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An algorithm to determine the impact point on the target surface using ultrasonic sensors

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Abstract
The article addresses the issue of using ultrasonic sensors to determine the bullet's impact point on the target surface, serving to evaluate the results of firing tests. The method of determining the impact point is based on the time difference of the time of arrival of the sound wave to the ultrasonic sensors. The constructed equations are complex nonlinear equations. To be able to solve this system of equations, the construction of the equation is combined with the arrangement of sensors to isolate each unknown, helping to simplify the solution of the system of equations. Sensor layout diagram and impact point determination algorithm have been proposed.

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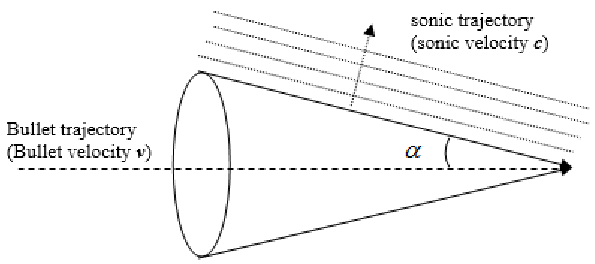
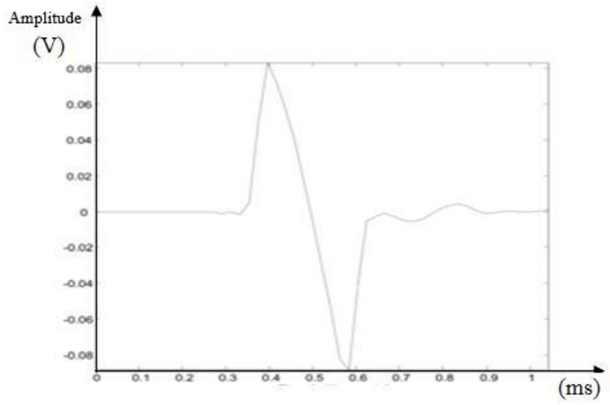
Introduction
Today, scoreboard systems are being widely used throughout the military for training, drills and competitions. Normal score markers are made according to the short circuit principle. According to this principle, the target surface is divided into regions corresponding to points. When the bullet passes through, it will cause a short circuit on two layers of the target surface. The processing system will then determine which area the short circuit is in and will give a corresponding score. The advantages of this type of scoreboard are that it is easy to make, high accuracy, and very intuitive when observing and evaluating the quality of the beer surface. However, it has the disadvantage of limited durability, especially in central areas, when the density of bullets is high, the target surface is crushed, causing breaks or short circuits, making it no longer usable. Researching and manufacturing a score marker system based on the non-contact principle has become an urgent issue with high practical significance. On the market, many companies have produced score markers [1, 6], and there are also many companies that provide various types of ultrasonic sensors suitable for integration into score marker systems [2, 7]. This is an important basis for researching and manufacturing score marker systems.

Methodology
A. Theoretical basis of using ultrasonic sensors to determine the bullet's impact point on the target surface
When the bullet flies through the air at supersonic speed, the sound waves caused by the bullet impacting the air spread out, forming a cone behind the bullet [3]. This cone gradually expands over time at the speed of sound in a direction perpendicular to its edge [4]. The angle at the top of the cone depends on the velocity of the bullet and the speed of sound. If we call the angle between the two edges of the cone on its plane of symmetry, its value is determined according to the bullet speed and the speed of sound in the air, specifically as follows: $\alpha = \arcsin\left(\frac{c}{v}\right)$, where c is the speed of sound in air and v is the bullet speed. This is illustrated in figure 1 below.



The sound waves created by a bullet moving at supersonic speed

The characteristics of sound waves recorded on microphones are described in Figure 2 below [3].



Sound wave characteristics

Thus, if using sound sensors, it is possible to determine the time of arrival at each sensor of the sound created from the projectile. Then using the TDOA method [5] it is possible to determine the coordinates of the bullet in space, which means determining the location of the bullet's impact point on the target surface. However, there is a difference with the TDOA method in that the sound wave source reaching the sensors propagates not from a point but from the trajectory of the projectile. Therefore, the equations describing the arrival time deviation to determine the bullet's impact point on the target surface must be newly constructed. Currently, there are no published works on these equations. This is the task that this article will solve. The article will address the following two issues:

- Build a system of equations to determine the coordinates of the impact point according to the time difference of the time the sound wave reaches the sensors in the general case.
- Select the coordinates of the sensor placement points to isolate the hidden objects that need to be found and build an algorithm to identify those hidden objects, which means determining the point of impact of the bullet on the target surface.

