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The experimental investigation of spatial resolution of ultrasonic coordinate meter

R.Kažys, L.Mažeika, O.Tumšys

Prof. K.Baršauskas Ultrasound institute

Kaunas University of Technology

Introduction

In many fields of industry it is necessary to determine the coordinates of various moving objects. Such a problem is met in measurements of spatial distribution of some physical quantities such as temperature, magnetic, electromagnetic fields and etc. In this case the position of the sensor must be determined at each measurement point. 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 [1-6]. The advantages of ultrasonic systems are simplicity in use, low sensitivity to the dust, fog or poor vision conditions caused by environmental factors and a relatively low price. The various types of ultrasonic transducers, signals and processing algorithms can be used to get the required accuracy. The principle of operation of the system analysed in this paper is based on the binaural approach. The objective of the work presented is to determine the reliability and potential accuracy of such a measuring system.

Approach

The coordinate measurement method is based on a binaural principle. On the mobile object, coordinates of which are measured, a transmitter of ultrasonic waves is mounted. According to the binaural principle it is necessary to measure the sound or ultrasound propagation time from the transmitter to two receivers placed at some distance from each other. The coordinates of the transmitter x_t, y_t can be calculated according

$$x_t = \frac{c^2 t_1^2 - c^2 t_2^2}{2L_0}$$
$$y_t = \sqrt{c^2 t_1^2 - \left(x + \frac{L_0}{2} \right)^2} \qquad (1)$$

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.

The ultrasonic positioning system consists of one mobile block with the transmitter and the fixed block with the two receivers of ultrasonic waves. For the synchronisation of operation of the mobile and the fixed blocks an infrared triggering signal is used. The mobile part includes also the generator, which operates in a stand-by mode. When it receives the infrared signal from the host unit then it transmits the ultrasonic signal. The ultrasonic signal is modulated by a coded sequence in order to avoid the influence of an acoustic noise [2]. The receivers are placed at some distance L_0 from each other. This distance is called the base distance and in our case was L_0=1m. The received signals are amplified and digitised. The digitised signals from the both receivers are processed using cross-correlation method. The time varying gain is used for compensation of attenuation and diffraction of ultrasonic wave. The ultrasound velocity variations caused by temperature are compensated using temperature sensor.

The result of the cross-correlation analysis is the propagation time of ultrasonic signal from the transmitter to the first and the second receivers. From these delay times, taking into account the ultrasound velocity and the base distance the coordinates of the transmitter are determined [3].

Experimental set-up

The system described above was used for investigation of the accuracy of determination of spatial coordinate by the binaural method. The generic structure of the experiment set-up is presented in Fig.1. The ultrasonic signals were acquired by a digital oscilloscope in order to have possibility for a more detailed analysis.

The position of the mobile unit was changed step-by-step up to 20 meters in front direction from the receivers and up to 12m in the perpendicular direction. (Fig.2).

The objective of the experiments was to determine the frontal and lateral accuracy of the system up to 20m. 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 reference signal was acquired at the distance 1m in front of the first receiver. During the experiments measurements were performed at the distances 1, 5, 10, 20 meters in the x axis direction and at the 0, ±1, ±2 meters in the y axis direction. The actual positions of the mobile unit were determined by means of mechanical measurements. At each point 3 measurements were performed and average value calculated. The test results are presented in Fig.3.

In general there was good correspondence between mechanical and ultrasonic measurements. The best accuracy was obtained on the x axis. At the distance 1m the absolute frontal error was 8mm and the lateral error 14mm. At the distance 20m corresponding these errors were correspondingly 11 and 10cm. The error was bigger

