8—28 Smart Ultrasonic Vision System for Mobile Robots

Rymantas KAŽYS*, Liudas MAŽEIKA+, Reimondas ŠLITERIS♦, Linas SVILAINIS×,
Kaunas University of Technology, Ultrasound Research Center

Abstract

For navigation of semi-autonomous robots various machine based vision systems are used. Ultrasonic systems are one of the cheapest, but some limitations reduce their performance. This paper is devoted to improvement of a data acquisition speed and noise robustness of such systems.

These goals were achieved using simultaneous data acquisition along a few different directions using orthogonal complex coded series as probing signals, parallel correlation processing of the received signals by individual digital signal processors (DSP) and determination of the coordinates of the obstacles detected using the tri-aural approach. In order to increase the environment scan speed, electronically steered ultrasonic phased arrays are used with the different code sequences for each direction. The data exchange with the host computer is performed via the LON Works interface.

Ultrasonic image formation and analysis algorithms are discussed.

1 Introduction

Semi-autonomous intelligent robots are widely used in manufacturing and hazardous environments such as nuclear power plants, for bomb disposal and etc. For navigation of mobile robots various machine based vision systems including laser systems, infrared imaging, television systems and ultrasonics are used. Ultrasonic systems offer potentially the cheapest and simplest solution, but there are some fundamental and technical limitations which cause serious problems in their successful implementation [1-3].

The data acquisition rate in ultrasonic sensors is limited by a finite value of the speed of ultrasonic waves, number of measurement directions and the maximal distance. That is of a crucial importance for mobile robots, because movement of a vehicle has to be limited to the environment perception speed. Another obstacle for implementation of ultrasound for a distance measurement is an ultrasound attenuation and a surrounding noise influence.

The main objective of this work was to develop ultrasonic vision system, suitable for navigation of semi-autonomous robots in industrial environment. The environment assessment speed and noise robustness were main goals to be achieved.

Principle of operation

In order to provide safe and reliable navigation of the mobile robot, the ultrasonic sensor consists of two side looking sonars and two main electronically steered sonars directed at different directions (Fig.1). All these separate units operate simultaneously and the data obtained by them are fused together. That ensures a high speed of data collection, which is essential in the case of dynamically changing environment. The side looking sonars determine the distance to the flat objects, like walls, which are parallel to the movement direction of the robot. In order to increase the update rate, ultrasonic signals are transmitted by electronically steered ultrasonic phased arrays. Steering of the array is performed digitally delaying driving signals, which are generated by the coded sequence generator. At different directions different orthogonal coded sequences are transmitted. That enables to increase the pulse repetition rate and to reduce the influence of a reverberation noise.

The use of electronically controlled arrays allows to perform all operations in the real time, what enables the sensor to adapt to a dynamic environment. The commands required for the adaptation are obtained from the host computer via the LON Works interface. In order to reduce the processing time of the received ultrasonic signals the signal processing is performed by 5 parallel digital signal processors. The correlation processing enabled to achieve a good noise robustness, which is essential for robots operating in a manufacturing environment.

The information obtained from the parallel signal processors is processed by the master processor, which

* Address: Studentu 50, Kaunas LT-3031, Lithuania
E-mail:rkazys@tef.ktu.lt

+ Address: Studentu 50, Kaunas LT-3031, Lithuania
E-mail: liudas.mazeika@tef.ktu.lt

