Hidden Transmitter Localization Accuracy Model Based on Multi-Position Range Measurement

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***Abstract*— The article considers a mathematical model of the accuracy of multi-position localization of hidden transmitters based on Distance Measuring Method. The model uses the distance from the transmitter to the group of synchronized receivers as the main parameter for calculations. The Least Squares Method is used to generate a localization accuracy model. The estimation of the localization accuracy is carried out on the basis of comparing the accuracy of finding the location of the hidden transmitter relative to the accuracy of measuring the range to the receiving antennas. Practical results of localization accuracy field for a typical office building are obtained by simulation.**

Keywords—localization, hidden transmitter, Distance Measuring Method, Dilution of Precision

I. INTRODUCTION

Today, information theft is becoming a global problem. Increasingly sophisticated devices are used to intercept information in any form. One way to obtain important information is covert eavesdropping (video recording) followed by retransmission using hidden transmitters. The hidden transmitter, together with a microphone, video camera and other recording devices, is a complex technical device that is installed in premises where important business processes take place and have the ability to transmit the received information to interested parties [1]. The received information is transmitted on a radio channel, as a rule, in the standard communication ranges disguised under work of GSM, Wi-Fi, Bluetooth, etc., detection of which is very difficult because of several factors:

1) To mask the radiation of transmitters, developers of spyware are using more and more sophisticated methods and technologies.

2) In a large city, almost the entire radio band is used for the application of many legal transmitters, which makes it difficult to find a hidden transmitter working in their background.

Finding hidden transmitters remains a very complicated problem and, at the same time, is insufficiently described in the technical literature. With the use of technical devices with elements of artificial intelligence, transmitters with the accumulation of information, pulse mode are increasingly used. The transmitter can appear on the air for seconds, and the rest of the time stays in a silent mode.

Traditionally, manual methods have been used to search for hidden transmitters, which are based on a combination of human intelligence and the technical capabilities of modern scanners. Thus localization of the transmitter is carried out exclusively by experts of special services. At the same time, the world is moving to automated search. Its main concept is 27/7 scanning of the air, recognition of the work of illegal transmitters against the background of legal ones and localization of all illegal transmitters.

Such a complex, as a rule, consists of several spread receiving antennas, and a signal processing unit. The algorithm of the signal processing unit involves searching for the signal, its filtering and localization of the transmission source. The transmitter can be localized by the direction or distance to it. When localizing by the direction, a smaller number of antennas is required, but such antennas must have a fairly narrow pattern, which requires the use of antennas of larger size and more complex design. Locating by the distance, you need to use more antennas, but such antennas can be omnidirectional and have small sizes. For hidden search of hidden transmitters, this approach is more promising.

II. ANALYSIS OF RECENT PUBLICATIONS AND PROBLEM STATEMENT.

Many academic publications are devoted to the problem of identifying and localizing hidden transmitters. Thus, in [2] an extensive overview of search devices and aids is made. The publication also provides a classification of methods for finding hidden transmitters, including manual, semi-automatic and automatic methods. However, the main method of localizing a hidden transmitter remains manual, which takes a significant amount of time.

[3] describes a method of finding a hidden transmitter based on "acoustic binding". This uses a low frequency amplifier and speakers that transmit a characteristic signal that is expected to be transmitted through a transmitter. The operator moves with the speaker indoors and when approaching the microphone, there is a mode of self-excitation of the amplifier, such as a conventional stage amplifier. This method was quite effective when using constantly turned on analog transmitters. At the same time, the widespread popularization of digital technology that

works in pulse mode, makes this method ineffective. In addition, this method is also manual and too noticeable. A potential intruder may turn off the hidden transmitter during the scan.

[4] describes methods of searching for hidden transmitters using manual direction finding equipment. In this case, a hyperbolic computation model is used to localize the transmitter, which uses data from a radiometric rangefinder. However, this approach is quite inaccurate and only allows you to determine the wide area of the hidden transmitter for further manual localization.