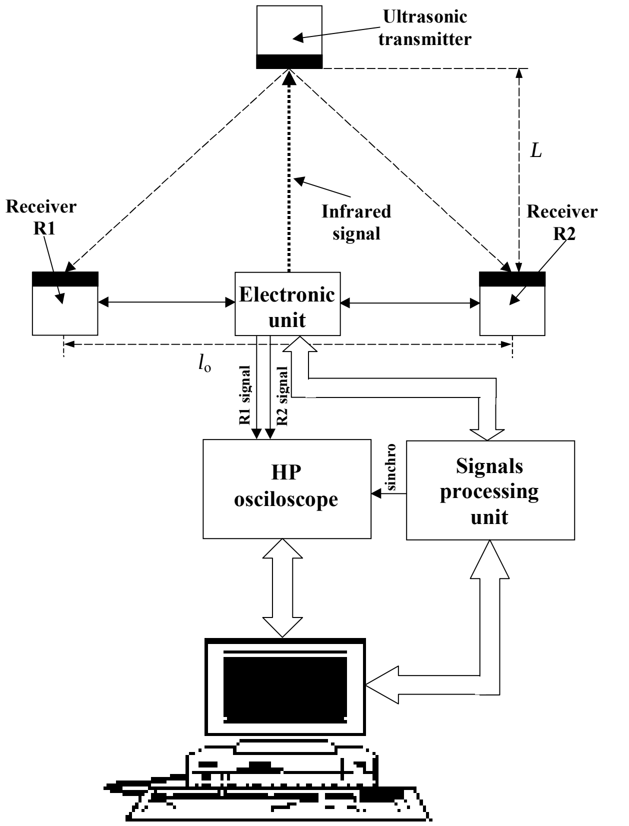


Fig. 1. **The generalised structure of the experiment set-up for the coordinates measurement**

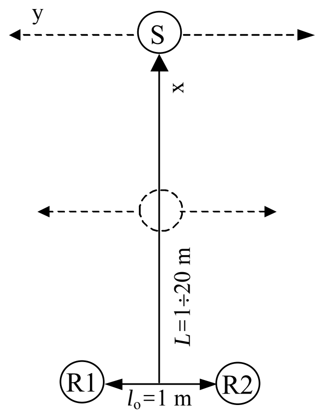


Fig. 2**. Scanning direction of the mobile unit during measurements**

at the positions in shifted from the *x* axis. At the distance 20m from the receivers and the lateral shift 2m the measurement error in the direction of the both axes was approximately 13cm. From the results obtained it is possible to see some systematic shift in the negative direction of the *x* axis for all positions. This can be explained by the error of mechanical measurements, probably in determination of the perpendicular direction with respect to the measurement base. For a more detailed analysis the measurements were repeated at the distances 10 and 20m in a lateral direction up to 10m with a step 2m. At each point ten measurements were carried out. The results of these measurements are presented in Fig.4. The results exhibits the same character of the measurement errors. The errors are increasing when the measurements are performed at bigger distances from the *x* axis. These errors obviously include a clearly expressed systematic term and may be compensated.

Conclusions

The experiments performed had proved that the analysed ultrasonic binaural coordinate measuring system can reliably determine spatial coordinates in the range of the distances up to 20m from the receivers and up to ± 12m from the symmetry axis with error less then ±0.2m. In this case the measurement base 1m base is sufficient.

