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Application of ultrasonic binaural method for measurement of spatial coordinates

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Introduction

In many fields of industry it is necessary to determine the coordinates of various moving objects. For this purpose the laser based, ultrasonic and television systems may be used. These systems differ in performance speed, amount of information obtained, accuracy and of course in price. There is a big variety of ultrasonic systems used for similar purposes.

One principle of spatial coordinates measurement is based on measurement of the delay time of ultrasonic pulses. There may be two different ways of localization of mobile objects:

- measurement of signals reflected by moving object;
- measurement of signals radiated by ultrasonic transducer mounted on the moving object.

The principle of operation of the system analyzed in this paper is based on the second method.

Method

The mobile object coordinate measurement method is based on a binaural principle [1-4]. On the mobile object, coordinates of which are measured, the mobile ultrasonic unit is mounted (Fig.1). This unit possesses the ultrasonic (US) generator with the transmitter of ultrasonic waves, infrared signal generator and digital signal processor. The US generator operates in a stand-by mode. For synchronization of operation of the mobile unit and the basic unit an infrared triggering signal is used. When US generator receives the infrared signal from the basic unit then it transmits the ultrasonic signal.

The ultrasonic signals transmitted by the mobile unit are picked up by two ultrasonic receivers. The receivers are placed at some distance L_0 from each other. According to the binaural principle it is necessary to measure ultrasound propagation times t_1 and t_2 from the transmitter to two receivers. The coordinates of the transmitter x_o, y_o can be calculated according to

$$x_o = \frac{c^2}{2L_0} \cdot \left(t_1^2 - t_2^2\right),$$
$$y_o = \sqrt{c^2 t_1^2 - \left(x_o + \frac{L_0}{2}\right)^2}, \quad (1)$$

where c is the ultrasound velocity, t_1, t_2 are delay times of the ultrasonic waves from the transmitter till the first and second receivers, L_0 is the distance between the receivers. This distance is called the base distance and in our case was L_0=1m.

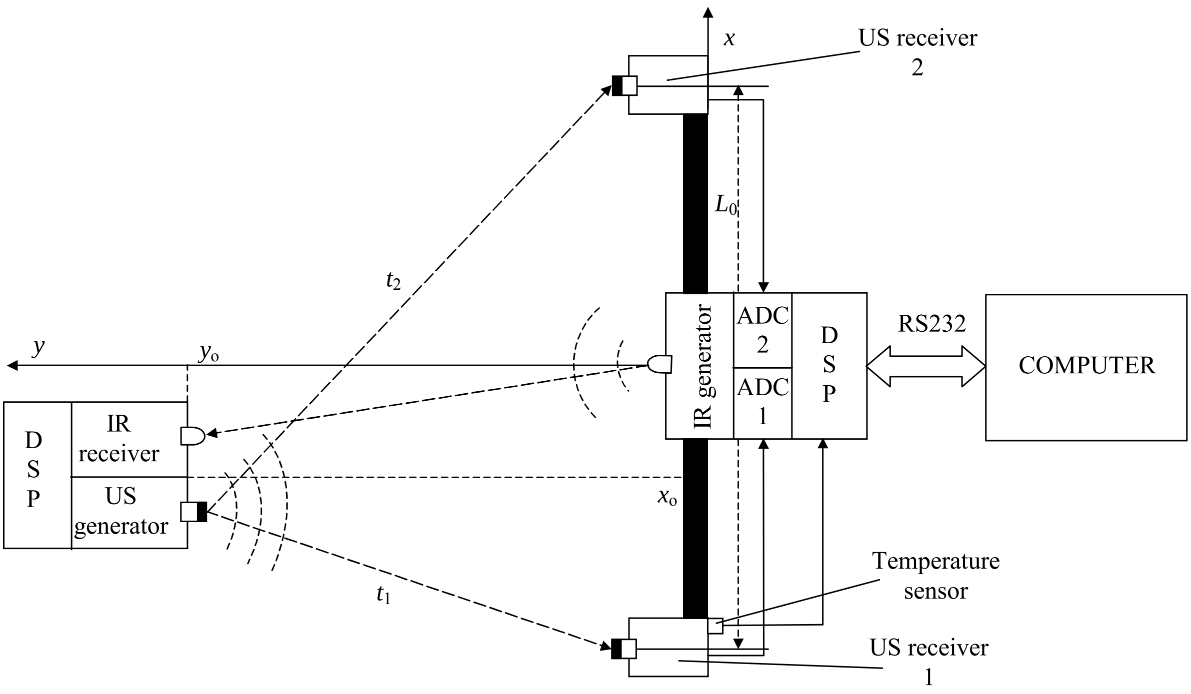

Fig.1. **Structure of the ultrasonic system for measurement of coordinates of mobile object**

Implementation of the binaural approach for measurements of coordinates in air meets some problems. Measurements may be performed only in an area, which is covered by overlapping directivity patterns of the transmitter and both receivers. It means that in order to have this area wide enough, the ultrasonic transducers must possess wide directivity patterns. That leads to big signal losses caused by beam spreading and consequently a low signal/noise ratio. Additional measurement errors are due to temperature dependence of ultrasound velocity and influence of air turbulence or convection flows.

