Design of Physically-based Virtual Cavity Simulation

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Abstract. In recent years, game and virtual reality contents using next-generation weapons have constantly been emerging. In the context of story development, the marks of the target's bullet are differently observed according to the unique characteristics of the rifle and bullets. There is also an example in which criminal traces are investigated by using forensic ballistics during criminal investigation. In this process, it is quite critical to recognize the relationship between the ballistic coefficient and the cavity due to the ballistic force. In this paper, we propose a physically-based cavity simulation that can enhance realism.

Introduction

In recent years, the next generation of weapons continues to emerge, but the importance of infantry fighting is still emphasized. Thus, the evolution of rifles and heavy weapon guns continues. The evolution of guns is directly linked to the evolution of bullets, a typical example being the Soviet Union's old AK-47 rifle in the 80s and 90s. The AK-74, an improved version of the AK-47, would have appeared while employing the 7.62 * 39mm used in 5.45 * 39mm. In recent years, there has been a move to replace the G36, which was hired by Germany's flagship rifle, with HK433. It is basically used 5.56 * 45mm Nato bullet but it can be mixed with 300 BLK, 7.62 * 39mm, 7.62 * 51mm [1]. In addition, the Israeli army will begin paying the X95 (MTAR-21), a shortened version of the TAR-21 in 2009, from 2013, replacing the M16 and M4 rifles currently in use by 2018. Based on 5.56 * 45mm Nato, 5.45 * 39mm, 300 BLK, 9mm can be mixed [2]. These rifles must undergo continuous simulations immediately prior to entry and delivery, usually to check accuracy, penetration, and resistance to fire. In addition, partially rifled rifles will only be replaced after replacement, and it is advisable to go through the simulation stage immediately before use to check for any anomalies. Among the simulations of rifles, considering the economical aspect, the consumption of bullets is not easy. Obviously, the need for virtual simulation to break is necessary. Forensic ballistics based on wound ballistics and collision mechanisms that induce permanent joints and temporary collision mechanisms are applied for forensic purposes [3]. In 1915, a farm worker, Charlie Stielow, was charged with murdering a farmer and a housekeeper. This incident led by an unscientific firearm investigation motivated the appearance of the US Bureau of Forensic Ballistics, the first independent crime research institute in the United States. Analysis of microscopic evidence such as firearms, fingerprints, and blood has provided a framework for scientific investigations [4]. However, the preservation of the gun accident scene is not always clear, and if the damage is added, the direction of the investigation becomes broader and more complicated. Forensic simulations can lead to close conclusions based on multiple assumptions, but it is inefficient in terms of time, considering that there are many variables, ranging from the launch and the launch of a shot. Therefore, the existence of virtual simulation for resolving the event is inevitable.

In this paper, we propose a method to simulate the shape of the cavity associated with the destructive force of the bullet based on the ballistic coefficient of the bullet using a modified Bresenham's line algorithm.
Methods

Ballistic Coefficient

In general, when a shot collides with a target at high speed, the penetration depends on the target and its intrinsic properties, and greatly varies with the angle at which the target is hit by the bullet. While there are physical properties such as hardness, strength, ductility, brittleness and mechanical properties and densities and application points of the materials that make up the target, the bullet has the speed, its shape and material properties. As a result, the penetration phenomenon of the shot is difficult to track and accurately interpret [5]. Therefore, in this paper, we have studied the simulation method focusing on the ballistic coefficient which represents the behavior of the bullet.

![Figure 1. G1 and G7 bullet model.](image)

The ballistic coefficient is a measure of the relative resistance of a particular bullet to its drag. The model has a different type of trajectory, and you can measure the ballistic coefficient to find out how it fits into the bullet. There are nine main models of bullets, two of which are commonly used in the G1 and G7 models in Figure 1. The ballistic coefficient reflecting the physical properties of the shot is defined as $BC = M / (D^2 I)$ [6]. $M$ is the mass of the bullet using grain units, $D$ is the diameter of the bullet, and $I$ is the form factor, which is the intrinsic shape of the bullet.

Such a ballistic coefficient has a great effect on the loss rate of kinetic energy that will be possessed from the time of the shot to the end of the shot. Also, if you have enough kinetic energy and the speed is enough, then the bullet penetrates the subject as it is. The kinetic energy that is not enough comes with slow speed. It has a penetrating power that relatively retreats to the electron. This movement of guns creates a relatively large temporary community, which becomes a permanent community over time. Figure 2 shows the visualization of the temporary cavity and the permanent cavity in an experiment in which the gun was fired at the gelatin [7].

