INDOOR LOCATION USING ULTAWIDEBAND CHAOTIC RADIO PULSES

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Abstract – **The report is devoted to the problem of indoor location using ultrawideband chaotic signals. Two cases are considered. The first corresponds to distance estimation between the transmitter and the receiver. In the second the position of the tag on the plane is determined. Efficiency of proposed systems in comparison with the ultrashort pulses systems is demonstrated.**

Index terms – **Dynamic chaos, indoor location, ultrawideband chaotic radio pulses.**

I. Introduction

Indoor location using radio facilities has many important applications. For example, tracking goods in warehouse, tracking moving objects (people, robots, ets.), marking some targets for their further location.

For purposes of navigation the Global positioning system, GPS, is employed [1]. It can locate objects with special radio receivers. Accuracy of the system usually changes from several tens of centimeters to several tens of meters. However, these special radio receivers have rather complex design. Furthermore GPS shows good results only in open surface. Indoors, the accuracy of the system becomes much worse [2]. This result is explained by existence of multipath propagation, which accompanies indoor communications. Therefore for indoor navigation much attention is given to development of local positioning radio facility. At the last time wideband and ultrawideband systems are considered as perspective systems [2-5]. In particular great hopes are put for the systems based on short and ultrashort pulses.

In this report an alternative variant of object positioning is proposed and examined. It uses chaotic radio pulses, CRP, formed from ultrawideband chaotic signals [6-7]. At first, let us consider the problem of distance estimation.

II. Distance estimation using ultra wideband chaotic radio pulses

An approach to distance estimation using chaotic radio pulses is as follows. Assume, there are a transmitter and a receiver of chaotic radio pulses. The transmitter emits a single CRP or pack of CRP, and, correspondingly, the receiver gets the single CRP or pack CRP. The receiver is synchronized with the transmitter. In the receiver the moment of pulse (pack of radio pulses) emission and the duration of chaotic radio pulse are supposed known. The duration of CRP is fixed. For the time of pulse emission the end of pulse emission by transmitter is accepted. The receiver gets CRP. The moment of arrival is evaluated using a special procedure described below. The difference between the moment of emission and arrival multiplied by the light velocity gives an estimate of the distance between the transmitter and receiver.

Hereinafter for simulation we use a one-dimensional tent-map as a model of chaotic source:

$$x_{n+1} = \begin{cases} 2x_n, & 0 \le x_n \le 1/2 \\ 2(1-x_n), & 1/2 < x_n \le 1 \end{cases}. \quad (2)$$

The number of map samples in the chaotic radio pulse (called processing gain or bandwidth-duration product) B is determined by the relation between the chaotic wave bandwidth Δf and the duration of CRP τ according to the Kotelnikov theorem:

$$B = 2\tau\Delta f. \quad (3)$$

The arrival moment of chaotic radio pulse in the receiver can be evaluated with different methods. In this work the following method is used.

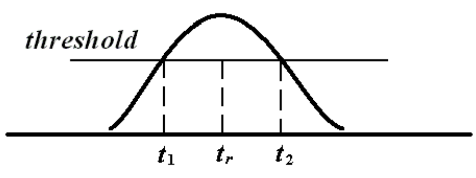

Fig. 1. Time of arrival of chaotic radio pulse t_r

The receiver consists of a quadratic detector and summator, which are connected in series. The summator collects the energy of the signal in the window equal to the duration of chaotic radio pulse and sliding along of the time line. (In the case of analog circuit the receiver consists of a quadratic detector and a low pass filter.) After the summator the threshold detector is placed. It detects the moment t_1

when the chaotic pulse begins to exceed some energy threshold and the following moment t_2 when the pulse amplitude becomes less than the same energy threshold (Fig. 1). Using these moments the moment of receiving chaotic radio pulse t_r is determined. In the first approximation t_r equals the half-sum of t_1 and t_2. More accurate value of t_r is determined by comparing the distribution of the interval center between t_1 and t_2 with exact arrival moment of chaotic radio pulse.

