Investigation of the emit source coordinates estimation accuracy using reflections from the ground clutter

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Abstract. The issues of improving the accuracy of determining the coordinates of a radio source by a single-position method due to the joint processing of multiple signals reflected from local objects are considered. The electronic terrain map was obtained on the basis of artificial images of a two-dimensional point-like reconstruction flow. The results of computer simulation are presented.

1. Introduction

The paper deals the ground source of illumination coordinates estimation using not illuminating (passive) means. It is the usual problem of the radio monitoring [1] and radio intelligence [2]. At the moment are popular direction finding or differential position finding methods [3]. One of the main parameters of the methods is the accuracy of the SI co-ordinates estimation. The obstacle on the way to the goal are distortions of radio waves along the rough path of propagation. To overcome this obstacle it is necessary to space the measuring devices by tens kilometers and organize exchange information between them using specially organized lines. These lines lower the advantage of passive systems - their security. Therefore since the fifties the designers of the direction finding means were to make the base shorter, preferably to measure SI co-ordinates from one point.

The physical background of one-position systems can use reflections of the illuminated waves by the ground and local objects. So there is created the measuring basis. Such systems for some particular applications are described in literature [4–8]. New technique of mono pulse direction fining and statistical methods of data processing allowed engineers of the TUSUR research institute to work out and experimentally test over the terrestrial paths one of the methods of the SI direction finding based on utilization the reflections from the ground clutter.

The method utilizes extreme correlation. It is not necessary to know from what object is the signal reflected. Only the map of the ground with possible reflectors is needed [9, 10]. Analytical description of the method is not easy. Therefore in this paper the accuracy is valued by the computer simulation.

2. Calculations, experiments and their analysis

In the simplest case the system of the illumination source co-ordinates estimation includes the receiving point $R_x$ receiving the signal illuminated at the point $T_x$ and the signal reflected by an object at the point $O$ (Figure 1).
If there is a map of the ground the distance \( d \) to the object \( O \) can be found:

\[
r = \frac{2d\Delta r - \Delta r^2}{2[\Delta r - d(1 - \cos \theta)]},
\]

where \( \Delta r = ct = d + l - r \) – is the difference of the illuminated and reflected signal paths, \( \theta = \alpha_i - \alpha_o \) – is difference of the illuminated and reflected bearing angles, \( c \) – the light speed.

The illuminator \( Tx \) co-ordinates are:

\[
Tx_x = Rx_x + r \cos \alpha_o, \quad Tx_y = Rx_y + r \sin \alpha_o.
\]

If at the receiving point \( Rx \) there are recorded several reflected signal reflected by different ground objects (Figure 2), the procedure described above can be applied to any of them. As a result will be vector which \( i \)-th co-ordinate is calculated using (1) with parameters \( \alpha_o, \alpha_i, \Delta r_i \).

The error of the distance estimation is difficult to describe. It depends on many factors - accuracy of the bearing accuracy \( \sigma_{\alpha} \), accuracy of the time delay \( \sigma_t \), of the illuminated and the reflected signals angles difference \( \theta \) and on the distance \( d \). In general case \( \theta \) and \( d \) are different for different signals and different would be the co-ordinates statistical characteristics \( \bar{r} \). There was done computer modeling of \( \sigma_t/r \) dependence on \( \sigma_{\alpha} \) in case of five signals. In the process of modeling \( \sigma_t \) was chosen to provide the accuracy of the paths difference measurement one pixel half on the map. Results are given in the Table 1.

![Figure 1. Geometry of the system meant to find co-ordinates of a source of illumination SI](image1)

![Figure 2. Geometry of the system meant to find the SI co-ordinates in case of mane reflections](image2)
Table 1. Dependence of the relative error of the distance to the SI $\sigma_r/r$ measurement on the bearing accuracy $\sigma_\alpha$ in case of five reflected signals

| $\sigma_\alpha$, degrees | $\sigma_r/r$, | 1  | 2  | 3  | 4  | 5  |
|--------------------------|---------------|----|----|----|----|----|
| 0                        | 0.70          | 0.74| 2.08| 26.65| 22.01|
| 0.1                      | 0.72          | 0.76| 2.10| 26.73| 22.06|
| 0.2                      | 0.75          | 0.80| 2.19| 26.95| 22.23|
| 0.3                      | 0.81          | 0.86| 2.32| 27.31| 22.50|
| 0.4                      | 0.89          | 0.95| 2.49| 27.84| 22.89|
| 0.5                      | 0.98          | 1.04| 2.69| 28.54| 23.38|

Statistical investigation of the distance vector $\vec{r}$ showed that if errors of measurements are normally distributed and $\sigma_\alpha$ and $\sigma_\tau$ are small, vector $\vec{r}$ also obeys the normal law of distribution.

The vector $\vec{r}$ covariance matrix in case of 1000 measurements is:

$$B_r = \begin{bmatrix}
0.439 & 0.055 & 0.199 & 4.695 & 5.891 \\
0.055 & 0.495 & 0.807 & 7.668 & 4.164 \\
0.199 & 0.807 & 3.55 & 20.915 & 11.778 \\
4.695 & 7.668 & 20.915 & 494.229 & 174.919 \\
5.891 & 4.164 & 11.778 & 174.919 & 335.528
\end{bmatrix}.$$

The matrix $B_r$ shows that the best accuracy can be in case of the first and the second reflected signals, the worst in case of the fourth and the fifth ones.

Accuracy of the SI co-ordinates estimation can be improved by the joint processing of the all vector $\vec{r}$ elements. If the $\vec{r}$ co-ordinates error is distributed normally with the known covariant matrix the joint signal processing by the method of maximal likelihood $r_{MP}$, estimation can be found by the weight vector $\vec{r}$ co-ordinates summation

$$r_{MP} = \sum_{i=1}^{N} \omega_i r_i,$$

where $N$ – is the number of reflected signals received, $\omega_i$ –are weight coefficients depending on covariant matrix $B_r$.

Figure 3 shows dependence of bearing accuracy $\sigma_r/r$ on the error of the signals angles of coming $\sigma_\alpha$.

Figure 3. Dependence of the distance to the SI measurement relative error $\sigma_r/r$ on the error of the angles $\sigma_\alpha$ measurement in case of the separate processing of the first (1) and the second (2) signals and the joint processing of five reflected signals (3)
Specially interesting is the case when the short-test signal is not received. For example - there is some obstacle between the receiver $Rx$ and transmitter $Tx$ (Figure 4). The SI co-ordinates can be found by the differential method if there at least tree reflected signals. When angles of the reflected signals are measured co-ordinates of the points $C_1, C_2, C_3$ on the objects $O_1, O_2, O_3$ can be calculated with the help of the area map. Having found distances $d_1, d_2, d_3$ from the receiving point $Rx$ to the points $C_1, C_2, C_3$ it is possible to calculate the difference of the reflected signals coming time and find the SI co-ordinates as it is done in multi-position systems.

When there are received three reflected signals the SI co-ordinates can be found by iterated successive approximation. If there are more than three reflected signals at the receiving point the known analytical method could be used [11]. The SI co-ordinates are calculated using four signals. The arrival moment of the signal reflected by the object nearest to the SI is the reference one. From this moment there are calculated the time of the three others reflections delay. The SI co-ordinates are calculated using the calculated delays and co-ordinates of the reflecting objects.

In the process of simulation there was used the map with five objects reflecting the SI signal in the direction of the receiving point. One of the signals was used as the reference one. There can be four possible ways to chose three signals of others four. Each combination gives its estimation of the SI co-ordinates.

![Figure 4. Geometry of the SI co-ordinates estimation in case of multi-beam reception without the original signal](image)

The accuracy of the SI co-ordinates estimation can be improved using the method described above. Figure 5 shows dependence of the error of the distance measurement $\sigma_r/r$ on the error of the waves paths difference $\sigma_\Delta$ (in pixels in the map) which is proportional to the signals time delay measurement $\sigma_t$,

$$\sigma_\Delta = M \cdot c \cdot \sigma_t,$$

where $c$ is the light speed,

$\Delta$ – the map scale (pixel/m).

In the process of simulation the average $\sigma_\Delta$ measurement was considered 0.5 degree.

Results of the simulation are shown in Figure 5. Without the short-test signal accuracy of the co-ordinate estimation was worse than with the short-test signal. The relative error of $\sigma/r$ became 1.5 - 2 times higher. Still the problem of co-ordinates estimation was solved.
3. Conclusion

Results of the computer simulation showed that the problem of the SI co-ordinates estimation can be solved by the one position method in case of the ground objects reflection both when there is the shortest SI signal and when there is not one. Accuracy depends on the local objects position accuracy of the bearing angle measurement and the signals time delay. Simulation showed accuracy of several percents.

It is advisable to go on simulation with different SI positions and different objects distribution on the ground.

Acknowledgments

The work was performed as part of the state task of the Ministry of Education and Science of the Russian Federation number 8.7348.2017/8.9.

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