The problem of localizing an unknown transmitter can be solved using approaches that are widely used in Wireless Sensor Networks. For this, either the ranges or directions between the transmitter and receiver are used. In particular, the propagation time of the signal from the transmitter to the receiver can be used to determine the distance between nodes. In [5], a comparative analysis of various methods and algorithms for localization based on measuring distances or angles is given. It is also mentioned that the accuracy of localization depends on the relative position of the transmitters and receivers. The main methods for calculating the hidden transmitter can be: trilateration, multilateration or triangulation. To choose a specific method, you need to determine the required localization accuracy. This usually depends on the computing capabilities of the system. Typically, at least three distance estimates must be used to estimate the exact location of a node. The most important thing for sensor networks is that the node itself calculates its own position, so it is necessary to have at least three nodes with known coordinates. In triangulation, the position of the unknown transmitter is estimated by the angles to each of the three support nodes that form a triangle, using simple trigonometric relations. The accuracy of this approach is limited by the possible attenuation of the signal on the measuring equipment, as well as due to the multi-beam reflections of the signal coming from different directions. When using the trilateration method, the location of an unknown point in 3D space can be determined from measured distances up to three known points. Distances can also be calculated from the propagation time of the signal.

In modern Sensor Networks, the distance to the transmitter can be measured with an accuracy of 10 to 20 cm [5]. This approach works well when localizing analog transmitters that operate in a constant mode. But for localization of a hidden transmitter, which operates in a pulsed mode (for example, with the accumulation of information), this method is ineffective due to insufficient signal observation time.

Thus, the problem of localizing hidden transmitters remains unsolved and requires the development of a new method of localization that would allow automated calculation of their position without the use of large equipment and manual actions.

III. PURPOSE AND OBJECTIVES OF THE WORK

For any localization system, the main indicator of its effectiveness is accuracy. Given the shortcomings of triangulation methods (the need to use large equipment and directional antennas), the aim of this work is to develop a model for the accuracy of localization of hidden transmitters based on measurements of the distances between the transmitter antenna and the set of receiving antennas of the search complex based on the multilateration method.

Achieving this goal requires the development of a model of localization accuracy, which will be based on the topology and structure of the search system based on the Distance Measuring method.

IV. MAIN PART

Since the exact distance from the transmitter to the receiver at the time of measurement is unknown, when using multilateration as the main measurement parameter, pseudorange is used. In order to assess the degree of deterioration of localization accuracy relative to the accuracy of range measurements, you can use the DOP (Dilution of Precision) parameter [6–8]:

$$DOP = \frac{\sigma_q}{\sigma_D}, \quad (1)$$

where σ_q – mean square error (MSE) of hidden transmitter localization; σ_D – MSE of range measurement from transmitter to receiver.

In [9–10] it is shown that the DOP value is completely determined by the topology of the system consisting of the transmitter and the receivers. At the same time, provided that the transmitter power and antenna sensitivity are sufficient, the range of the system is practically unlimited and its scale does not affect the DOP value. The values themselves are determined only by the mutual arrangement of nodes in space.

As shown in [11–12], in order to obtain the MCE value, which is included in formula (1), it is necessary to calculate the trace of the matrix $\boldsymbol{A}$

$$\sigma_q = \sqrt{Tr\left(\boldsymbol{A}^{-1}\right)}, \quad (2)$$

which can be obtained by applying of the Least Squares Method to range measurements.

As shown in [12], matrix $\boldsymbol{A}^{-1}$ can be represented as

$$\boldsymbol{A}^{-1} = \boldsymbol{C}^{-1}\boldsymbol{P}^{-1}\left(\boldsymbol{C}^{-1}\right)^{\mathrm{T}}, \quad (3)$$

where $\boldsymbol{P}^{-1}$ – is a diagonal matrix of variances of the range measurements; $\boldsymbol{C}^{-1}$ – inverted direction cosine matrix from receivers to transmitter in a rectangular 3D coordinate system, which can be obtained by differentiating the distance matrix $\boldsymbol{R} = \left\| D_i - D_{0i} \right\|^{N\times 1} = \left\| r_i \right\|^{N\times 1}$ by variables x, y, z, w for $i = 1,...,N$:

$$D_i - D_{0i} = \frac{\partial D_i}{\partial x_0}\delta_x + \frac{\partial D_i}{\partial y_0}\delta_y + \frac{\partial D_i}{\partial z_0}\delta_z + \frac{\partial D_i}{\partial w_0}\delta_w, \quad (4)$$

where D_i – measured range to i antenna; D_{0i} – calculated range to i antenna.

