Using ultrasonic sensors to create 3D navigation model of area with ultrasonic sensors

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Abstract - In this paper, 3D model of area using ultrasonic signal was created. In order to achieve this goal they were presented two techniques. Both techniques are based on analytical knowledge to sort data and get required information to create 3d model of the area. The 3D model is created in software MATLAB and also served to gain basic information about resolution of objects and others obstacles, which could cause restriction in movement of wheeled robot. Thus obtained data will be used to control motion of wheeled robotic platform in indoor environments such as warehouses. This 3D ultrasonic navigation system together with mechanical arm placed on same robotic wheeled platform will be used for fire detection and to extinguish a fire.

Keywords— Signal processing, Time of flight, Ultrasonic sensors wheeled robot platform

I. Introduction

Ultrasonic localization of obstacles has been studied in recent years by many researchers. This studies has been mainly focused on improvement of achieved result due to two dimensional arrays with dozen of ultrasonic sensors for example. In these studies authors used various methods for accomplishing desired results. Most of them used methods like beamforming and its variation. This approach give sufficient results, nevertheless it makes high demands on hardware and software. Especially processing data from all sensors in array take significant amount of time.

In this paper it will be shown two representation of data in order to locate obstacle position and their proportion in 3D. This goal was achieved by mathematical method. Method is bases on analytical knowledge to manage the goal has been described and applied on this specific problem to detect obstacle. Method is very spread in different research array, however in this field is very rarely use.

Data was obtained from created ultrasonic measured board with four pair of ultrasonic sensors. At first raw data was processed in microcomputer on ultrasonic measured board and after that was send via selected UART interface into personal computer. In PC was data processed and displayed into appropriate form with Matlab software. Measurement has not been performed in any special acoustic laboratory, but in ordinary environments, where will be robot operate in real situation.

In comparison with others methods for obstacle recognition ultrasonic detection is commonly used in various industry sectors. Main advantages of ultrasonic detection are its low cost and ability to operate in various environments with reduced visibility, where camera systems are not very effective.

There are many different types of localization techniques. In this paper it will be described novel method to locate obstacles. Proposed method is based on following localization theoretical techniques through which a position and resolution can be found. Every method has its own advantages and disadvantages, and all require the use of sensors array.

Data obtained from these localization technique has to be processed to creation of 3D model of scanned area in front of measuring ultrasonic sensor array. One of methods to display measured data are disparity maps, which are using weight for recognition of significant points in 3D model.

A. Disparity maps

Disparity refers to the distance of two corresponding points in two stereo views. For instance on the Figure 1 it can be seen highlighted point P and their projection on left image and on right image. Due to projection of this point on left and right images it can be found disparity for this P point as the magnitude of the vector between these two projected points. However, in this process it is important to choose point in the left and then correctly find its match in the right image. [10]

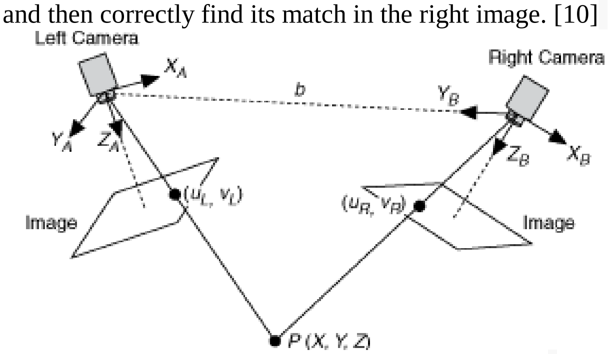

Fig. 1 example of creation of disparity map [11]

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II. LOCALIZATION TECHNIQUE

A. TOA

Time of arrival (TOA), uses the time of flight between transmitter and receiver to measure the distance to obstacle. In order to locate some object in front of sensors array with TOA, it has to be used at least three sensors. The position of the object can be found from intersections of three circles with radius being calculated from distance. Measurement, which contains various errors, can produced region in which might be transmitter located instead of precise position. Example of TOA technique is shown on Figure 2. [12]

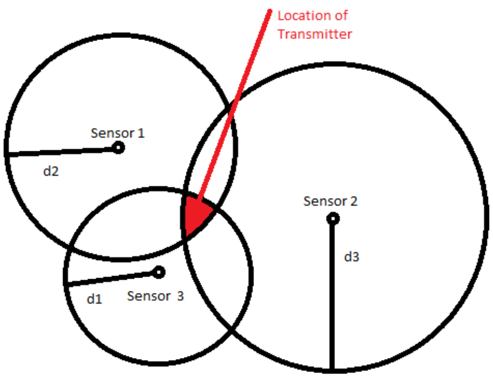

Fig. 2 example of TOA location technique [12]

In TOA techniques it is not only important to synchronize time of transmission of individual sensors but remain synchronized for all time, when localization is proceeding.
Due to synchronization of all transmitters and receivers the error in the time differences is not presented. However in sensitive measuring systems, there is significant processing delays it must be accounted with this in calculation of the correct distance. [12]

B. Time Difference of Arrival

Time difference of arrival (TDOA), uses multilateration or hyperbolic positioning, to locate the obstacle. There are many similarities with TOA. In TOA technique, it is used the travel time from each receiver to find the distance between the transmitter and receiver. [12]

TDOA uses the travel time from the transmitter to the receiver in order to measure distance. The difference in travel times from each sensor are used to find the distance between each sensor. Obtained results from intersections of hyperbolas, which can be seen on Fig. 3 can be used for location of object.

This technique need for proper localization of objects synchronization like in TOA technique. However, TDOA does not require synchronization of transmitters in sensor array. Synchronization is needed only between all receivers since the calculation is based on difference of time. [12]

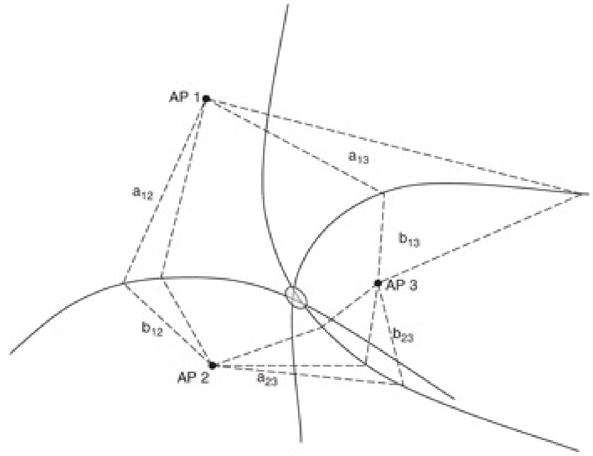

Fig. 3 example of TDAO localization technique [12]

In this paper, as was mentioned before, it is used TOA technique in 3D space. Of course this technique had been adjusted for purposes of ultrasonic signal processing.

III. MEASUREMENT SYSTEM

A. Ultrasonic measurement board

Raw data were obtained from ultrasonic measurement board and evaluated by analytical and least square method. Proportion of ultrasonic measuring board is 15x 15 (cm). This distance between has been chosen to simulate humans hearing system. Measuring board is shown on Fig. 4.
Ultrasonic measurement board contains four transceiver 400ST160 and four receiver 400ST/R160. Moreover on this measurement board are placed: 32 bit microcomputer STM32F407VG core ARM Cortex-M4F and 192 kB RAM. Microcomputer has sixteens 12 bit ad converter and four DA converters. Power supply is done by switching power supply, which supply microcomputer itself (3,3V) and also operational amplifiers TLC274AC (±18V)

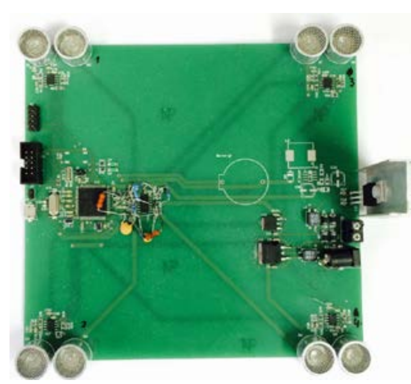

Fig. 4 ultrasonic measurement board

Operational amplifiers are inverting amplifiers and their gain is given by connected resistors.

Circuit on following picture Fig.5 shows input inverting amplifiers, which amplifies received ultrasonic signal. These circuit has been used for all four ultrasonic receivers.

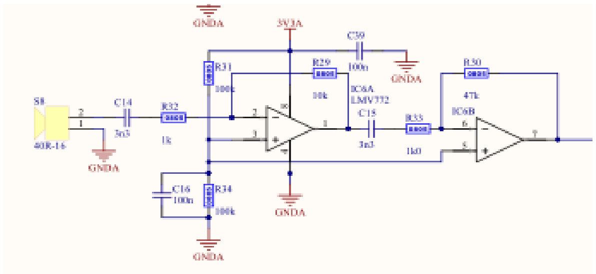

Fig. 5 electrical circuit of input inverting amplifiers

Following circuit on figure Fig. 6 has been used for transfer of generated ultrasonic signal. This circuit was also used for all four ultrasonic transmitters.

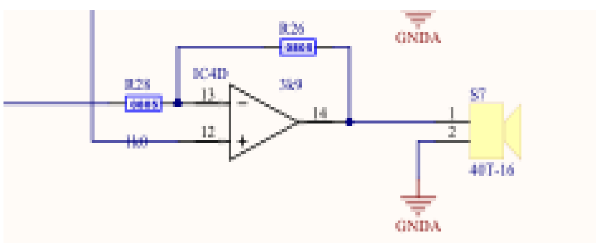

Fig. 6 electrical circuit of output inverting amplifiers

B. Processing of raw data

Created program which was implemented into microcomputer generates ultrasonic signal with 1/40 000 second width see on Fig. 7.This signal is amplified and sent into one of ultrasonic transceivers. After transfer of ultrasonic signal, data are read from coupled receiver and send via serial link to the pc. This method is repeat for all four pairs of sensors.

For this approach, it was used DMA controller, which is included in above mentioned microcomputer. The DMA controller uses its own bus connecting memory and chosen output. From the foregoing is clear that data transfer between AD converter and memory does not use computing power of CPU. Data flow is controlled by DMA controller by itself.

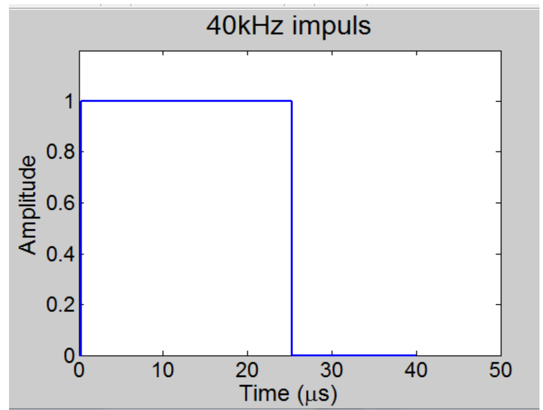

Fig. 7 generated square impulse

When data are saved into memory of microcomputer, after that are processed. Data, which were collected from one of four receivers, are mapped into appropriate form as can be seen on Fig. 8. Original raw data from one receiver are shown on Fig. 9

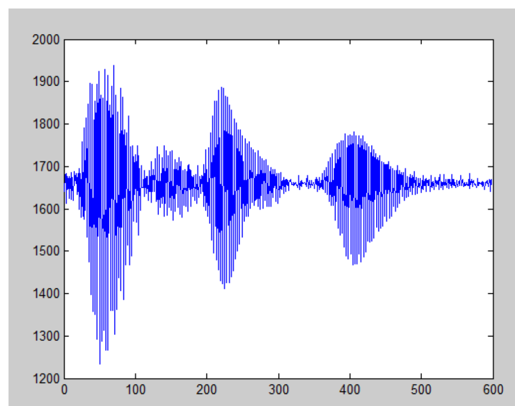

Fig. 8 measured data from one ultrasonic sensor

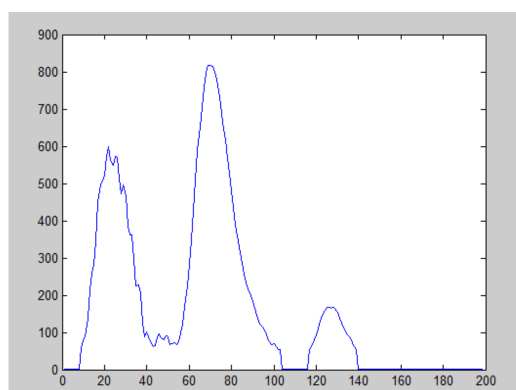

Fig. 9 modified data from one sensor

From previous Fig.9 can be deduced performed changes. First change was to define mean value and move all values in such way, that obteined mean value will be in origin of coordinate system. Last change which was applied was averaging three consecutive values into one.

IV. Processing Algorithms

Algorithms created in this paper are based on intersection of the spheres. The sphere is used because that ultrasonic signal is spreading in air in spherical surfaces. This means that if we use measured data we can create 200 spheres with radius, which matches distance of reflected ultrasonic signal from obstacle. Therefore the radius is calculated from distance and ultrasonic wave speed in air (about 350 m/s).

Further, it is important to process another included information in obtained data see in Fig. 8 and 9. Amplitude in every time, in given distance, represent size of reflected energy from distant obstacle. This reflected energy can be marked as significant value, which will be identifying value in following process. Every point of sphere have this value and its value determine if this point is interesting for us or not.

V. Analytical Method

On base of dimension of square ultrasonic measurement board with a side equal 15 cm they were established four centers: S1= [0,0,0], S2= [15,0,0], S3= [0,15,0], S4= [15,15,0]. In these centers were progressively generated points for all 200 spheres with radius from 0,875 to 175 cm see Fig. 10

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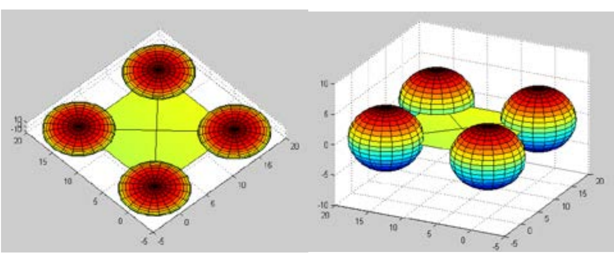

Fig. 10 placement of spheres centers

Radius values are calculated from received data by following formula

$$\mathrm{r} = (1\,\text{až}\,200\,/40\,000) * 350\,00 \;\; [\mathrm{cm}] \tag{1}$$

, where values 1 to 200 can be seen on Fig.8, 40 000 is used for conversion into seconds and 35 000 is speed of ultrasonic signal in air.

The algorithm, which generate all point of intersection of spheres is: In first step is chosen one sensor and after that intersection of all neighboring spheres are calculated.

From analytical geometry the sphere equation is:

$$(x-x_0)^2+(y-y_0)^2+(z-z_0)^2 = r^2 \tag{2}$$

Intersection of sphere S1 and S3 is given as follows:

$$2\cdot S3_y y - S3_y{}^2 - r_1{}^2 + r_3{}^2 = 0 \tag{3}$$

Calculation of intersection of S1 and S2 will be defined same way. Obtained plane equation are used for calculation of final intersect see Fig. 11.

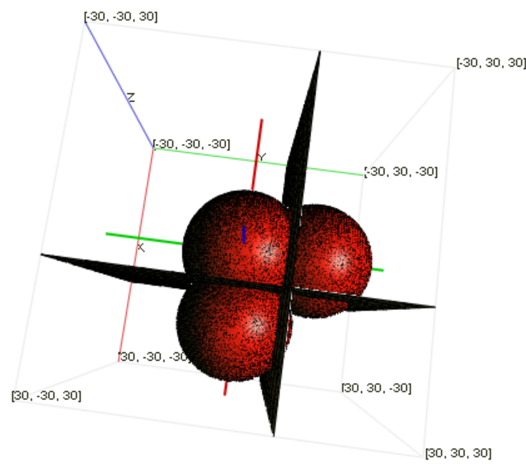

Fig. 11 intersection of three generated spheres

The transversal line of above mentioned planes and original sphere with center S can be calculated from distance of plane and center S1[0,0,0] of sphere and direction vector:

Distance of a first plane

$$2S2_x x - S2_x{}^2 - r_1{}^2 + r_2{}^2 = 0 \tag{4}$$

and center S1 [0,0,0]

$$v_x = \frac{\left|2\cdot 2_x \cdot x - S2_x{}^2 - r_1{}^2 + r_2{}^2\right|}{\sqrt{(2\cdot S2_x)^2}} \tag{5}$$

And distance of second plane and center S1.

$$v_y = \frac{\left|2\cdot S2_y \cdot y - S2_y{}^2 - r_1{}^2 + r_3{}^2\right|}{\sqrt{(2\cdot S2_y)^2}} \tag{6}$$

Direction vector was defined as $\vec{u}$ = (v_x,v_y,1-2t) and after introduced into the formula of sphere with center S1 coordinates of intersect points will be :

$$\begin{aligned} P1 &= [v_x, v_y, 1-2\cdot t_1] \\ P2 &= [v_x, v_y, 1-2\cdot t_2] \end{aligned} \tag{7}$$

Refine of obtained results can be done by including measured data from fourth sensor.

VI. Measurement

These generated points will be assign calculated values of energy, which have been collected from receivers, in given distance from every sensor. Values of energy in every distance from each sensor are multiplied. This value determines which point can be displayed.

Accurate results from sensors are displayed in final 3d model in two different way. At first, it will be displayed in concise but efficient. In other hand second displaying algorithm will display measured data in adjusted disparity map. This representation is more complete and provide more complex view on measured object.

A. Algorithm for displaying data into 3d model

Chosen algorithm, which display significant point into 3d model, searches maximal value of energy from measured data on one sensor. This maximal energy says in what distance ultrasonic was reflected from object and its energy lost was minimal. This maximal energy can be seen on Figure 12.

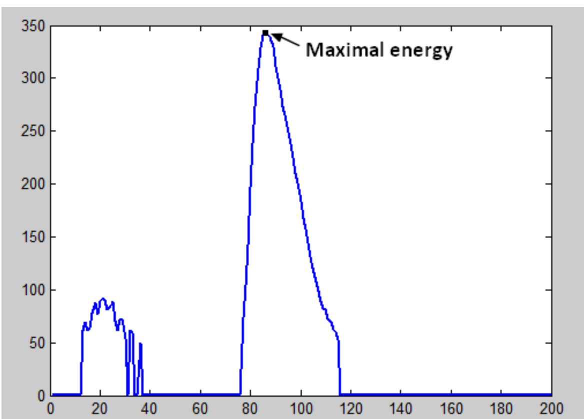

Fig. 12 Maximal energy from first sensor

In this phase, it is selected set of generated points. All points are saved in three dimensional array, where first dimension determines radius of sphere S1, second dimension radius of sphere S2 and last one radius third sphere. This data scheme was chosen for faster and efficient processing in following phase. From foregoing is clear that now is only necessary to find radiuses of S2, S3 and radius of sphere S1, where is energy of the sphere S1 equal to the maximum energy.

For example selected set of points can include ten triads, in which first value will be distance given by maximal energy form first sensor. Another two values will be pointers at energy in measurement data on sensor S2 and S3. The values of energies are multiplied and compared with others nines calculated energies. Maximum of this multiplied energy values will be corner point, which is displayed on Fig. 13

This method is repeated for every sensor and results are corners points of sensed obstacle. See Fig. 13

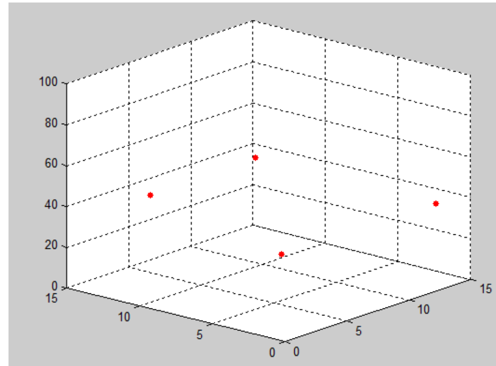

Fig. 13 four corner points of scanned board

The described algorithm is suitable for simple and regular shapes, because only significant values are selected and used in following processing.

B. Advanced algorithm for displaying data into 3d model

In this adjusted algorithm it is main goal to improve reached result from previous algorithm more useful form for autonomous movement.

Algorithm is based on previous one but with little difference in each step. At the beginning data from sensors are loaded and after that it is evaluate maximal energy from first sensor. This energy serves to identify significant points in data obtained from another sensors. These significant points are nothing more, then intersections of created spheres with defined centers and radiuses.

Of course, it is important to recalculate given radiuses of created spheres form neighboring sensors into correct form. If maximal energy is known it will be created grid which will cover all area of measuring board. Grid contains points with distance evaluated form sample frequency. Each point on this grid will be colored according to size of energy given from all energies form all spheres.

This energy is calculated with maximal energy of first sphere (first sensor) and with energy from another sensors. Energy is obtained by calculation of distance between maximal energy point and centers, where another are created. Due to this distance it is possible to define required energy and after that it is possible to color specific point in the final grid.

It is obvious that this process is need to be done for all four sensors in order to get satisfactory results.

VII. Discussion

In this paper has been presented method for obstacle detection based on mathematical knowledge in analytical geometry Method has been chosen due to ability to interpret obtained results. Method is mainly used in triangulation method for obtaining target position in GSM networks [4].

Obtained results from presented algorithm was displayed in 3d graph by software MATLAB. This 3d model can be improved by adding another significant points, however overall image of scanned area will not be clear as is now.

VIII. Conclusion

Main aim of this work was to create 3d model of scanned area for steering wheeled robotic platform. This aim was achieved by 3d model algorithm and results obtained was displayed in 3d model by MATLAB software. Next step in my actual research is to use this created model to steer real robotic platform and perform basic avoiding actions.

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