct detection was higher than 0.6. As the result, we identified the conditions suitable for the designed algorithm. For the unsharpened beam, we obtained that the width of the stripe object should be equivalent or greater than the radius of the exposure spot, in which the LOs orientation changed from 30 up to 90 degrees to the flight direction. In this case, we selected (from 20 combinations) the next stripe objects "river in forest", "asphalt road in forest", "asphalt road in bushes", "river in bushes" and "asphalt road in bushes", which were detected by the algorithm. For the sharpened beam, we obtained that the number of detected objects increased roughly twice (we added "river on the meadow", "river on the ground", "asphalt or concrete road on the meadow", "asphalt or concrete road on the ground") and the width of the stripe objects can be narrowed up to 0.2 of the exposure spots diameter. However, false detection can arise for rough terrains, such as "forest". The only recommendation is to increase the number of counts in the window.

V. The Flight Experiments Notes

We also made two flight experiments, which are described in [7]. Here, we introduced some notes, which are important for the algorithm application in a real flight. As shown in [7], we made two flight experiments: the first was made for etalons creation (etalons for "forest", "ground", "grass" and "water" were obtained), and the second was the test flight. The information from the satellite navigation system was compared with the information obtained from the pulse radar altimeter and the video camera. After the synchronization, we processed the information by the designed algorithm. As the result, we detected unsharpened beam, which are the "forest", "ground" and "grass" in 60 percent of the cases, and "water" in more than 80 percent. For the sharpened beam, we obtained similar results, but we detected some more "water" stripe objects (plus 10% of the detected objects, in which the width was near 0.2 of the exposure spots width).

Therefore, the results of flights confirmed the designed algorithm. The next stage is the recommendations about the algorithm realization in the real-time system.

VI. The Recommendations

We explored the opportunities of the realization in onboard system and found that the modern onboard computer allows to include the algorithm without additional devices. It was obtained that it is necessary about 2 Mb memory and about 2 millions operations per second without overhead. It allows to process information in two modes (the unsharpened beam and the Doppler filtration) 20 etalons with time-discrete 20 ms, 300 counts in window and amplitude variation 20 dB.

For the correction zone, we need to choose informative and stable zones, if we are allowed to choose the trajectory of the flight in advance. The recommendations for the choice of the lengthened objects are as follows. Their width must be greater than 0.2 width of the exposure spot for the Doppler filtration and 0.5 accordingly for the unsharpened beam. The orientation of the lengthened objects has to be in the range from 30 up to 90 degrees to the flight direction (the preferable angle will be 90 degrees). We recommended the next types of lengthened objects, namely the "the river in the forest/meadow/ground" and we anticipate (but we didn't have etalon for the "asphalt road") that "asphalt/concrete road in the forest/meadow/ground" would be suitable for the correction of the UVAs position. The length of the lengthened object must be larger than the two diameters of the exposure spot plus the zone of uncertainty. However, in most cases, the length of the lengthened objects is much more larger than the necessary correction algorithm.

The next recommendation is about the choosing process of the flight conditions and correction zone. For the correction, we need to have the horizontal flight without evolutions (less 10 degrees in all directions). The height difference must be less than 10% during the accumulation window.

The next recommendation is about the combination of the modes. To get a gain in algorithm application, we suggest that the unsharpened beam mode and Doppler filtration should be combined and applied as the base of the unsharpened mode. If narrow lengthened objects are presented in the correction zone (we must set a flag about it in system), the second mode will be used as additional step to find these objects.

VII. The Conclusion

In this paper, the algorithm for lengthened objects detection and identification by the pulse radar altimeter was presented. The algorithm allows to detect lengthened objects, such as "river in the forest" or "asphalt road". The flight experiments shows that algorithm works in accordance with the model experiment. The important points about model and flight experiments are presented as well.

The recommendations about the algorithm realization are the most important results. They could be useful for the correction system design for the inertial navigation system.

Future exploration will be concentrating on obtaining the etalons of the typical terrains for different conditions, the algorithm realization in real-time onboard system and realization of the some spatial filtration algorithms, for example, the comb Doppler filtration or the time-frequency radar image [8] that identifies the form of the lengthened objects.

Acknowledgment

The research was executed by the grant of the Ministry of education and science of the Russian Federation (project № 8.2538.2017/PCh)

References

[1] M.I. Skolnik, *Radar handbook*. Radar Handbook, 3rd ed., The McGraw-Hill Companies, 2008, 1351 p.

[2] T.W. Anderson, *An Introduction to Multivariate Statistical Analysis.* Wiley&Sons Ltd., 2003, 721 p.

[3] F.T. Ulaby, M.C. Dobson, *Handbook of radar scattering statistic for terrain*. Artech house, USA, 1989, 357 p.

[4] M. Bassvile, A. Benveniste , "Detection of abrupt changes in signals and dynamical systems", *Lecture notes in control and information science*, Ed. , 1986, Vol.. 77, 373 p.

[5] A.K. Sorokin, V.G. Vazhenin "Algorithm of border detection of underlying surfaces by pulse altimeter signal", *2014 IEEE International Conference on Antenna Measurements & Application,* DOI: 10.1109/CAMA.2014.7003375.

[6] A.K. Sorokin, V.G. Vazhenin "The application of pulse altimeter for linear references detection", *Procedia Computer Science,* 2015, Volume 58, 2015, pp. 659-664.

[7] A.K. Sorokin, V.G. Vazhenin, L.L. Lesnaya "The terrain identification by the pulse radar altimeter", *in 5th International conference on advances in computing, communications and informatics proceeding*, India, aug. 21-24, 2016, submitted for publication.

[8] Sorokin, A. K., V. G. Vazhenin "Algorithm of space-time processing for pulse radar altimeter", *the Proceeding of 11th European Radar Conference*, Italy, Rome, 2014, pp. 265-268.