Computer simulation and its results. Computer simulation is implemented under the following conditions. The bandwidth of radio signal is 2 GHz; the duration of chaotic radio pulse is 10 ns. According to equation for the bandwidth-duration product (3) the number of chaotic samples of the pulse equals 40. The threshold, which is used for detection of the initial and final moments of pulse receiving, is determined as follows. A statistics of pulse energies (in our case, we calculated 1000 chaotic radio pulses) is gathered, and distribution of these energies is plotted (Fig. 2).

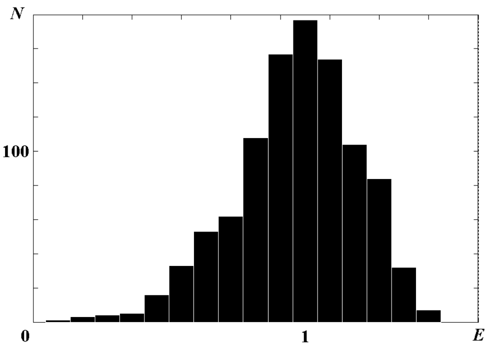

Fig. 2. Distribution of the energies of chaotic radio pulses

The distribution is used to find an energy value, which is exceeded by 99% of radio pulses gathered in the statistics. This value is taken as the threshold.

The next step after choice of the threshold is calculation of the displacement of the central point of the interval between t_1 and t_2 (Fig. 1) relative to exact arrival time of chaotic radio pulse. The distribution of central point is shown in Fig. 3. As can be seen in the Figure the displacement of the central point is about 0.25 ns (or 7.5 cm). This displacement is a systematic error and must be taken into account in distance estimation.

Then mean-square error of distance estimation is computed

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N}}, \tag{4}$$

where x_i is the distance defined by i-th chaotic radio pulse, $\bar{x}$ is the average distance for all pulses, N is the number of pulses gathered in statistics. Calculations show that the mean-square error in distance estimation is about 10 cm.

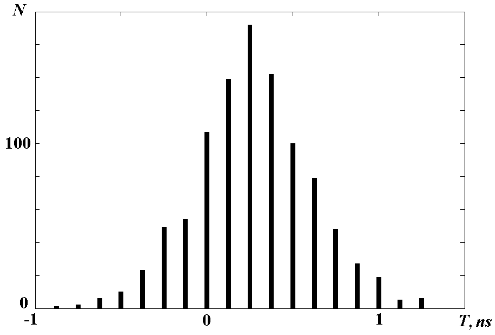

Fig. 3. Distribution of central point of interval between t_1 and t_2 relative to exact arrival time of chaotic radio pulse

A question is: how does the accuracy of distance estimation depend on the duration of chaotic radio pulse? To understand that, we made above calculations for CRP having 2 and 50 ns durations. That is, at first we reduced the pulse duration by a factor of five in comparison with the initial duration (10 ns), and increased the initial duration also by a factor of five. In these cases, the mean-square error for 2 ns duration was 6 cm and for 50 ns it was 14 cm. Thus, variation of the CRP duration has little effect on the accuracy of distance estimation between the transmitter and receiver. Moreover, by changing the threshold it is possible to improve the accuracy to 6-7 cm for pulses with 2-50 ns durations.

We ascertained that the accuracy of distance estimation weakly depends on the duration of CRP. What is it determined by reality? As follows from simulations the mean-square error approximately equals the distance between the samples in pulse. Indeed, for 10 ns radio pulse the intervals between the samples are 0.25 ns or 7.5 cm. It means that if we reduce the time intervals between the samples then the accuracy will increase. As follows from equation (3) these time intervals are

$$\tau_{samples} = \frac{\tau}{B} = \frac{1}{2\Delta f}, \tag{5}$$

i.e., the accuracy directly depends on the bandwidth of the signal. The broader the bandwidth, the better the distance estimation.