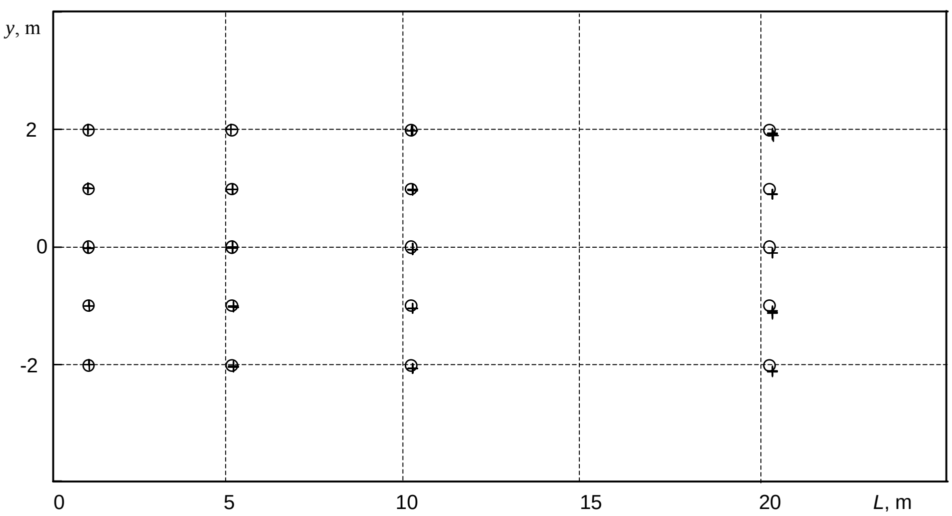
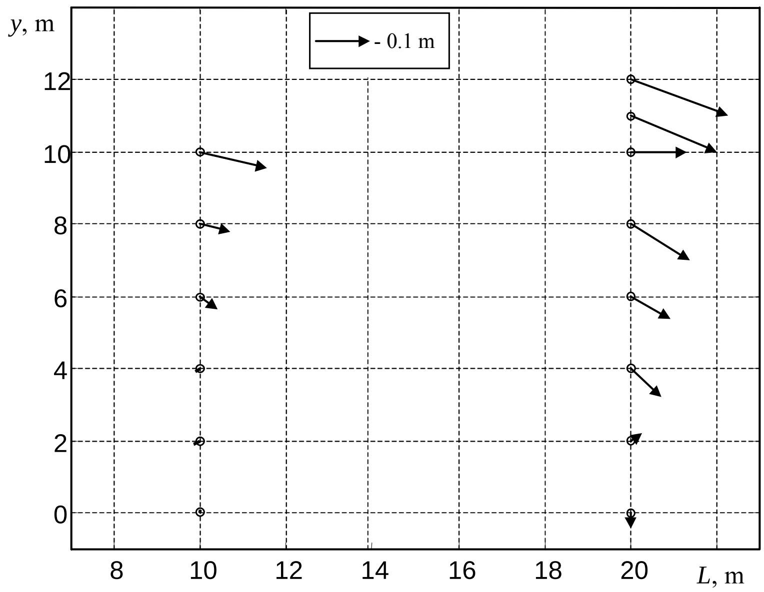


Fig.3. **The test results of the measurement at distances 1, 5, 10 and 20 meter in front of the receivers: by "o" are denoted the actual positions of the mobile unit; by"+" are denoted the coordinates reconstructed by the ultrasonic meter**



4 pav. **The results of determination of coordinates at the distances 10 and 20m: "o" - the origin points of arrows coincides with the positions of mechanical measurement sand the end points of arrows coincides with positions measured by the ultrasonic meter. The scales are zoomed. The arrow in the upper part of the figure corresponds to the error 10cm**

The existence of systematic errors shows that it is necessary to perform more detailed analysis of the factors influencing measurement uncertainty.

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R. Kažys, L. Mažeika, O. Tumšys

Eksperimentiniai ultragarsinės pozicionavimo sistemos erdvinio skiriamumo tyrimai

Reziumė

Darbe nagrinėjama ultragarsinė pozicionavimo sistema, skirta judančių objektų erdvinėms koordinatėms nustatyti. Sistemą sudaro mobilus ultragarsinis spinduolis, du priėmimo keitikliai bei signalų apdorojimo blokas. Objektų erdvinės koordinatės nustatomos binauraliniu metodu, kai atstumai iki objektų išmatuojami panaudojant atraminio ir dviem keitikliais priimtų ultragarsinių signalų koreliaciją.

Pateikti šios sistemos erdvinio skiriamumo eksperimentinių tyrimų rezultatai. Nustatyta, kad sistemos patikimo veikimo zona yra iki 20 m x ašies kryptimi ir ±10 m y ašies kryptimi. Tolimiausiame matavimų taške nuokrypiai šių krypčių atžvilgiu sudaro ne daugiau kaip ±0.12 m.

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