Goal's three-dimensional trajectory reconstruction based on the adaptive multiple target surface iteration method

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Received 1 July 2014, www.cmnt.lv

Abstract

In order to solving the problem of the multiple bullet target matching and multiple bullet three-dimensional trajectory calculation., this article proposes a method for bullet three-dimensional trajectory measurement based on an adaptive multiple target surface and multiple iteration algorithm. In this method, it set up a virtual cuboids target space, which includes multiple bullet trajectories. It used two high speed cameras, one in left and another in right, to capture images. In the vertical direction of the bullet flying, these images were segmented into infinite plane, which are multiple target surfaces. It used the projective transformation to recover the target two-dimensional image from the left and the right images, and repeated this process until finding the bullet point in left view is coincide with that in right view. If the points were found, it indicated that it achieves the goal's accurately matching and every space location of the bullet. The simulation experimental results show that this method is feasible, image processing and analysis is merely influenced by background. This method can effectively realize the bullet three-dimensional trajectory target matching, and it has strong manoeuvrability.

Keywords: three-dimensional trajectory, target matching, perspective transformation, multiple iterations, adaptive multiple target surface

1 Introduction

In the field of the three-dimensional coordinates and the three-dimensional trajectory, a key question is how to achieve multi-target bullet points of the match of the two-dimensional image on the left and right cameras. How to automatically and efficiently improve the accuracy of matching that is an important link in achieving the bullet matching. The commonly used image matching technology is mainly divided into the method based on pixel and the method based on feature [1-3]. Based on the direct method is to directly calculate the difference value of image pixel grey value and that the same part of the pixel grey value should be inferior to different parts of the pixel grey value of value. This method is simple and intuitive, but the drawback is a large amount of calculation, and as the image has a larger under the condition of different rotation and illumination, the method cannot obtain satisfactory results. In order to reduce the grey-scale image matching method based on the false match rate and improve the matching algorithm noise is less affected by noise, so the method based on characteristic is presented. Based on the characteristics of the method is to extract contains important image feature points from the necessary matching image, and then use similarity measure for image feature points matching. The commonly used features are edge, outline linear and angular point in image matching. Matching based on feature for image distortion has certain robustness, but its matching performance largely depends on the quality of the image feature extraction, and this kind of method of image feature extraction are susceptible to noise interference and influence [4, 5]. Due to the complexity of imaging in the scene condition as well as a variety of different sensor has the characteristics of different imaging mechanism, the features of the extraction of image stabilization point will sometimes be very difficult. But when handling the bullet target matching in the actual situation, if the background of image is relatively complex, so the extraction of feature points is inevitably affected by the noise and caused error rate in the extraction of feature points, which lead to the decrease of matching precision. So the above methods cannot fully applicable to the situation, it need to find a new method that is less affected by the environment, and can be accurate and efficient implementation of the target matching. The adaptive multiple target surface represents a planar target surface can be unlimited extension and the distance between the planes can be equidistance change. Thus, this paper proposes a new adaptive multiple target surface iteration method to achieve the objectives matching. By finding about camera imaging of left and right view the same target at the same time in the same plane to achieve the goal of matching. The method by the left and right view image perspective transformation [6-8] front view image then compare the pixels in the graph in the face to judge the pixels are consistent about the corresponding view of whether the bullet is the same goal. This method is rapid, easy to solve the matching problem of the bullet, thus calculated to the three-dimensional coordinate in the process of bullet flight.

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2 Adaptive target face multiple iterative method principle

2.1 ADAPTIVE MULTIPLE TARGET SURFACE MODEL

In reality, the bullet's flying process can be seen as the bullet through countless planes, which are parallel to each other. As shown in Figure 1, the bullet's flying state can be expressed as a process that the bullet flies through the first plane to the *N*-th planar. The plane is parallel to each other and the relative distance is very tiny. So three-dimensional coordinate received in each plane when the bullet flies through each plane can be used to represent the bullet's flying 3D trajectory figure.

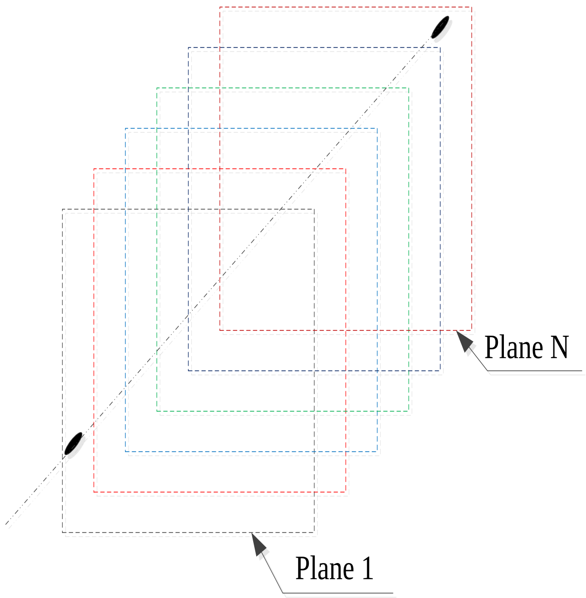


FIGURE 1 The process of the bullet flying

Through the theoretical analysis above, we can adopt the virtual plane, which is made of 8 landmark point when the bullet flies through it. The plane *ABCD* is parallel to the plane *EFGH*, and the line *AD*, *BC*, *EH*, *FG* are horizontal and have equal spaces. If we divide the planes between the plane *ABCD* and plane *EFGH* in average, we can get *N* parallels planes and form random number of parallel planes. The bullet's flying through the construction plane is shown in Figure 2.

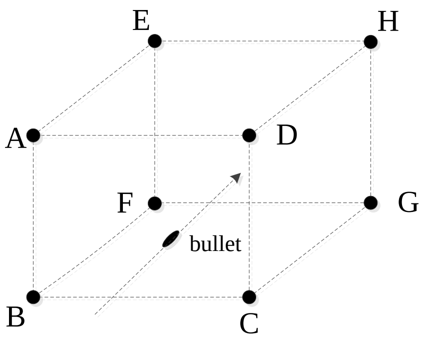


FIGURE 2 The bullet's flying through the construction plane

2.2 THE PRINCIPLE OF MODEL ANALYSIS

When we use two array high-speed cameras, which are placed in both the left and right sides to capture images of the bullet flight, the imaging process of each image can be seen stationary. Because of rotation and translation, orthography is formed on the image plane when we move the observation point and the image plane on condition that the object plane is stationary. The imaging process can be seen as a plane, which the actual orthography plane is mapped to at any angle. That is to say, the imaging process is the projective transformation, which transfers from a two-dimensional planar scene to another, the point, which transfers from one plane to another [9].

Therefore, the transformation can be expressed as *H*, which is a 3×3 holography regardless of global scale factor in the projective space [10-13]. Thus, *H* has 8 DOF. As shown in Equation (1), *M* is the homogeneous coordinates in the plane of the scene; m is the imaging coordinates on the image plane.

$$M = Hm. \quad (1)$$

Thus, according to the camera model, Equation (1) can be rewritten as Equation (2) by transformation. The coordinates on the plane of random point *M* is (*X*, *Y*, *Z*) the corresponding coordinates of image point is (*u*, *v*, 1). Through calculating multiple points, we can obtain holography transferring Equation (1) to Equation (2).

$$\begin{bmatrix} u_1 & v_1 & 1 & 0 & 0 & 0 & -X_1u_1 & -X_1v_1 \\ 0 & 0 & 0 & u_1 & v_1 & 1 & -Y_1u_1 & -Y_1v_1 \\ u_2 & v_2 & 1 & 0 & 0 & 0 & -X_2u_2 & -X_2v_2 \\ 0 & 0 & 0 & u_2 & v_2 & 1 & -Y_2u_2 & -Y_2v_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ u_n & v_n & 1 & 0 & 0 & 0 & -X_nu_n & -X_nv_n \\ 0 & 0 & 0 & u_n & v_n & 1 & -Y_nu_n & -Y_nv_n \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \end{bmatrix} = \begin{bmatrix} X_1 \\ Y_1 \\ X_2 \\ Y_2 \\ \vdots \\ \vdots \\ X_n \\ Y_n \end{bmatrix}. \quad (2)$$

Assuming that the cameras on both sides film the same target, and adopting the unified reference coordinate system, then we can get that the coordinates (*X*, *Y*) of random point *M* on the scene plane are the same, while the imaging coordinates (*u*, *v*) on the imaging plane resulted from left and right view are different. Thus, the relationship between pixels of front view images and pixels of different angle images can be obtained from the deformation of Equation (4) and expressed as Equation (5). The coordinates (*u*, *v*) is on the imaging plane after the perspective transformation, while (*u'*,*v'*) is on the front view coordinates.

$$\begin{bmatrix} u_1 & v_1 & 1 & 0 & 0 & 0 & -X_1u_1 & -X_1v_1 \\ 0 & 0 & 0 & u_1 & v_1 & 1 & -Y_1u_1 & -Y_1v_1 \\ u_2 & v_2 & 1 & 0 & 0 & 0 & -X_2u_2 & -X_2v_2 \\ 0 & 0 & 0 & u_2 & v_2 & 1 & -Y_2u_2 & -Y_2v_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ u_n & v_n & 1 & 0 & 0 & 0 & -X_nu_n & -X_nv_n \\ 0 & 0 & 0 & u_n & v_n & 1 & -Y_nu_n & -Y_nv_n \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \end{bmatrix} = \begin{bmatrix} u'_1 & v'_1 & 1 & 0 & 0 & 0 & -X_1u'_1 & -X_1v'_1 \\ 0 & 0 & 0 & u'_1 & v'_1 & 1 & -Y_1u'_1 & -Y_1v'_1 \\ u'_2 & v'_2 & 1 & 0 & 0 & 0 & -X_2u'_2 & -X_2v'_2 \\ 0 & 0 & 0 & u'_2 & v'_2 & 1 & -Y_2u'_2 & -Y_2v'_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ u'_n & v'_n & 1 & 0 & 0 & 0 & -X_nu'_n & -X_nv'_n \\ 0 & 0 & 0 & u'_n & v'_n & 1 & -Y_nu'_n & -Y_nv'_n \end{bmatrix} \begin{bmatrix} a1 \\ b1 \\ c1 \\ d1 \\ e1 \\ f1 \\ g1 \\ h1 \end{bmatrix}. \quad (3)$$

Thus, perspective transformation can be simplified as the relationship between pixels of front view images and image point of the plane image after the perspective transformation. As shown in Equation (3), *A* is pixel coordinates of image after perspective transformation. *B* is pixel coordinates of the front view, is the perspective transformation function.

$$A\lambda = B, \quad (4)$$

We can get the perspective transformation function expressed as Equation (5) from Equation (4).

$$\lambda = (A^T A)^{-1} A^T B, \quad (5)$$

If there are n corresponding points, we will get $2n$ equations about perspective transformation function, so we can get the corresponding perspective transformation function through 4 groups corresponding points. Because the perspective transformation is the relationship from pixel coordinates on one plane to another, so we can get different perspective transform coefficients from different front views of different sizes. At the same time, we can get different perspective distortion when we film the same object in a different angle, and the image of front view in different position is different. In order to make the subsequent match precisely intuitive, we should choose the front view of same size, so that we can guarantee the consistent results offering convenience for subsequent image processing.

Using the double array camera capturing the image of the bullet flight, we can obtain the bullet's both sides images when the bullet flies through the adaptive multiple target surfaces. As shown in Figure 3, the left and right view image represents the bullet 1 and bullet 2 fly through the plane and respectively at the same time. When the left camera and the right camera to capture the bullet image, the angle of the camera, which led to the left, and right view image has the projective transformation, so the collected images are not front view image. The bullets 1 and 2 at the same time *t* are not in the same plane of the actual three-dimensional space.

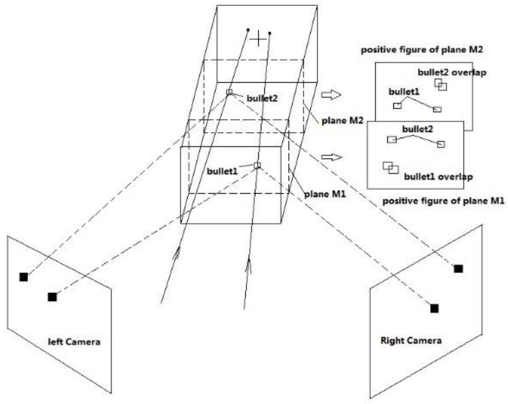


FIGURE 3 The different imaging bullets in the left and right camera

As the same target that the camera of both sides film at the same time must meet the actual space target in one plane of real space. As shown in Figure 3, target 1 is in the adaptive multiple target surface plane M_1 at the moment *t*. Suppose that the four fixed points are *ABCD*, you'll get these four image point coordinates after image of left and right view. The image point on the left side of these four fixed points in the *M* plane is marked as A_1, while the right side is marked as A_2. The image point of front view with the uniform size is marked as *B*. We can obtain the perspective transformation relationship between left view and right view of the uniform size through Equation (5). It can get Equations (6) and (7).

$$A_1\lambda_1 = B, \quad (6)$$

$$A_2\lambda_2 = B. \quad (7)$$

Apply λ_1 and λ_2 separately to the left and right view, we can recover the coordinates of bullet point target1_left on the left to the coordinates in the front view and we will get the new image coordinates B_1. When recover the coordinates of bullet point target1_right on the right to the coordinates in the front view, we will get the new image coordinates B_2. Because target1_left and A_1 are in the left view images of M_1 plane, target1_right and A_2 are in the left view image of M_1 plane, and target1_left and target1_right are the images of target1, then we can obtain Equation (8) from Equations (6) and (7).

$$A_1\lambda_1 = A_2\lambda_2. \quad (8)$$

Then, it can transfer Equation (8) to Equations (9) and (10).

$$A_{11}\lambda_1 = B_1, \quad (9)$$

$$A_{12}\lambda_2 = B_2. \quad (10)$$

Therefore, we can get that the coordinates of B_1 and B_2 are the same. So we can finish the match of bullet points through finding the intersection plane in which the image points of front view are fit by multiple iterations. The image is shown in Figure 4.

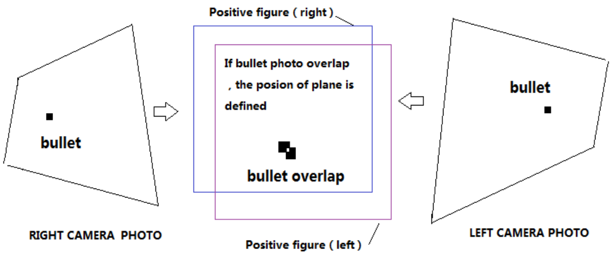


FIGURE 4 Perspective transformation relations of the same bullet

Assume that the two bullet targets are both in M_1 plane. We can respectively recover the two bullet targets to the front view through perspective transformation. The recovery of bullet 1 can be obtained by Equation (9) and Equation (10), at the moment the bullet 1 is in M_1 plane, and we can get the same bullet coordinate points. For the bullet 2, through the same principle analysis, the coordinate of the left image is A_{t11}, while the right is A_{t22}, and the images of front view are C_1 and C_2. They are shown in Equations (11) and (12):

$$A_{t11}\lambda_1 = C_1, \tag{11}$$

$$A_{t22}\lambda_1 = C_2 \,. \tag{12}$$

While in practice, the bullet 2 is not in M_1 plane of the actual space, but in M_2 plane. Thus, the coordinates of C_1 and C_2, which resulted from the transformation of perspective transformation function in the front view can not recover the both sides images to the front view images in M_2 plane where the bullet 2 is. So the coordinates of C_1 and C_2 will not overlap. The recovered front view images of bullet 1 and bullet 2 are shown in Figure 5.

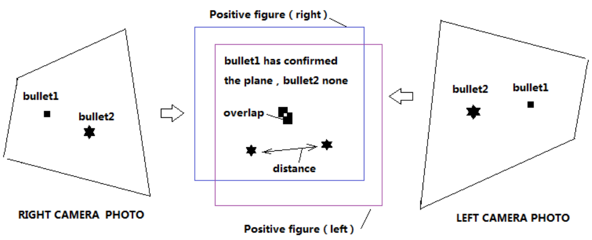


FIGURE 5 Perspective transformation relations of the two bullets

Through the principle of the analysis, we can clear the match of bullet points and achieve the goal of one to one correspondence. According to Equation (13), we can calculate the type *3d* coordinates (X_w, Y_w, Z_w) of space target. The parameters with the letter l are calibration parameters and pixel coordinates of the left camera, while the parameters with the letter r are calibration parameters and pixel coordinates of the right camera in Equation (13).

$$\begin{bmatrix} u_l m_{l31} - m_{l11} & u_l m_{l32} - m_{l12} & u_l m_{l33} - m_{l13} \\ v_l m_{l31} - m_{l21} & v_l m_{l32} - m_{l22} & v_l m_{l33} - m_{l23} \\ u_r m_{r31} - m_{r11} & u_r m_{r32} - m_{r12} & u_r m_{r33} - m_{r13} \\ v_r m_{r31} - m_{r21} & v_r m_{r32} - m_{r22} & v_r m_{r33} - m_{r23} \end{bmatrix} \begin{bmatrix} X_W \\ Y_W \\ Z_W \end{bmatrix} = \begin{bmatrix} m_{l14} - u_l m_{l34} \\ m_{l24} - v_l m_{l34} \\ m_{r14} - u_r m_{r34} \\ m_{r24} - v_r m_{r34} \end{bmatrix} \tag{13}$$

3 Experimental analysis and simulation

3.1 EXPERIMENTAL SCHEME

In order to prove that the proposed algorithm can be implemented with, as well as to solve problems in practical application, experimental simulation standard 5.56mm bullets, high-speed analogue camera with PhantomV12.1. Camera that full frame resolution of 1280×800, full frame shooting rate of 6,242 frames/sec, the maximum recording rate of up to 1,000,000 frames/sec, experimental simulation 6,242 frames/sec.

Given experimental conditions, cannot get PhantomV12.1 speed cameras. So using old-fashioned shoot animation processing forms, taking photos with a digital camera to simulate every artificial speed camera frames of all, according to the bullet velocity 860m/s, each piece can be calculated bullet moving distance of about 0.137 meters, after several manual shooting, and ultimately can get high-speed camera to capture the effect on the bullet. If it does not consider the iris of the camera, capture efficiency and the target, respectively, this and the actual site situation is almost the same, so it can be used to verify the algorithm.

Specific structure of experiments shown in Figure 4, which constitute a rectangle *EFGH* is the target region of the bullet, the trajectory of the bullet 1 and 2. With two thin leads from the target surface area, put a line marker bullet black fake bullet marks, as the bullet frame shooting targets, which two thin three-dimensional trajectory as a follow-up compared in order to test the correctness of trajectory calculation.

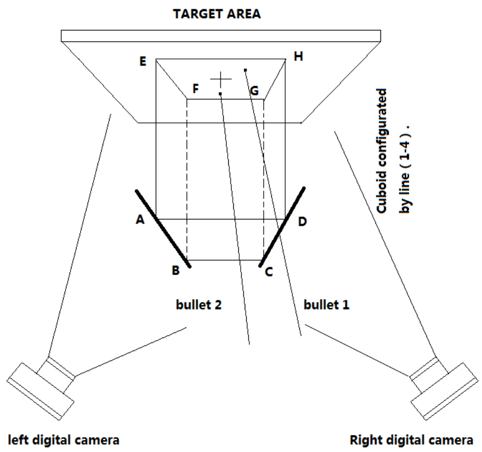


FIGURE 6 Test chart of the algorithm

AE, BF, CG, DH are perpendicular to the target surface *EFGH* four thin, with the target area together constitute a virtual rectangular multi- target surface, *A-H* these eight signs point constructed bullet during flight through space plane. Where in the surface and the surface is a surface parallel to each other, the distance between the same. Figure 6 is a schematic structural view of a test algorithm, