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Sound Source Coordinates Calculation

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Abstract- Object detection through calculation of coordinates is widely used in various fields. Objects can be detected through sounds as well [1]. Coordinates can be calculated with the help of the sound impulses produced by a particular object. This is vital for exploration of wilderness areas while searching for endemic animals.

The suggested method enables to address similar problems.

Sounds generated by species of whales and dolphins can be used to determine their location under water. Besides, sound devices, which produce periodical signals, can be mounted on objects to be used thereafter for the purpose of determination of their location following the released sounds. The problem solution suggested within the scope of this article is applicable both in the daytime and nighttime due to the fact that the suggested system has no dependence on lighting.

The mounted sensors will serve for the problem solution. Tests have revealed that the possible minimum quantity of the sensors required to detect the coordinates of an object is 4. Sensors and sound releasing objects were presented in a three-dimensional area, and a system of formulas was elaborated. The solution of these formulas led to formulas which can be used to determine the x, y, and z coordinates of the sound releasing objects on the bases of the system of sensors set on the object. To put the system into effect, we used the time difference that various sound sensors display when receiving sound signals, which is dependent on sound dispersion velocity in space.

The accuracy of the deduced formulas has been attested as well. The system modeling was carried out in a software environment provided with conditions appropriate for the problem solution. After the program has been operated in the software environment, the accuracy of the coordinates detected by the sensors has been verified. The program has confirmed that the formulas are accurate.

Keywords- *Object Detection, Locating, Tracking, Moving Object, Coordinate Calculation, Formula Verification*

I. Method Description

It is essential to develop a system to fix the initially unknown coordinates of an object in search [1]. The system comprises one main sensor and several supplementary sensors [2]. For the sake of optimal use of resources we must define the satisfactory quantity of sensors to be used to solve the problem. The tests have resulted in discovering that with two or three sensors the problem will have an indefinite number of solutions. Therefore, we have concluded that the minimum number of sensors should be four to be able to precisely detect the coordinates of an object. In the observation system we will consider the main sensor to be point 0 (with coordinate 0, 0, and 0) on the three-dimensional system of coordinates. We will set distance A in advance. It is preferable to take a big value which will decrease the number of faults when calculating coordinates in practical conditions [3]. We will select the derections of axes x, y, and z so that they form 90°. The direction of axes x and y can be random since object coordinates are computed proportionally to the selected axes. For clarity reasons, we advise to set axes x and y on a horizontal plane. The supplementary sensors will be set in each of the base axes directions at the same pre-selected distance A. Thus, we will have sound sensors 1,2,3 and 4 (see picture 1) with respective coordinates of (0,0,0) (A,0,0) (0,A,0) (0,0,A) in the system of coordinates [4].

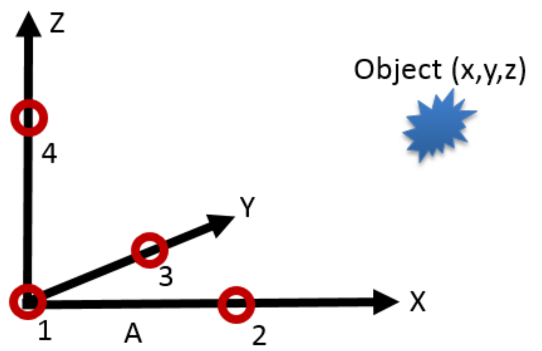

Figure 1. Sensors marked in red

Once the object releases a sound, the sensors will fix the given time. Since sound disperses with a limited velocity, the time fixed by the sound sensors will differ [5]. We will subtract the time value of the released signal fixed by sensor 1 from the time values fixed by sensors 2, 3 and 4. We will obtain three parameters - $T\delta x$, $T\delta y$ and $T\delta z$ [1]. Let us determine the distance of the object from sensor 1 as r and from sensor 2 as l. Then, let us define the distance differences as $\delta x=l-r$. From physics we know that

S=v*t

To find δx we will multiply the time difference $T\delta x$ by the sound velocity of the given environment (v).

$\delta x = T\delta x * v$

Let us perform the same mathematical functions with respect to $T\delta y$ and $T\delta z$ variables and obtain δy and δz. We will come up with the distance differences from sensors 2, 3, 4 of the sound releasing object in respect to sensor 1. If the signal is fixed by the sensor situated on the axis (sensor 2 for example) earlier, the parameters will be negative (δy<0); if fixed simultaneously, it will equal 0, i.e. the distance is the same (δy=0).

To resolve the problem, it is essential to apply parameters δx, δy, δz and A. We can see the illustration of the plane formed by axis x and the object which released sound (picture 2). In the picture, r is the distance of the object from sensor 1, $r+\delta x$ is of sensor 2. On the given plane the dotted vertical line h_χ drops down from the object point to axis x. Let us define the distance of sensor 1 from h_χ as x. A will be the distance of sensor 2 from sensor 1.

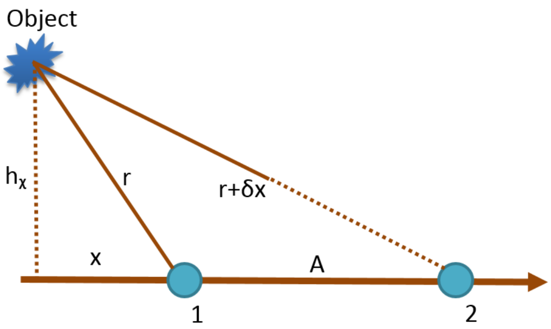

Figure 2. Plane formed by the object and axis *x*

Applying Pythagorean Theorem, we arrive at the following formula:

$$r^2 = x^2 + h_\chi^2 \quad (1)$$

$$(r + \delta x)^2 = (A - x)^2 + h_\chi^2 \quad (2)$$

We subtract formula 1 from formula 2 to reduce h_χ and express the dependence of r from x. We simplify the formula and come up with the following equation:

$$r = \frac{A^2 - 2*A*x - \delta x^2}{2\delta x} \quad (3)$$

Similarly, we consider axis y, afterwards axis z on one plane with the object, and carrying out the above-mentioned calculations we acquire the dependence of r from y and z:

$$r = \frac{A^2 - 2*A*y - \delta y^2}{2\delta y} \quad (4)$$

$$r = \frac{A^2 - 2*A*z - \delta z^2}{2\delta z} \quad (5)$$

Since (3) equals (4), we can express the dependence of y from x as follows:

$$y = \frac{2A*\delta y*x + \delta x^2*\delta y - A^2*\delta y - \delta x*\delta y^2 + A^2*\delta x}{2*A*\delta x} \quad (6)$$

Similarly, we get the dependence of z from x:

$$z = \frac{2A*\delta z*x + \delta x^2*\delta z - A^2*\delta z - \delta x*\delta z^2 + A^2*\delta x}{2*A*\delta x} \quad (7)$$

Please note that h_χ is the vertical line from the object's coordinates to axis X, hence it passes through the planes parallel to the one formed by axes (Y, Z) and constitutes the hypotenuse of the triangle formed by sides x and z of the object (see picture 3).

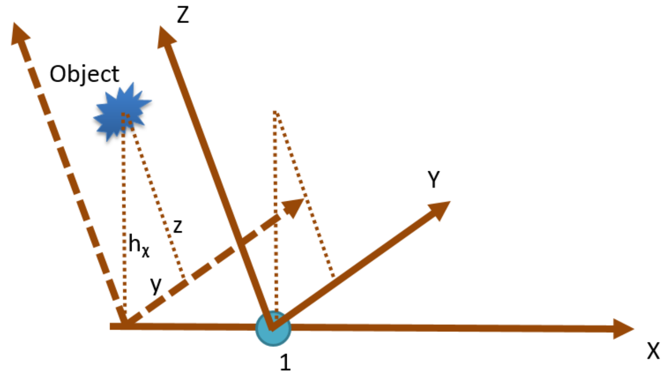

Figure 3. h_χ dependency on *y* and *z*

From the above-mentioned and h_χ equation in formula (1) it is obvious that

$$y^2 + z^2 = h_\chi^2 = r^2 - x^2 \quad (8)$$

We apply (3) in (5) and simplify the expression as follows:

$$y^2 + z^2 = \frac{x^2*4*(A^2-\delta x^2) + x*4*A*(\delta x^2 - A^2) + (A^2 - \delta x^2)^2}{4*\delta x^2} \quad (9)$$

We make notations as follows:

$$\alpha_y = \delta x^2 * \delta y - A^2 * \delta y - \delta x * \delta y^2 + A^2 * \delta x$$

$$\alpha_z = \delta x^2 * \delta z - A^2 * \delta z - \delta x * \delta z^2 + A^2 * \delta x$$

We replace y and z by formulas (6) and (7). We simplify and come up with the following equation:

$$y^2 + z^2 = \frac{x^2(4*A^2*\delta y^2 + 4*A^2*\delta z^2) + x(4*A*\delta y*\alpha_y + 4*A*\delta z*\alpha_z) + \alpha_y^2 + \alpha_z^2}{4*A^2*\delta x^2} \quad (10)$$

Since (9) equals (10), with x being the only unknown in the right side of both equations, we can equalize the formulas. From reduced calculations we will have the following expression:

$$x^2 4A^2(\delta y^2 + \delta z^2 + \delta x^2 - A^2) + x4A\left(\alpha_y \delta y + \alpha_z \delta z + A^2(A^2 - \delta x^2)\right) + \alpha_y^2 + \alpha_z^2 - A^2(A^2 - \delta x^2)^2 \quad (11)$$

In closed form, we have obtained an equation with one unknown. After calculating the value of x we will put it in formulas (6) and (7) to calculate y and z. Thus, we have resolved the problem of coordinates detection having deduced 3 formulas - (11), (6) and (7).

II. DUBLE-CHECKING THE FORMULA ACCURACY

In order to check the accuracy of the formula the system was modeled in a software environment. We selected the scripting language *Python* which proved to be very reliable for addressing this kind of problems. A model of the system consisting of a sound releasing object and sensors was generated. As illustrated in the block scheme in picture 4, the program is made up of two parts. The first is the key part which corresponds to the sensor system. The formula is integrated in this particular module and only after obtaining parameters δx, δy and δz, it can define coordinates x, y and z of the object by applying the formula for coordinates detection.

The second part of the program includes the location of the object, i.e. the coordinates which are not available for the main program module.

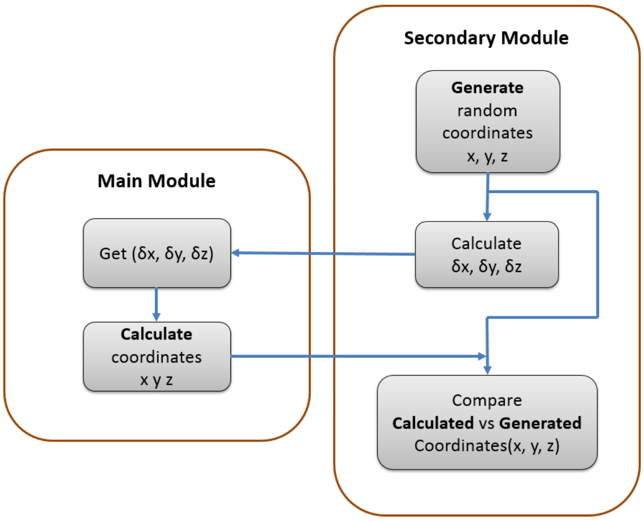

Figure 4. Block-scheme of the double-checking program

The second module randomly generates object coordinates x, y and z (see picture 4). Using the generated coordinates, parameters δx, δy և δz are calculated in the given module following the principles of trigonometry. Since the system of sensors effortlessly gets the parameters δx, δy և δz as input data by the method proposed at the beginning of the description, the given parameters, calculated by the supplementary module, are transmitted to the main module of the program, whereas the generated x, y and z coordinates are kept secret from the main program.

When parameters δx, δy և δz are known, the main part of the program inserts them into the formulas and computes values x, y and z. Discriminant equation has 2 x values for coordinates based on which 2 (x, y and z) coordinates are calculated respectively, one of which is constantly situated inside the cube illustrated by dotted lines in picture 5. Since the object under study is not anticipated to be located between the sensors, the hypothetical case of the object situated inside the cube is not regarded. Deduction brings to one solution of the equation, the object being situated outside the cube.

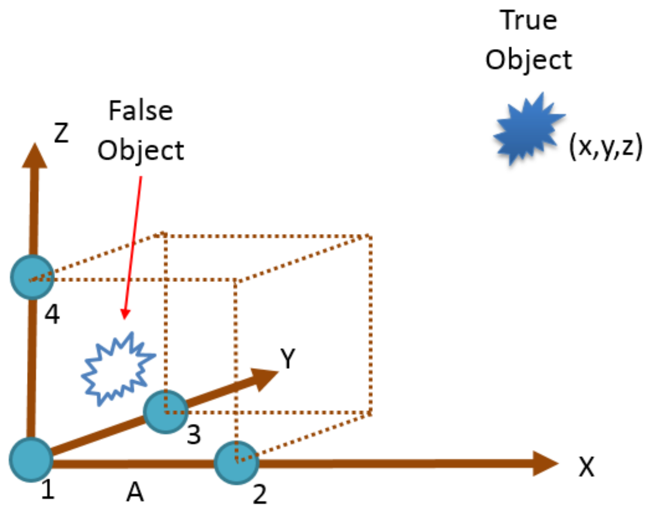

Figure 5. Illustration of the calculated coordinates.

In case of generation of multiple *x*, *y* and *z* random values the program has demonstrated accurate calculation of coordinates based on *δ*x, *δ*y,*δz* and *A* solely. The calculations of the coordinates have been accurate in case of negative values of the generated *x*, *y* and *z* as well. Even in case of big values of the generated coordinates the calculations have proved to be precise.

III. CONCLUSION

The problem of calculation of coordinates of sound impulse sources has been addressed with the help of 4 sound sensors. One of the sensors was set at a selected equal distance from the three other sensors. We have taken into account the fact that sounds are received by sensors at different time subject to a limited velocity of sound dissemination. Distance differences (δx, δy և δz) between an object – the main sensor (r) and objects – the tree other sensors (L1, L2, L3) have been calculated. The sound releasing object and the sensor system have been studied in space. Composing trigonometrically equations and using the differences between the obtained distances, the equation for coordinates *x* was deduced by the presented parameters known to us, as well as the dependence of coordinates y and *z* on coordinates *x*.

Thus, based on time difference of sound fixation by sensors, δx, δy and δz distance differences have been calculated. The three final formulas that we have deduced using these differences allow detecting the coordinates of the sound releasing object.

To double check the theoretical accuracy of the deduced formula, the system essential for the solution of the problem has been modelled in a software environment. It includes the sensor system and the model of the sound releasing object which remain unidentified for the sensor system. The coordinates of the object are selected randomly. It is assumed that the object releases sounds, based on which δx, δy and δz parameters are calculated and transmitted to the sensor system.

In working conditions this step is respectively performed by sensors when they receive the sound signal.

Applying the sensor system for problem solution, the suggested formulas compute coordinates *x*, *y* and *z* of the object. After that, the computed values are transmitted to the module which double checks the data by comparing the calculated coordinates with the real (generated) coordinates of the object.

In a number of tests, in the result of the coordinates of the sound releasing object generated randomly, the program verified that the calculated coordinates match the real coordinates of the object, which means the accuracy of the formulas has been proved.

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