In order to overcome these problems and to get a good noise robustness it was proposed to use coded ultrasonic signals, time varying gain and correlation processing, which should be carried out on-line. In order to avoid the influence of an acoustic noise the ultrasonic signal is the phase manipulated 40 kHz M – sequence of 32 elements, duration of each element is 5 periods of the carrier. The time varying gain is used for compensation of attenuation and diffraction of ultrasonic wave. The measurement errors caused by ultrasound velocity changes due to temperature variations are compensated using the temperature sensor mounted on the receiver.

The delay times from the ultrasonic transmitter till the first and second receivers are with cross-correlation method calculated. The essence of this method is that the calculation of the cross-correlation function was splitted into two steps:

- during the first step the coarse delay time estimation of the received ultrasonic signal is obtained;
- during the second step the position of the signal in the time domain is found by means of the conventional cross-correlation algorithm in the time domain, but calculations are carried out only in a very narrow window.

The duration of the first step depends on the distance and is longer for longer distances. The second step does not depend on a distance and is relatively fast. In the case of averaging the first step is performed only once for the first measurement. In averaging mode only the second step of algorithm is performed. Therefore, 10 measurements in averaging mode takes only 30% longer time then a single measurement.

The described ultrasonic mobile object coordinate measurement system was investigated experimentally and uncertainties of measurements results were analyzed.

Results

The objective of the experiments was estimation of measurement accuracy in closed spaces and determination of potential limits of measurements. Experiments were carried out in a closed hall [5]. The measurements were performed in the following steps:

- calibration of the system;
- acquisition of the reference signal at the given position;
- measurements at the prescribed points along a few directions parallel to the measurement base at various distances from the ultrasonic receivers.

The aim of the calibration of the system was to determine a complete parasitic delay time in electronics and acoustics. For this purpose the reference signal was used. The reference signal was acquired at the distance 1m in front of the first receiver. The parasitic delay time was determined comparing mechanical and ultrasonic measurements.

For a detailed system analysis measurements of spatial coordinates of mobile objects in air were performed. The position of the mobile unit was changed at the distances 10 and 20 meters in the *y*-axis direction and up to 10 m with a step 2 m in the *x*-axis direction. The actual positions of the mobile unit were determined by means of mechanical measurements.

The uncertainty of measurements of spatial coordinates was characterized by a standard deviation. In our case the position of the active beacon is given by two – *x* and *y* coordinates, therefore the total uncertainty was determined from the uncertainties of measurements of *x* and *y* coordinates:

$$s(x,y) = \sqrt{s^2(x) + s^2(y)}, \qquad (2)$$

The spatial distribution of these uncertainties is presented in Fig.2.

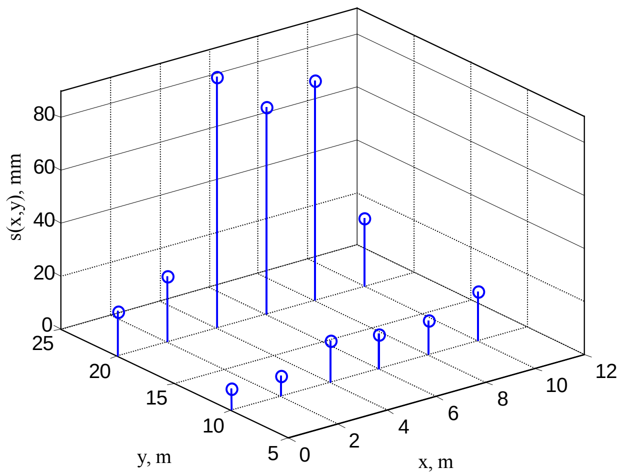

Fig.2. **Graphical illustration of the experimental standard deviation modulus**

The experimental standard deviation of the measurements results with ultrasonic system is not bigger than 0.09 m at 20 m from the ultrasonic receivers.

Conclusions

The proposed ultrasonic system for measurement of coordinates of a mobile object enables measurement of spatial coordinates in air up to 20 m from the receivers and up to ±10 m from the symmetry axis with experimental standard deviation of the measurements results not bigger as 0.09 m. The measurement accuracy may be improved increasing the measurement base.

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Ultragarsinio binauralinio metodo taikymas objektų erdvinėms koordinatėms matuoti

Reziumė

Mobilių objektų erdvinėms koordinatėms matuoti pasiūlytas kombinuotas metodas, apimantis ultragarsinį binauralinį metodą ir distancinį valdymą infraraudonaisiais spinduliais. Žemojo dažnio ultragarsinis spinduolis tvirtinamas prie mobilaus objekto, o jo paleidimas sinchronizuojamas infraudonosiomis optinėmis bangomis. Išspinduliuoti ultragarsiniai signalai priimami dviem ėmikliais, o mobilaus objekto koordinatės nustatomos binauraliniu metodu. Tikslumui ir atsparumui triukšmams pagerinti ultragarsinių signalų sklidimo trukmės nustatomos koreliacinio apdorojimo metodu. Pateikti eksperimentinių matavimų duomenys ir jų neapibrėžtys.

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