Distance estimation using packs of CRP. Above analysis shows that the considered system has a good accuracy of distance estimation. However, this result can be additionally improved if a pack of chaotic radio pulses is used for distance estimation instead of a single radio pulse. In this case the distance between the transmitter and receiver is determined by means of averaging the distances determined using each radio pulse from the pack. Such an averaging must lead to less the mean-square error approximately inversely proportional to square root of the number of pulses in the pack N_{imp}, i.e.

$$\sigma_p \approx \frac{\sigma}{\sqrt{N_{imp}}}. \qquad (6)$$

For example, for 10 pulses in the pack the accuracy must increase about by 3 times in comparison with the case of a single pulse.

To check this statement simulations for different number of radio pulses in the pack (10 to 100) were carried out. The mean-square error σ_p was determined by the expression:

$$\sigma_p = \sqrt{\frac{\sum_{i=1}^{N_p}\left(x^i - \bar{x}_p\right)^2}{N_p}}, \quad x^i = \frac{\sum_{j=1}^{N_{imp}} x_j^i}{N_{imp}} \qquad (7)$$

where x^i is the distance determined using i-th pack of chaotic radio pulses, x^i_j is the distance determined by j-th chaotic radio pulse from i-th pack, $\bar{x}_p$ is the average distance for all packs, N_p is the number of packs used in the statistics. The duration of radio pulse was 10 ns. Results of simulations are shown in Fig. 4.

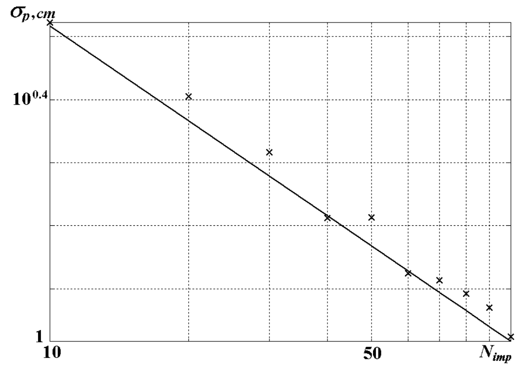

Fig. 4. Mean-square error of distance estimation (straight line is theoretical estimation, (x) is experimental results) as a function of the number of pulses in pack.
The duration of radio pulse is 10 ns.

Straight line corresponds to theoretical evaluation of the mean-square error calculated with relation (6). Crosses mark experimental data. As can be seen from the Figure, the modulation results confirm the above assumption, and the distance estimation error decreases as square root of the number of pulses in the pack.

III. Indoor location

Now we turn from the problem of distance estimation to the problem of indoor location, and consider a special case when both the object and the positioning devices are situated on the same plane, i.e., they have the same coordinate along axis z. (The below discussion will also be applicable in the three-dimensional case.)

Let this plane have dimensions 100x100 square meters. A single transmitter of chaotic radio pulses (called the subject of positioning object or a tag) and some receivers of chaotic radio pulses (called positioning devices) are located within the plane. There must be more than three chaotic receivers to determine uniquely the tag position.

For simulation we utilize three receivers of CRP. Dispose them at the plane points with coordinates (0,0), (100,0) and (0,100). As in the case of distance estimation assume we suppose that the transmitter and the receivers clocks are synchronized. The transmitter emits a single CRP or a pack of CRPs, and, correspondingly, the receivers get the single CRP or the CRP pack. Emission time is assumed known in each receiver. The bandwidth of chaotic radio signal is 2 GHz, the duration of CRP is 10 ns, and one chaotic pulse consists of 40 chaotic samples. The tag position is estimated as follows.

Let x_j, y_j be the coordinates of the receivers, t_j be the time of arrival of pulse to the j-th receiver, t_0 be the moment of pulse emission by the transmitter. A functional

$$\varepsilon = \sum_{j=1}^{N}\left[\sqrt{\left(x - x_j\right)^2 + \left(y - y_j\right)^2} - c\left(t_j - t_0\right)\right]^2, \qquad (8)$$

where c is the light velocity, N is the number of the receivers, represents the sum of squared errors of distance estimation between the transmitter and receivers.

It has a single minimum equaled zero at the point with the coordinates of the transmitter (Fig. 5). Computing the minimum of functional (8) we determine the position of the transmitter.

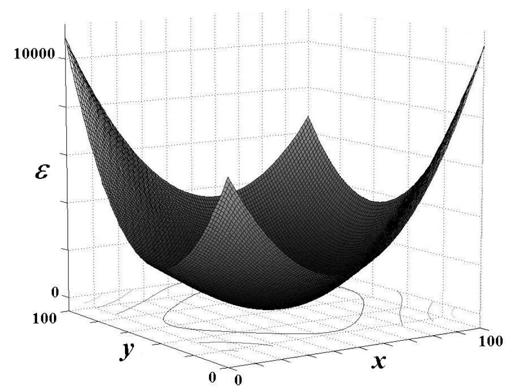

Fig. 5. Functional ε as a function of coordinates x and y. The minimum correspond to the coordinates of the transmitter

Then, in accordance with equation (7) we calculate the mean-square error of the tag position estimation. Results show that the mean-square error for each coordinate is about 7.5 cm.

To improve the accuracy of position estimation a pack of radio pulses is used instead of a single pulse. In this case the coordinates of the tag are defined by means of averaging the coordinates determined using each radio pulse from the pack. The dependence of the mean-square error on the number of pulses in the pack is shown in Fig. 6.

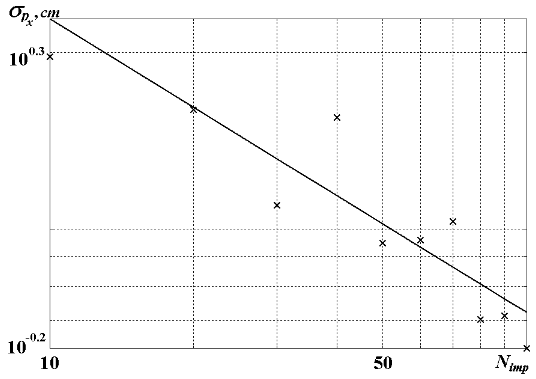

Fig. 6. Mean-square error of distance estimation along axis x (straight line is theoretical estimation, (x) is experimental results) depending on a number of pulses in the pack. The duration of radio pulse is 10 ns.

As can be seen in this graph, employing packs allows us to decrease the mean-square error approximately by a factor of square root of the number of pulses in the pack.

In conclusion we will compare the quality of tag position estimation using the systems with ultra wideband chaotic radio pulses with that of the systems based on short and ultrashort pulses. As is noted in introduction short pulses are considered more perspective for indoor location.

The accuracy of positioning of both systems is determined by the interval between the samples of pulse. Therefore from accuracy standpoint the efficiency of the first and second systems is the same. However as we have seen before, in the case of the systems with CRP the duration of radio pulse has little effect on the results of estimation. As to the systems with ultrashort pulses the duration of pulse strongly depends on the bandwidth

$$\tau \approx \frac{1}{\Delta f}.$$

It means that the requirements to the parameters of positioning systems based on CRP are softer than the requirements to the systems with ultrashort pulses. So, the CRP systems have a potential advantage in cost by comparison with the ultrashort pulse systems.

VI. Conclusions

In the report the problem of indoor location using chaotic systems with ultra wideband signals was discussed. Efficiency of such systems in comparison with the ultrashort pulses systems was demonstrated.

Location was performed using chaotic radio pulses (packs of radio pulses) formed from ultrawideband chaotic signals. Simulation was carried out for one and two-dimensional cases, which corresponds to distance estimation and positioning of the tag on the plane, respectively. The experimental results showed that in both cases the mean-square error of tag positioning for 10 ns pulses was 6-10 cm. Simulation, which was carried out for radio pulses with other duration, namely for 2 and 50 ns pulses, allowed to draw conclusion that the duration of chaotic radio pulse has little effect on the positioning accuracy.

Possibility of decreasing the mean-square error by employing radio pulse packs instead of a single radio pulse was shown. The positioning is improved by square root times of the number of pulses in the pack.

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