Methods for Determination of Coordinates in Two-Dimensional Navigation System by Measuring the Delay of the Signal

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Abstract – **The use of satellite positioning systems in densely populated urban areas is becoming more difficult because of the extensive construction of complex surface and underground infrastructure facilities. At the same time, the need for accurate and precise determination of the position of moving objects in different cities is steadily increasing. This requires the creation of terrestrial navigation systems that allow easy implementation in urban environments and at the same time meeting the high demands for accurate and timely determination of the position of the tracked objects. In this paper is proposed a new method for determining the two-dimensional coordinates of an object by measuring the delay of its broadcast signal, received in various synchronized receiver stations.**

Keywords – **terrestrial positionin system, navigation, urban areas**

I. Introduction

The need for localization in the modern urban architecture is becoming more and more important in the recent years. At this stage, for outdoor localization of different objects are used global satellite navigation systems such as Global Positioning System (GPS), which provides locating accuracy of a few meters to 10 meters in normal mode of operation or a few tens of centimeters to several meters in differential mode (DGPS). However, when reducing the number of satellites, to which the site has direct visibility, below the minimum set for example when object enters closed spaces, in buildings, tunnels, underpasses, underground garages, subway or even between tall buildings in densely built urban areas / urban canyons / localization of the object is difficult and in most of the cases it becomes impossible.

To solve this problem it is necessary to combine the satellite navigation system with a local terrestrial positioning system which can determine the position of the object in indoor spaces. Such terrestrial network for positioning is proposed in [1]. This is a synchronous terrestrial positioning system which includes stationary receiver stations, located in a network of several hundred meters apart (Fig. 1).

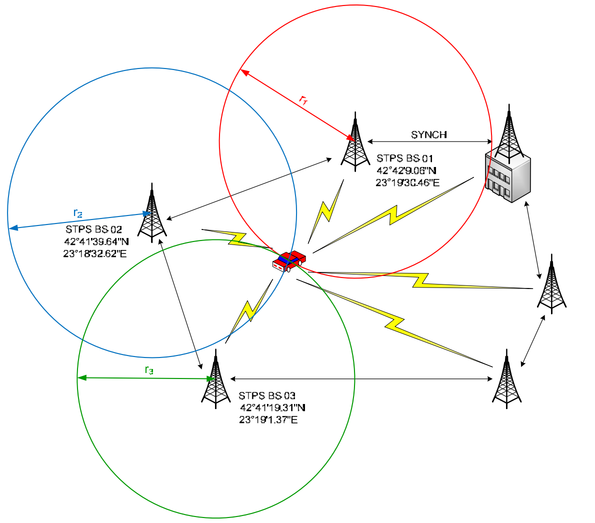

Fig. 1 Synchronous terrestrial positioning system

The tracking device broadcasts a special identification signal which is received from the stationary stations. The position is determined by analysis of three parameters - attenuation of the signal, the delay of the signal and the direction from which the signal is coming. In each station the received signal is measured and on the basis of the attenuation model and the preliminary calibration, the distance from the receiving station to the transmitter is calculated. At the same time the difference in the delay of the signal going into the individual stations is measured, which in the greatest extent carries information about the position of the transmitter. Direction to the tracking device is determined by the use of directional antennas in the receiving stations. Their data also allow the detection of reflections.The data obtained from the measurements of the received signal in all receiving stations are combined and sent to the central station, where the position of the tracking object is calculated. To improve the accuracy is performed calibration and tuning of the system by prior passing with a reference transmitter at the service area, the location of which is determined by the operator.

In the article are discussed methods for the determination of coordinates on the basis of the delay of the signals in general, and in some particular cases. [2]

II. Positioning Algorithm

The propagation of the radio waves in densely populated urban areas, combined with underground and indoor areas is very difficult to model because of the multipath propagation of the signals, the low probability of line-of-sight between the

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mobile transmitter and fixed receiver stations and the specific parameters of the environment, as moving objects and reflective surfaces.

A. Delay of the signal

The idea is to determine the relative position of mobile transmitter, by measuring the delays in time for which the signal reaches to the plurality of stationary receiver stations that are synchronized in time and have known positions.

The time for distribution of the signal can be directly converted into a distance on the basis of the known speed of propagation of the electromagnetic waves.

It is necessary to be estimated the distances from the transmitter to each one of the receiving stations.

The position of an object in two-dimensional space can be calculated by measuring the delay of the signal to two or more receiving stations.[3]

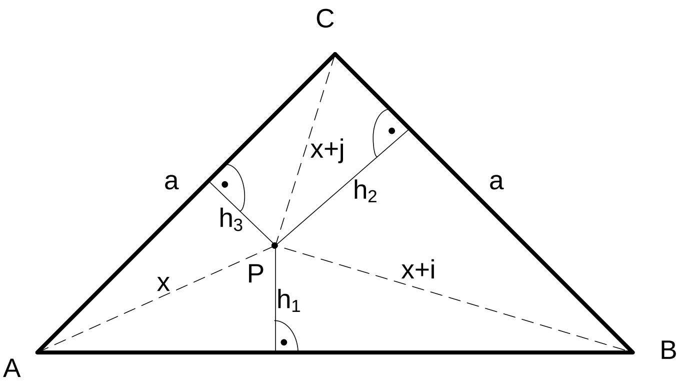

Fig. 2. Determination of the coordinates by measuring the delay of the received signal

Let A, B and C to denote stationary receiving stations (Fig. 2). Let the distance between receiving stations A and C is equal to the distance between receiving stations B and C. If we have transmitter (denoted by P), which is located inside the isosceles triangle (ABC) formed by the stationary receiving stations, and it broadcast a radio signal, its position can be easily determine.

The distance x between the transmitter P and the receiver A is proportional to the time of propagation of the signal from point P to point A, respectively, if it is measured the difference in arrival time of the signal to receiver C and respectively the difference in the arrival time of the signal to receiver B, in comparison to the arrival time of the signal in reception point A, it can be found the differences in the distances between PC and PB in relation to RA. From here it can be easily found the distance PA and respectively the distances PC and PB

From triangle ABC can be drawn the system:

$$\left| \begin{aligned} & h_3^2 + a^2 - 2ah_2 + h_2^2 = x^2 \\ & h_3^2 + h_2^2 = (x + j)^2 \\ & h_2^2 + a^2 - 2ah_3 + h_3^2 = (x + i)^2 \end{aligned} \right. \qquad (1)$$

where:

$x=AP;$
$a=AC=BC;$
$j=PA\text{-}PC;$
$i=PA\text{-}PB;$
h_n $(n=1,2,3)$ – respectively the distances from P to AB, BC and AC;

the distances i and j are directly proportional to the delays of the signal received respectively at station B and station C to station A, therefore, after transformation the system leads to the following equation for x:

$$4((i-j)^2+j^2-a^2)\,x^2+(4i^3-6ij^2-4ia^2-2ji^2-4ja^2)\,x+2j^4+2a^4+i^4-2j^2 i^2-2a^2 i^2=0 \qquad (2)$$

hence can be derived the distances:

$$\begin{aligned} AP&=x; \\ BP&=x+i; \\ CP&=x+j; \end{aligned} \qquad (3)$$

B. Calculation of the position

The defined in the previous section distances determine circles with centers corresponding to the coordinates of the receiving stations. The transmitter which coordinates are looking for is located on the circles.

The determination of the relative coordinates of the transmitter is achieved by the geometry of circles or hyperbolas. There are used a set of reference vectors [Xi, Yi, Ri] that are parameters of the circles, where Ri represents the calculated distance between the receiver and the requested object, and Xi and Yi represent the coordinates of the position of the receiving station. The intersection of these circles represent the position of the sought object.

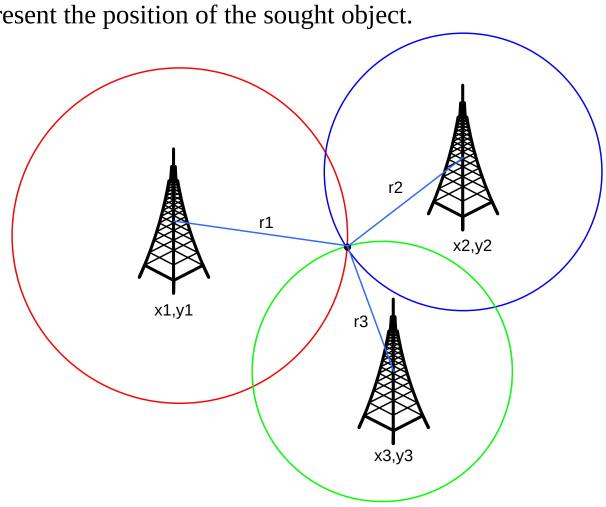

Fig. 3. Determination of the coordinates of the transmitter

On Fig. 3. is presented the ideal case when there is only one point of intersection between the circles. Then the position of the sought object is only defined by intersection point. In real terms the measurement of the signal parameters is not so accurate. Usually the calculated radius and the number of intersections does not match the ideal case. The intersections form a probability domain of the position of the sought object.

The final position is calculated as the gravitation center of this area.

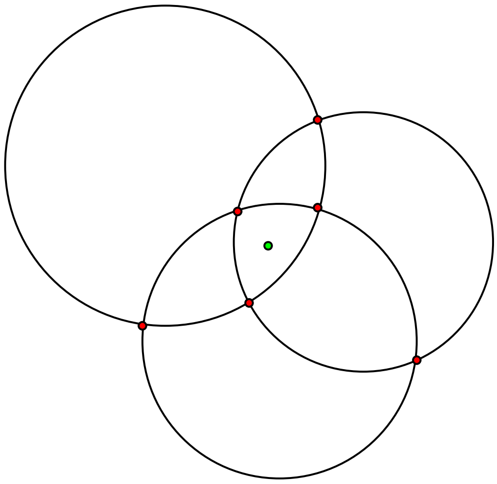

Fig.4.

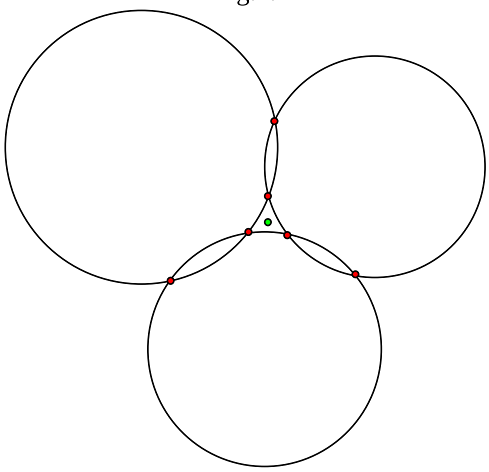

Fig.5.

There are two cases, the first is shown in Fig. 4 - every two circles intersect at two different points. The intersection of the two circles, which lies in the third circle is an internal intersection point. Internal intersections are used for calculation of the position of the sought object, they are called major intersections. For each combination of the two circles there is one major intersection. Model with three circles defines 3 different major intersections. These intersections determine domain that is common to all three circles, the exact position of the sought object is expected to be within this area.

The second case is shown in Fig. 5. This is more complex scenario than the previous one because there is no internal intersections. Therefore, major intersections are chosen in another way. Any two circles have two intersection points. Only one point in this pair is taken into account and this is the point with the shortest interconnection distance. In this way are taken three major intersections. These intersections define the area in which is expected to be located the sought object.[1][4]

For both previous situations, the major intersections determine the area where it should be positioned the requested object. The magnitude of this domain depends on the particular case. The smaller it is, the more accurately can be determined the position of the sought object. The final calculation of the position of the sought object is defined as centroid or gravity center of the polygon defined by all major intersections.

In a real situation, some of the rays are reflected, wich results in additional delay and a phase change of the signal at high frequency. When analyzing the data this is difficult to be taken into account and the resulting errors can only be reduced through the analysis of the other parameters. However, to take account of the reflections and their impact on the delay of individual rays is performed a monitoring of hopping change of the delay and the phase of the signal and the direction from which it came.

C. Determination of the coordinates in case of two reception stations

The location of the tracked object can be determined, and even when signal is recieved by only two stationary stations (Fig. 6) by using a priori information about its movement or data for its previous position.

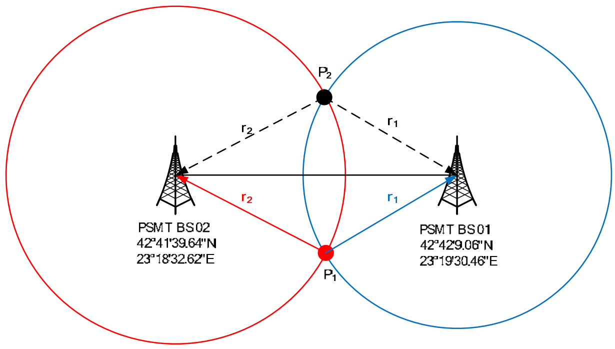

Fig. 6 Determining the position of tracked mobile object only with two stationary stations

For achieving the required accuracy is required fixed stations to have exactly synchronized clocks, which is achieved by optical or radziovrazka between them. In processing of the received signal are used algorithms for accounting the reflections, as it is assumed that in urban areas the reflected signals will dominate. The synchronization of the mobile devices can be performed or by request-response and / or by stationary VHF or medium-wave household transmitter.[2]

D. Supplement of the system with checkpoints

For improving the accuracy of the positioning and to overcome the problems of insufficient radio coverage, to the above-described system can be added a system of checkpoints /control stations/, which can be permanent or temporary according to the nature of the operation. These control stations are responsible for registering the passage of the tracking object in the given point and immediately to send the information to the control center. They can be equipped with video cameras, and additional navigation system for determining the position of the tracking object when it is away from the point. The connection of the point to the control center can be via GPRS or other techniques according to the specific situation.

The control points will be placed strategically on all inputs and outputs of suspected indoor spaces - entrances, platforms and exits of the subways, to the stairways and lifts of multistory buildings, etc. They are compact and low cost, and their number can be very large. When the mobile device must be protected by easy detection the link between the checkpoint and the tracking device can be performed not on radio channel but by ultrasonic, infrared, ultraviolet, X-ray or other emission that we call alternative channel. The use in this case of a low-power transmitter with short radiation will be only in exceptional cases, and only when the other channels for some reason do not work - eg. if they are shielded. All transmissions from the mobile device are in response to a call from checkpoints, they will be performed by special codes, which further reduces the risk of discovering the device with simple tools. To reduce the probability of unregistered removal of the tracking device from the observed object, close to its position can be placed one or more miniature passive sensors from the type of access cards. On separation of the sensor from the tracking device, a signal is sent by the tracking device to the control center.

III. Conclusion

The above analysis and the obtained computational formulas allow calculation of the coordinates of tracked object in a two-dimensional coordinate system, where it has no visibility to enough GPS satellites.

Sufficient accuracy can be obtained in the case of sight of only two receiver stations by analyzing the previous trajectory of the object. Ideas, and methods for further improvement of the accuracy of the system, including accounting the impact of the delays in the analysis of the signals have been proposed. System of checkpoints can significantly improve the effectiveness of the tracking system.

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