![Figure 2. Permanent cavity and temporary cavity experiment with gelatin.](image)

Modified Bresenham’s Line Algorithm

Rasterization is an algorithm that determines which pixel value should be selected when mapping points, lines, and surfaces to an object space [8]. Bresenham's line algorithm is a very efficient algorithm in terms of standard computer architecture, using only integer addition, subtraction, and bit shift operations.
In this study, we assume 30 * 30 * 30 voxel as a target to represent the cavity inside the target. We calculate the slope based on the maximum height voxels and the voxels that start the cavity, and store the maximum size voxels of each frame in the array through the Bresenham’s algorithm. Based on the slope between the maximum width voxel of the frame passing through the bullet and the maximum height voxel, the joint voxels of the corresponding frame are painted using the Bresenham’s algorithm once again as shown in Figure 3. The pseudo code is shown in Figure 4.

Figure 3. Voxels of each frame in Simulation with the strar, middle, max size frames and the simulated voxels.

```
Bresenham(beginX1, beginY1, endX1, endY1, array){
    int dx, dy, IncrEast, IncrWest, D, x, y;
    dx = endX1 - beginX1; dy = endY1 - beginY1;
    D = 2*dy - dx;
    IncrEast = 2*dy - 2*dx;
    IncrWest = 2*dy - 2*dx;
    x = beginX1; y = beginY1;
    SaveVoxel(beginX1, beginY1, 0); // save height voxel
    while(x < endX1){
        if(D<=0){
            D = IncrEast; x++;
        } else {
            D = IncrWest; x++; y++;
        }
        SaveVoxel(x, y); // save voxel(x,y) in array
    }
}
```

Figure 4. Virtual cavity simulation algorithm.

Experiments
In this study, we used OpenGL in MFC (Microsoft Foundation Class) to create a simulation program based on ballistic coefficients. After you select the bullet model, enter the mass and diameter, and press the 'SHOOT!', the bullet coefficient is calculated and the simulation result is shown, by displaying the temporary cavity where the trajectory of the bullet and the bullet pass. At this time, the method of calculating the trajectory of the bullet using the Bresenham’s algorithm is to confirm whether or not each point constituting the bullet is located between the eight points constituting the voxel, and confirm the penetration. Also, the size of the cavity is adjusted according to the calculated ballistic coefficient.

Analytical Validation
The shapes of the bullets G1 and G7, which are commonly used, were formulated, and the mass and diameter of the bullet were determined as user variables. If M is proportional to the trajectory coefficient, the D squared value is inversely proportional. As a result, the higher the trajectory coefficient we have, the higher the preservation of the kinetic energy of the bullet is observed. Similarly, the lower the energy loss rate we obtain, the higher the penetration power is shown, which results in the fact that the smaller the size of the void in the voxel. Conversely, if the coefficient of trajectory is low, the energy conservation is poor, and the penetration force is somewhat reduced and the stopping power is increased, so that a large cavity can be formed in the object. In this case, the size of the cavity in the voxel becomes large. Finally, if we have identified the largest diameter of the cavity, we express the exit of the bullet from the voxel using the Bresenham’s algorithm for visual representation. Figure 5 shows the result of executing the simulation program. In the above two images, M and D are fixed to 12g and 4mm, respectively, and bullets are set to G1 and G7. It can be
seen that a large and small cavity occurs. The following two images show that the bullet model is set to G1, and the right side is set to 8g and 6mm respectively, and the left side is set to 16g and 4mm respectively. It can be confirmed that the coefficient of traction becomes large and the cavity becomes small.

![Bullet simulation images](image)

**Figure 5.** The results of simulation (Top row: comparison of bullet model, bottom row: comparison of M & D).

![Graph](image)

**Figure 6.** Max size of wound according to ballistic coefficients.

Figure 6 shows the result of plotting the max size of the wound according to the ballistic coefficient in the simulation. Max size of wound is defined as the maximum number of voxels among the frames when expressing the cavity. Since the size of the cavity caused by the bullet cannot be precisely defined by the ballistic coefficient, in this simulation, the ballistic coefficient level is set to 1 to 8 by dividing the ballistic coefficient by 0.2 units so that the size of the cavity can be confirmed. The cavity is formed from a predetermined value and becomes larger as it passes through the frame, and becomes smaller again when it reaches a certain frame.

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Conclusion
In this study, we designed a simulation based on the ballistic coefficient and the physical parameters of the cavity. We have confirmed the direct relationship between the bullet and the object by actively utilizing the ballistic coefficient. And we also confirmed the feasibility of the simulation of the actual observed phenomenon using the graphics contents. Furthermore, it is necessary to consider the external forces such as the characteristics of firearms and the physical factors that occur in the daily environment by extending from the direct relationship between the trajectory and the cavity. If these parameters are established, a deeper graphics algorithm needs to be designed for future research.

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References