♦ Address: Studentu 50, Kaunas LT-3031, Lithuania
E-mail:ulab@tef.ktu.lt

× Address: Studentu 50, Kaunas LT-3031, Lithuania
E-mail:svilnis@tef.ktu.lt

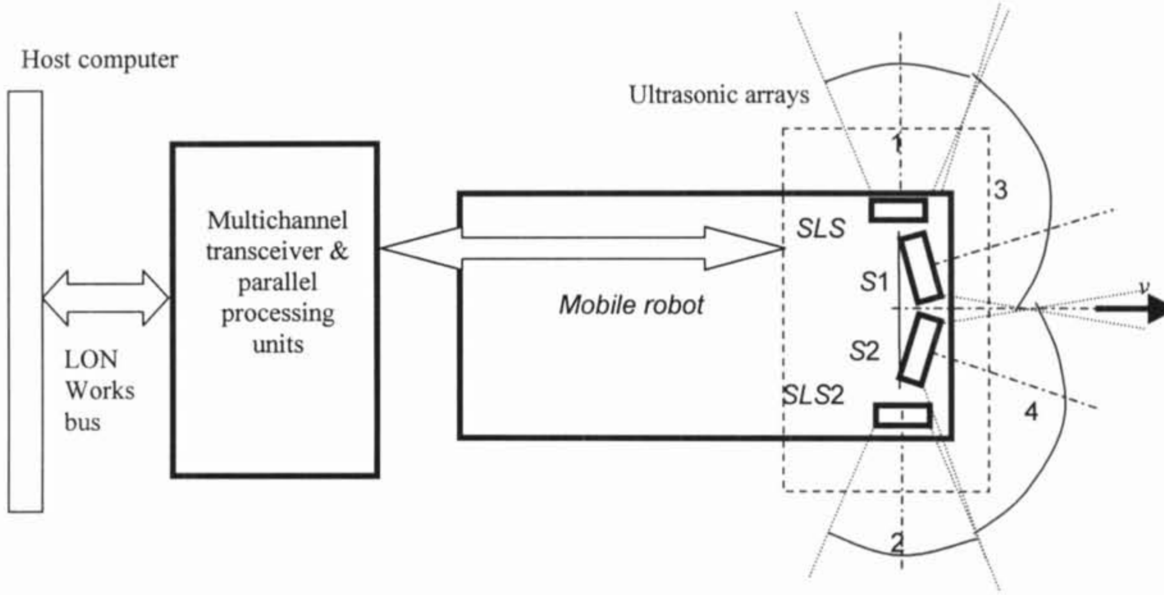


Fig.1. The structure of the ultrasonic sensor: SLS1, SLS2 are the side looking sonars, S1, S2 are the main electronically steered sonars, 1, 2, 3, 4 are the areas covered by corresponding sonars.

produces the ultrasonic image of the surrounding environment using tri-aural approach.

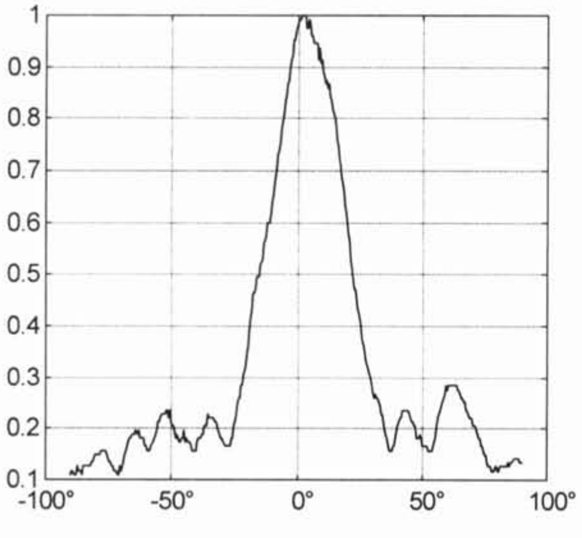
From the image obtained the coordinates – the distance and the bearing angle of the objects in the range from 0.5m up to 5m are determined.

Ultrasonic signals are transmitted by phased arrays, in which 40kHz piezoelectric transducers are used. The diameter of the transducers is 10 mm, which slightly exceeds wavelength. In order to reduce the level of parasitic sidelobes in a directivity pattern of the array, densely packed honeycomb-type arrays are exploited. The directivity pattern of such an array in a horizontal plane is presented in Fig.2.

Implementation of the system

The block diagram of the ultrasonic vision system is presented in Fig.3.

The main DSP controls all acquisition process and collects data from parallel DSP's and estimates the coordinates to feed them into LON Works interface. In order to have a good signal-to-noise ratio, the coded binary sequences are used. In order to obtain a good noise robustness and to improve the temporal resolution, the received signals are processed using the correlation



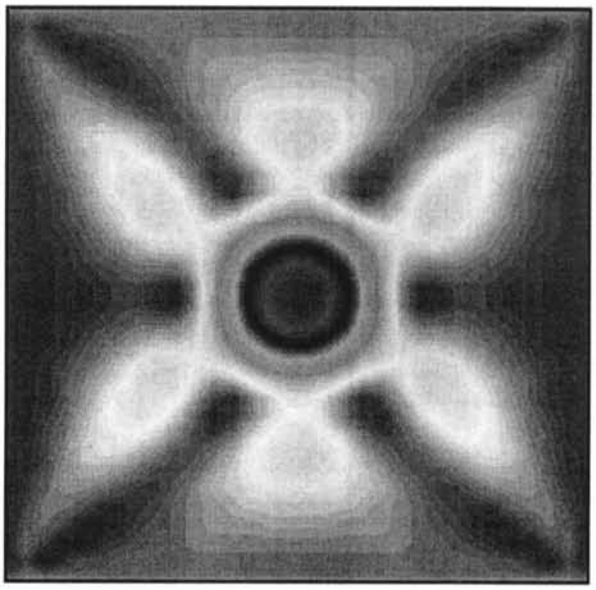


Fig.2. Directivity pattern of the honeycomb-type array, consisting of 3 elements

processing. A conventional way of collecting distance data is to transmit the probing signal and to wait for a next transmission the time necessary for ultrasound to propagate the maximal distance. Acquisition requirements for mobile robots demand the next pulse to be transmitted before the previous pulse reflected by the most remoted object arrive. Using the orthogonal sequence for the next transmission allows to cancel the reflected signals and multiple reflections from the previous transmission in the received signal. Such an approach enables to reduce significantly the acquisition time. Electronical beam steering allows to eliminate the mechanical parts and to reduce the time for an environment scan. The considerations mentioned above put specific requirements on the exciting generator. It must be capable to generate the required code sequence a with required delay and switch from one sequence to another quickly.

The phased array have separate transducers for transmission and reception of the ultrasonic signals. Such an approach allows to avoid an overload of the input channels by the excitation signal. All signals received are prefiltered to avoid an overload of the channel by noise frequency components outside the frequency range used for measurements. A gain of the preamplifier can be controlled remotely in order to get a better dynamic range. The both units – filters and preamplifier are placed close to the receiving transducers in order to improve a noise robustness. The signal is sent into main unit via cable for a further amplification, filtering and acquisition. The main amplifier contains the time varying gain (TVG) amplifier. This feature can be used for beam spreading and ultrasound attenuation compensation. Filtering is performed by the fourth order active RC filters. It must be noted here, that all components of the system are synchronised in order to avoid a jittering noise. The synchronisation block is designed for elimination of the jittering noise and analog signal sampling control. The A/D converters are included in each DSP processing channel and they are feeding data directly into DSP's memory.

As DSP TMS320C50 type signal processors are used. Calculation of the cross-correlation function of the received and reference signals takes 160ms. All processors are connected by the same local bus, controlled by the host DSP. Communication with the host computer is performed via the LON Works type field bus.

Evaluation of coordinates

The coordinates of the reflectors around the robot are found using the time of flight technique and binaural or tri-aural signal processing. In order to improve a noise robustness of the ultrasonic system, the received signals are processed using the correlation processing [4]. The time-of-flight of ultrasonic signals is evaluated from the cross-correlation functions and used as initial data for the binaural processing [5, 6]. For that purpose transmitter and 2 or 3 receivers of ultrasonic signals are located at different positions (Fig.4).

The possible positions of the reflector for the time-of-flight t_{ij} can be defined as the set of the ellipse points (i is the transmitter number, j is the receiver number). The ellipse are defined by the equation:

$$a = t_{ij}/(2c),$$
$$b = \sqrt{a^2 - d_{ij}^2/4}, \qquad (1)$$

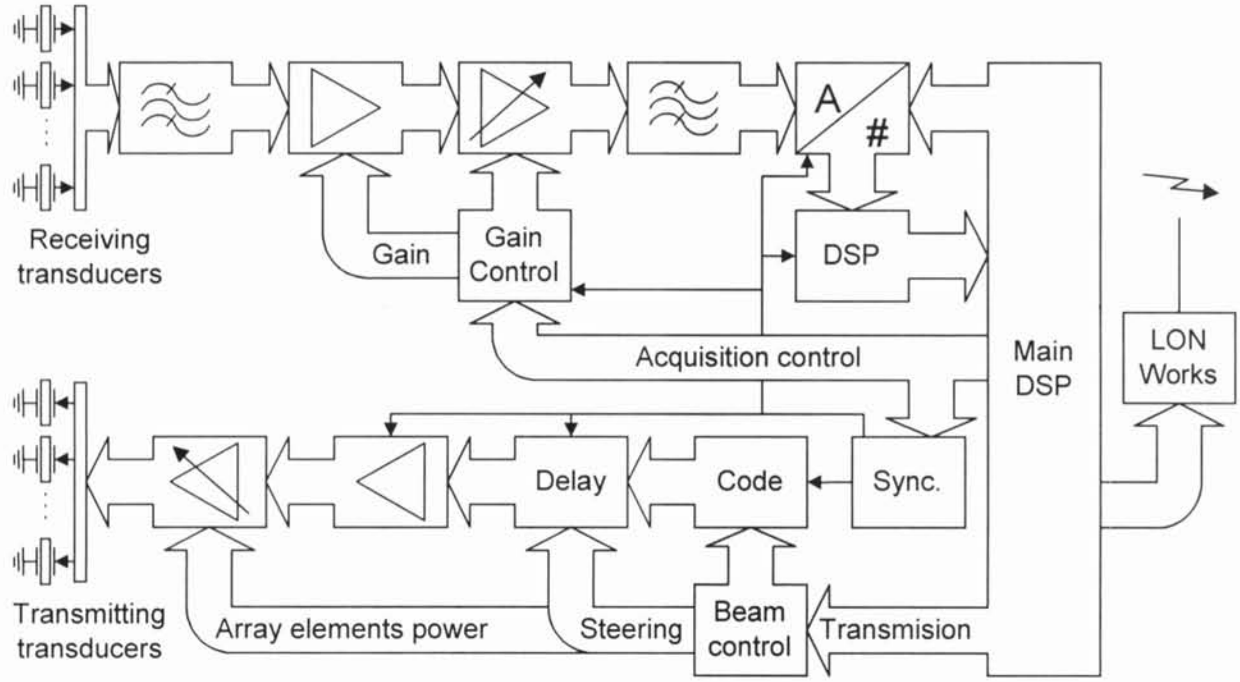


Fig.3. System block diagram

where a, b are the semimajor and semiminor axes of the ellipse respectively, t_{ij} is the time of flight, d_{ij} is the distance between the transmitter and the corresponding receiver.

From two pairs of the transducers the two intersecting ellipse arcs are obtained. The intersection point defines the position of the reflector and is given by

$$\begin{cases} x = a\cos(\theta) \\ y = b\sin(\theta) \end{cases} \tag{10}$$

where

$$\theta = \arcsin\left(\sqrt{\frac{b'^2(a^2 - a'^2)}{a^2 b'^2 - a'^2 b^2}}\right),$$

a', b' are the axes of the ellipse obtained from the second pair transmitter-receiver.

The experimental results obtained for various targets – human beings, corner type reflectors, solid rods, illustrate a good performance of the system [1].

Conclusions

The use of electronically controlled arrays, different code sequences for different directions and parallel signal processing together with the tri-aural perception allows the sensor to perform assessment of an environment in the real time. Implementation of coded sequences together with the correlation processing and filtering enabled to achieve a good noise robustness, which is essential for robots operating in an industrial environment.

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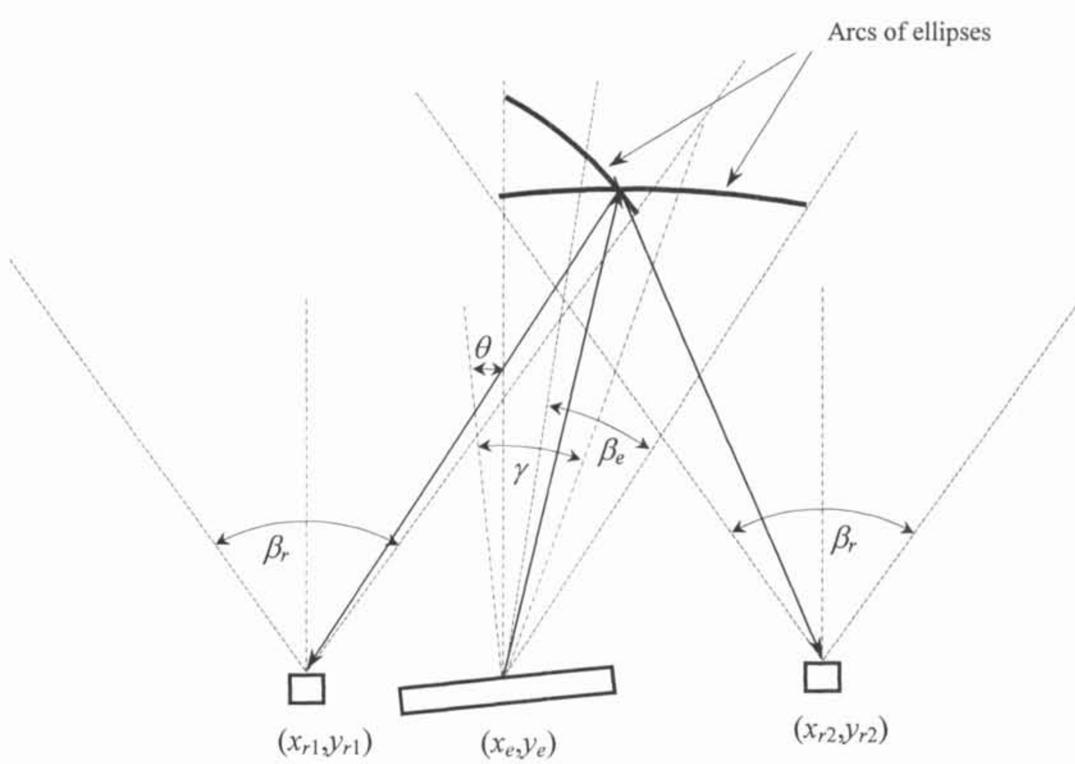

Fig.4. Determination of the coordinates of the reflectors by means of binaural perception. x_e, y_e are the coordinates of the emitter, x_{r1}, y_{r1}, x_{r2}, y_{r2} are the coordinates of the receiver