A. Build a system of equations to determine the coordinates of the impact point according to the time difference of the time the sound wave arrives the sensors

1. Definition of coordinates

Because sound waves travel in space in a cone with the axis of symmetry being the ballistic trajectory, the time it takes to reach the sensors will depend on the coordinates of the sensors in relation to the ballistics. Therefore, it is necessary to describe the relationships in the ballistic coordinate system. However, the arrangement of sensors is done not depending on the projectile but according to the target surface, the coordinates of the sensors are determined relative to the target surface. Therefore, it is necessary to build two coordinate systems, the projectile coordinate system and the target surface coordinate system.

Definition 1. The projectile coordinate system is a coordinate system with the center O_d located on the intersection of the projectile with the target surface, the O_dX_d axis is in the direction of the projectile, the O_dY_d axis is on the vertical plane containing the projectile and points up , the O_dZ_d axis is perpendicular to the $O_dX_dY_d$ plane and combined with the two axes O_dX_d and O_dY_d to form a positive triangle.

Definition 2. The target surface coordinate system is a coordinate system with center O located on the left corner of the target surface looking in the direction of the projectile, the OX axis is perpendicular to the target surface, facing the direction of the projectile, the OY axis lies on the vertical plane containing the OX axis and points up to the OZ axis perpendicular to the OXY plane and combines with the two axes OX and OY to form a positive triangle.

The projectile coordinate system is different from the target surface coordinate system in that its origin will have coordinates in the target surface coordinate system $O_d\left(0 \quad y \quad z\right)$ and has Euler angles relative to the target surface coordinate system as β - or projectile angle deviation and ε - projectile inclination angle.

2. Build the system of equations

The main idea of building the system of equations is to describe the time deviation of the sound wave arriving at the sensors according to its coordinates in the target surface coordinate system in the form of equations which have unknowns that are the coordinates of the sensors in the ballistic coordinate system, or the coordinates of the origin of the ballistic coordinate system in the target surface coordinate system.

Thereby, by solving the system of equations with unknowns being the coordinates of the origin of the projectile coordinate system in the target surface coordinate system, the projectile direction and inclination angles, and the bullet's velocity. Thus the system of equations has 5 unknowns. To build 05 equations, at least 06 sensors are needed to determine 05 degrees of time delay to the sensors.

The known parameters are the coordinates of the sensor placement points in the target surface coordinate system: : $C_i(x_i, y_i, z_i)$, i=1,…,6.

The measured parameters are 06 times when the sound wave reaches the sensors, thereby determining 05 arrival time deviations.

The unknowns to be found are: Coordinates of the origin of the bullet coordinate system, or the impact point of the bullet with the target surface O_d: O_d (0,y,z).

The intermediate unknowns are: the orbital angle relative to the OX direction is β, the orbital tilt angle relative to the OXZ plane is ε, and the projectile's velocity is v.

Suppose that when passing through the target surface, the bullet's velocity is and remains constant within a large enough neighborhood of the target surface.

Let the speed of sound in air be c .

Below will be determined the time difference between the moment the bullet passes through the target surface and the moment the sound wave reaches the sensors.

The coordinates of the sensors in the ballistic coordinate system are:

$$\begin{bmatrix} x_{di} \\ y_{di} \\ z_{di} \end{bmatrix} = \begin{bmatrix} \cos\varepsilon & \sin\varepsilon & 0 \\ -\sin\varepsilon & \cos\varepsilon & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix} \begin{bmatrix} x_i - x \\ y_i - y \\ z_i - z \end{bmatrix} \quad (1)$$

The distance from the sensor placement point i to the projectile is d_{di}, $d_{di} = \sqrt{y_{di}^2 + z_{di}^2}$ (2)

Assuming the time the bullet passes through the target surface is t_0 , then, as depicted in Figure 3, the time the sound wave reaches sensor i is:

$$t_i = t_0 - \frac{S_iP_i + P_iO}{v} + \frac{S_iC_i}{c} \quad (3)$$

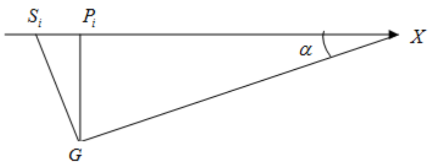


Diagram depicting sound wave propagation time

In Fig.3, we have:

$$\sin\alpha = \frac{c}{v}, \quad C_iO = x_{di}, \quad C_iP_i = d_{di}, \quad d_{di} = \sqrt{y_{di}^2 + z_{di}^2},$$
$$S_iP_i = d_{di}tg\alpha, \quad S_iC_i = d_{di} / \cos\alpha \quad (4)$$

Apply (4) to (3), one can get:

$$t_1 = t_0 - \frac{\frac{d_1c/v}{\cos\alpha} + x_{d1}}{v} + \frac{\frac{d_1}{\cos\alpha}}{c}$$
$$t_2 = t_0 - \frac{\frac{d_2c/v}{\cos\alpha} + x_{d2}}{v} + \frac{\frac{d_2}{\cos\alpha}}{c}$$
.....
$$t_6 = t_0 - \frac{\frac{d_6c/v}{\cos\alpha} + x_{d6}}{v} + \frac{\frac{d_6}{\cos\alpha}}{c} \quad (5)$$

Since t_0 is unknown, other times cannot be determined either. We can only determine the time difference to each sensor compared to one or a few pre-selected sensors. Suppose we choose sensor number 6 first, then we get the following system of equations:

$$\Delta t_1 = t_1 - t_6 = t_0 - \frac{\frac{d_1c/v}{\cos\alpha} + x_{d1}}{v} + \frac{\frac{d_1}{\cos\alpha}}{c} - \left(t_0 - \frac{\frac{d_6c/v}{\cos\alpha} + x_{d6}}{v} + \frac{\frac{d_6}{\cos\alpha}}{c} \right) = (d_1 - d_6)\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right) - \frac{x_{d1} - x_{d6}}{v}$$
$$\Delta t_2 = t_2 - t_6 = t_0 - \frac{\frac{d_2c/v}{\cos\alpha} + x_{d2}}{v} + \frac{\frac{d_2}{\cos\alpha}}{c} - \left(t_0 - \frac{\frac{d_6c/v}{\cos\alpha} + x_{d6}}{v} + \frac{\frac{d_6}{\cos\alpha}}{c} \right) = (d_2 - d_6)\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right) - \frac{x_{d2} - x_{d6}}{v}$$
.....
$$\Delta t_5 = t_5 - t_6 = t_0 - \frac{\frac{d_5c/v}{\cos\alpha} + x_{d5}}{v} + \frac{\frac{d_5}{\cos\alpha}}{c} - \left(t_0 - \frac{\frac{d_6c/v}{\cos\alpha} + x_{d6}}{v} + \frac{\frac{d_6}{\cos\alpha}}{c} \right) = (d_5 - d_6)\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right) - \frac{x_{d5} - x_{d6}}{v} \quad (6)$$

If (1) is taken into account, the equation system (6) has 5 unknowns, namely $v, \beta, \varepsilon, x, y$ and 5 equations. The given parameters are the coordinates of the sensors in the target surface coordinate system and the speed of sound in the air. Thus, the solutions of the system of equations are completely determined. However, because this is a system of nonlinear equations, it is very difficult to construct an explicit solution.

B. Choose the coordinates of sensors placement points and algorithm construction

To reduce the difficulty in solving these equations, introduce some limitations to the problem.

First, assume that the target surface is well installed so that the direction of the projectile is perpendicular to the target surface, which means $\beta = 0$. Then equation (1) becomes:

$$\begin{bmatrix} x_{di} \\ y_{di} \\ z_{di} \end{bmatrix} = \begin{bmatrix} \cos\varepsilon & \sin\varepsilon & 0 \\ -\sin\varepsilon & \cos\varepsilon & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_i - x \\ y_i - y \\ z_i - z \end{bmatrix} \quad (7)$$

Next, choose to place the sensors into groups so that in each group their coordinates along the OX and OY axes are equal. Then, from (7) we see that in each group there will be equal x_j and equal y_j . First consider group 1, set $x_j = x_{11}$, $y_j = y_{11}$.