In this case x, y, z – are the current coordinates, and w – an additional coordinate that takes into account the time discrepancy in the synchronized system. Time synchronization in the localization system is essential as it eliminates the need to accurately measure the distance between transmitter and receiver. Thus the value σ_D in (1) can be set based on experimental studies.

Thus, the localization MSE obtained by formula (2) can be taken as the main parameter for assessing the localization accuracy in a synchronized search and localization system for hidden transmitters. In this case, its value depends only on the potential accuracy of measuring the ranges and the relative position of the receivers relative to the transmitter. Since the location of the transmitter is not known in advance (this is the purpose of localization), then to assess the effectiveness of the entire system, it is necessary to build an accuracy field for an object (room or building) to determine the possibility of finding a hidden transmitter.

To calculate the localization accuracy field, the following algorithm can be proposed:

Step 1. The coordinates of the receivers x_i , y_i , z_i , $i = 1...N$ are entered into the model. The number of receivers must be at least 3 in case of determining 2D coordinates and at least 4 for determining 3D coordinates. With a larger number of receivers, the localization accuracy will only increase.

Step 2. The search area is determined, which is limited by the size of the building or room. For multi-storey buildings, it is advisable to build accuracy diagrams for each of the floors.

Step 3. Within the entire area, points are determined at which the MSE value will be calculated to search for a hidden transmitter. Thus, a network of points for calculation is formed.

Step 4. The first (next) point is selected for calculations with coordinates x_{0i} , y_{0i} , z_{0i} , $i = 1...M$, where M is the total number of points for calculating the accuracy field.

Step 5. For each receiver, the distances from the receiver to the survey point are calculated.

Step 6. By formulas (3) and (2), the values of the matrix $\boldsymbol{A}^{-1}$ and σ_q are determined.

Step 7. If the value of M has not yet been reached, then return to Step 4, otherwise – the end of the algorithm.

The resulting diagram shows with what accuracy you can find a hidden transmitter in a room without resorting to a total search. As already mentioned, the main parameters for the calculation are the accuracy of measuring the range to the transmitter (the larger the error in measuring the range, the worse the localization accuracy will be) and the relative position of the receivers relative to the possible location of the transmitter.

V. THE RESULTS OF MODELLING OF MULTI-POSITION LOCALIZATION SYSTEM FOR HIDDEN TRANSMITTERS

For practical testing of the capabilities of the localization accuracy model for hidden transmitters, the two-storey office building shown in Fig. 1 was taken [13–14]. We chose the basement level as the zero height level. Three external antennas were installed around the building at a distance of 10 m and a height of 3 m. The location of the antennas is chosen evenly around the observed house, as shown in Fig. 1 [15]. Based on the statistical studies of the MSE, the distance to the transmitter was determined 0.5 m [16].

The simulation results are as follows.

Fig. 1. Typical office building and antennas deployment

Fig. 2 shows the result of the accuracy of the location of the hidden transmitter with the accuracy of determining the range (MSE = 0.5 m). As you can see, the first and second floors of the building are completely covered by the detection field, which with varying accuracy determines the source of radio waves. On the first floor, the accuracy of localization is much lower than on the second, which is due to extremely unfavorable DOP values. Thus, the MSE on the ground floor remains at the level of 10-15 m, decreasing closer to the location of the receiving antennas and increasing in the center of the building.

On the second floor, the MSE is maintained at 5-6 m due to more favorable DOP values with increasing height. However, in both cases, such values of the MSE localization of the hidden transmitter are unacceptable from a practical point of view, because they are comparable to the size of the building itself. The way out of this situation is to install an additional receiving antenna that would improve the global DOP.

From the practice of implementing the distance Measuring method, such an additional antenna should be placed above the building, for example on a drone (Fig. 1). Fig. 3 shows that the additional antenna can significantly reduce the MSE, because in this case the DOP is minimal.

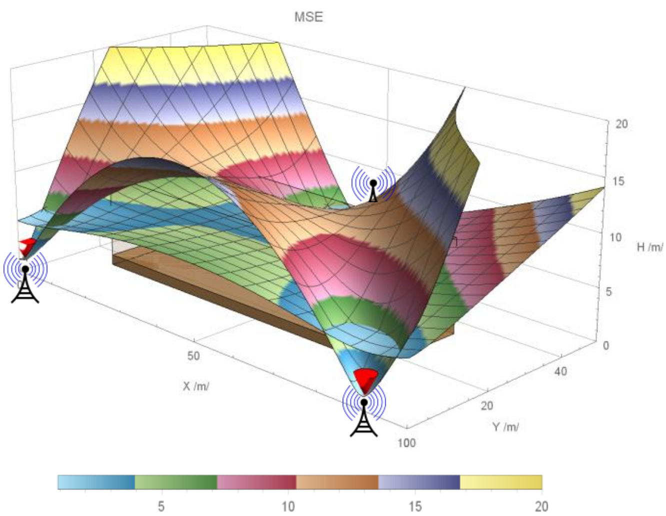

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Fig. 2. Precision (MSE, m) of hidden transmitters localization within the office area by 3 antennas at height of 4 and 8 m

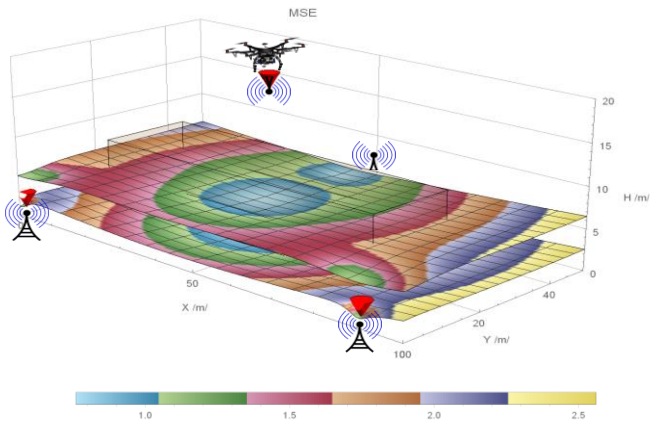

Fig. 3. Precision (MSE, m) of hidden transmitters localization within the office area by 4 antennas at height of 4 and 8 m

The zone of the highest accuracy (minimum MSE) is located in the center of the building on both floors. The value of MSE is less than 1 m.

It should be noted that with this method of determining the localization accuracy, based on the Distance-Measuring method, if necessary, you can cover all the premises with a given accuracy of determining the transmitters. It can be used to model various parameters, such as localization accuracy, number and location of antennas, antenna performance, etc.

The proposed method has a wide range of applications, and in this way you can explore a whole group of buildings or territory. Since the localization accuracy depends on the number of antennas, it is possible to choose the structure and topology of the system according to the specified localization accuracy.

VI. CONCLUSIONS

The problem of developing algorithms for the automated search for hidden transmitters is still very urgent. To preliminarily assess the possibility of using the automated search complex, it is necessary to know in advance the accuracy of localization. The existing approaches to assessing the accuracy of localization are rather complicated and do not take into account the peculiarities of the automated search for hidden transmitters.

The search algorithms are based on the Least Squares Method and therefore the proposed accuracy model is also based on this method. Given that the receivers are synchronized, it is possible to calculate the location mathematically due to the redundancy of the system of equations.

The proposed method for assessing the localization accuracy makes it possible to calculate not only the MSE for transmitter localization, but also the required number and topology of the receiver antennas in the given conditions of the search area. The simulation results confirm the possibility of remote localization with the specified accuracy parameters.

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