Then: $$\begin{cases} x_{n1} = x_{dj} = (x_{11} - x)\cos\varepsilon + (y_{11} - y)\sin\varepsilon \\ y_{n1} = y_{dj} = (y_{11} - y)\cos\varepsilon - (x_{11} - x)\sin\varepsilon \end{cases} \quad (8)$$

Suppose all sensors are in group 1. Then (6) becomes:

$$\Delta t_1 = t_1 - t_6 = (d_1 - d_6)\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right) = (\sqrt{y_{n1}^2 + z_{d1}^2} - \sqrt{y_{n1}^2 + z_{d6}^2})\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right)$$
$$\Delta t_2 = t_2 - t_6 = (d_2 - d_6)\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right) = (\sqrt{y_{n1}^2 + z_{d2}^2} - \sqrt{y_{n1}^2 + z_{d6}^2})\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right)$$
.....
$$\Delta t_5 = t_5 - t_6 = (d_5 - d_6)\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right) = (\sqrt{y_{n1}^2 + z_{d5}^2} - \sqrt{y_{n1}^2 + z_{d6}^2})\left(\frac{v^2 - c^2}{cv^2\cos\alpha} \right) \quad (9)$$

Assuming the sensors in group 1 are arranged evenly, in the target surface coordinate system they have coordinates along the OZ axis evenly spaced at a distance Δz with coordinates 0, Δz, $2\Delta z$, $3\Delta z$, $4\Delta z$, $5\Delta z$. Then (9) becomes:

$$\Delta t_1 = (\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)$$
$$\Delta t_2 = (\sqrt{y_{n1}^2+(\Delta z-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)$$
.....
$$\Delta t_5 = (\sqrt{y_{n1}^2+(4\Delta z-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right) \quad (10)$$

Take the equations in the equation system (10) and divide by the first equation, getting:

$$\Delta\Delta t_1 = \frac{(\sqrt{y_{n1}^2+(\Delta z-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})}{(\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})}=\frac{\Delta t_2}{\Delta t_1}=\frac{(t_2-t_6)}{(t_1-t_6)}$$
$$\Delta\Delta t_2 = \frac{(\sqrt{y_{n1}^2+(2\Delta z-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})}{(\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})}=\frac{\Delta t_3}{\Delta t_1}=\frac{(t_3-t_6)}{(t_1-t_6)}$$
.....
$$\Delta\Delta t_4 = \frac{(\sqrt{y_{n1}^2+(4\Delta z-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})}{(\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(5\Delta z-z)^2})}=\frac{\Delta t_5}{\Delta t_1}=\frac{(t_5-t_6)}{(t_1-t_6)} \quad (11)$$

The equation system (11) only has 2 unknowns, which are y_{n1}, z. So to determine these two unknowns, only 2 equations are needed. Without loss of generality, choose the first 2 equations, and therefore 4 sensors are needed. For continuity, replace sensor number 6 with the 4th sensor, and thus the system of equations (10) with 4 sensors will be:

$$\Delta t_1 = (\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(3\Delta z-z)^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)$$
$$\Delta t_2 = (\sqrt{y_{n1}^2+(\Delta z-z)^2}-\sqrt{y_{n1}^2+(3\Delta z-z)^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)$$
$$\Delta t_3 = (\sqrt{y_{n1}^2+(2\Delta z-z)^2}-\sqrt{y_{n1}^2+(3\Delta z-z)^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right) \quad (12)$$

Also (11) can be written as:

$$\Delta\Delta t_1 = \frac{(\sqrt{y_{n1}^2+(\Delta z-z)^2}-\sqrt{y_{n1}^2+(3\Delta z-z)^2})}{(\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(3\Delta z-z)^2})}=\frac{\Delta t_2}{\Delta t_1}=\frac{(t_2-t_4)}{(t_1-t_4)}$$
$$\Delta\Delta t_2 = \frac{(\sqrt{y_{n1}^2+(2\Delta z-z)^2}-\sqrt{y_{n1}^2+(3\Delta z-z)^2})}{(\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(3\Delta z-z)^2})}=\frac{\Delta t_3}{\Delta t_1}=\frac{(t_3-t_4)}{(t_1-t_4)} \quad (13)$$

After solving the system of equations (13), determining the unknowns y_{n1}, z, replacing the first equation of system (12) will determine the function f(v) of the velocity v of the bullet:

$$f(v)=\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)=\frac{\Delta t_1}{(\sqrt{y_{n1}^2+(0-z)^2}-\sqrt{y_{n1}^2+(3z_n-z)^2})} \quad (14)$$

After determining y_{n1}, to determine y from equation (7), it is necessary to determine the projectile inclination angle ε. To determine the projectile inclination angle ε, arrange another group of sensors, called group 2, with the group's coordinate parameters as follows: $x_k = x_{22} = x_{11}+\Delta x$
First consider a sensor whose coordinates along the OZ axis are $z_4 = 3\Delta z$. Then this sensor has new coordinates in the ballistic coordinate system:

$$\begin{cases} x_{n2} = x_{d5} = (x_{11}+\Delta x - x)\cos\varepsilon + (y_{11}-y)\sin\varepsilon \\ y_{n2} = y_{d5} = (y_{11}+\Delta x - y)\cos\varepsilon - (x_{11}-x)\sin\varepsilon \end{cases} \quad (15)$$

From (8) and (15):

$$y_{n2} = (y_{11}-y)\cos\varepsilon-(x_{11}-x)\sin\varepsilon+\Delta x\cos\varepsilon = y_{n1}+\Delta x\cos\varepsilon \quad (16)$$

Similar to (9), the time difference between the time the sound wave arrives at sensors number 4 and number 5 is determined as follows:

$$\Delta t_5 = t_5 - t_4 = (d_5-d_4)\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)=(\sqrt{y_{n2}^2+z_{d4}^2}-\sqrt{y_{n1}^2+z_{d4}^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right) \quad (17)$$

Substitute y_{n2} from (16) and $z_{d4} = z+3\Delta z$ to (17):

$$\Delta t_5 = t_5-t_4 = (\sqrt{(y_{n1}+\Delta x\cos\varepsilon)^2+(z+3\Delta z)^2}-\sqrt{y_{n1}^2+(z+3\Delta z)^2})\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right) \quad (18)$$

In equation (18) all parameters have been determined after solving equations (13) and (14), Δx and Δz are design parameters. So from (18) we can determine ε:

$$\cos\varepsilon = \frac{\sqrt{\left(\frac{\Delta t_5}{\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)}+\sqrt{y_{n1}^2+(z+3\Delta z)^2}\right)^2-(z+3\Delta z)^2}-y_{n1}}{\Delta x} \quad (19)$$

$$\varepsilon = \arccos\frac{\sqrt{\left(\frac{\Delta t_5}{\left(\frac{v^2-c^2}{cv^2\cos\alpha}\right)}+\sqrt{y_{n1}^2+(z+3\Delta z)^2}\right)^2-(z+3\Delta z)^2}-y_{n1}}{\Delta x} \quad (20)$$

After determining ε, it is necessary to determine y. The equation system (8) has two equations and 2 unknowns, which are x_{n1} and y because the coordinates of the bullet's impact point on the target surface in the target surface coordinate system have coordinates along the OX axis equal to 0.
Transform the system of equations (8) by multiplying the first equation with $\cos\varepsilon$ and multiplying the second equation with -$\sin\varepsilon$, then taking the sum we get:

$$x_{n1} = \frac{(x_{11}-x)+y_{n1}\sin\varepsilon}{\cos\varepsilon} \quad (21)$$

From equation (7), y_{n1} is obtained by solving the system of equations (13) and x_{n1} is obtained from (21), the y coordinate of the impact point can be determined:

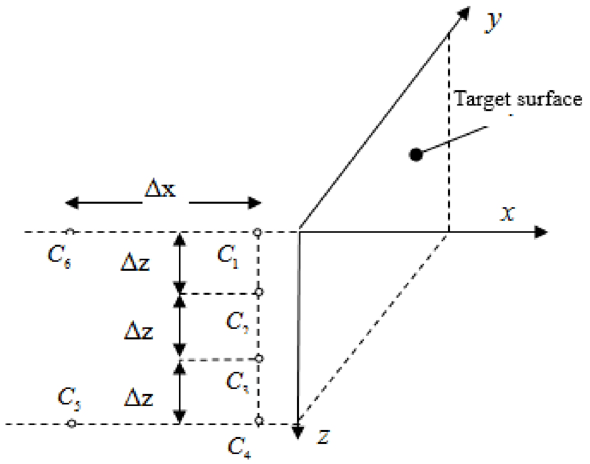
$$\begin{bmatrix} x_i - x \\ y_i - y \\ z_i - z \end{bmatrix} = \begin{bmatrix} \cos\varepsilon & -\sin\varepsilon & 0 \\ \sin\varepsilon & \cos\varepsilon & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{di} \\ y_{di} \\ z_{di} \end{bmatrix} \quad (22)$$

In (22) $x_{dj} = x_{n1}$ and $y_{dj} = y_{n1}$. $x_i = x_{11}$ and $y_i = y_{11}$. Then, one can get:

$$y = y_{11} - y_{n1}\cos\varepsilon - x_n \sin\varepsilon \quad (23)$$

To further check the reliability of the results, an additional sensor can be arranged in group 2 with coordinates $x_5 = x_4 = x_{11} + \Delta x$, $z_5 = 0$, $y_5 = y_4$

The sensor layout diagram to implement the above algorithm is presented in Figure 4 below:



Arrangement diagram of the ultrasonic sensor measuring the bullet's impact point on the target surface

Thus, with the ultrasonic sensor layout diagram as shown in Figure 2, the algorithm to determine the bullet's impact point on the target surface is as follows:

1. Determine the time when the ultrasound wave reaches each sensor t_1, t_2, t_3, t_4, t_5, t_6.
2. Determine the time difference between the time the ultrasonic wave reaches the sensors and the time the ultrasonic wave reaches the 4th sensor according to (9) and (12).
3. Xác định tỷ số độ lệch thời gian theo (13).
4. Sole the system of equations (13), determine y_{n1}, z.
5. Determine $f(v) = \left(\dfrac{v^2 - c^2}{cv^2 \cos\alpha}\right)$ by (14).
6. From the time difference between the time the ultrasound wave arrives at the 5th sensor and the time the ultrasound wave arrives at the 4th sensor, determine the projectile inclination angle according to (19) and (20). (can take the arrival time difference between the time the ultrasonic wave arrives at the 6th sensor and the time the ultrasonic wave arrives at the 1st sensor as backup information)
7. Determine the coordinates of the touching point along the OY axis according to (23).
8. Bring out the calculation results of steps 4 and 7, report the hit point results according to coordinates or compare with the coordinate field of the point frames on the target surface to report the results in the form of shot points.

Results and Discussion

Some practical results will be presented below. The results are presented in table form. Scoreboard systems were used with dimensions of 900mm*900mm. The initial coordinate system is centered on the lower left edge of the target, the sensors are located at the following coordinates: S_0(0 -20 0), S_1(0 -20 30), S_2(0 -20 60), S_3(0 -20 90), S_4(-30 -20 90). The results of each shot are shown in the table 1 below.

Table 1: Test result of calculated and actual impact points coordinates and distance errors

No.	Δt_1	Δt_2	Δt_3	Δt_4	y_{n1}	ε	Calculated impact point coordinates		Actual measuring impact point coordinates		Distance error
							z	y	y	z	
1	-0.0039	-0.02332	-0.02481	-0.04644	74.80241	3	46.6	54.7	54	46	0.92
2	0.080453	0.02624	-0.00708	-0.04654	45.45421	2.8	70.2	25.4	25	70	0.45
3	-0.00729	-0.0261	-0.02344	-0.04674	94.9132	2.8	41.4	74.8	74	41	0.89
4	-0.05024	-0.057	-0.03835	-0.04778	80.18893	2.7	22.8	60.1	60	22	0.81
5	-0.04675	-0.07212	-0.05095	-0.04871	40.75214	2.9	31.5	20.7	20	31	0.86
6	-0.11344	-0.09901	-0.05633	-0.04934	53.85973	2.7	3.4	33.8	34	4	0.63
7	0.037628	0.004245	-0.00955	-0.04679	88.59111	2.6	62.8	68.5	69	62	0.54
8	-0.00078	-0.02856	-0.02826	-0.04755	68.37031	2.6	48.3	44.7	45	48	0.42
9	-0.05653	-0.07126	-0.04799	-0.04831	51.6661	2.9	31.6	26.4	26	31	0.57
10	0.096097	0.03843	-0.00129	-0.04667	41.34585	2.7	21.3	74.2	75	21	0.85

Test results show that the calculation error compared to the actual impact point is not large. The distance between the actual impact point and the impact point determined by the proposed method is not greater than 1cm, which confirms the effectiveness of the proposed method as well as its practical applicability. The proposed scoreboard, therefore, can be used in training as well as for ballistic correction.

Conclusions

In this article, the problem of arranging ultrasonic sensors to determine the bullet's impact point on the target surface and the algorithm using the time difference of the time the ultrasonic wave reaches the sensors have been built. The results of calculating the impact point coordinates in actual testing have demonstrated the effectiveness of the method.

By this method, scoreboard system can be changed from contact to non-contact. This is the basis for manufacturing scoreboard systems to serve training and check future training results.

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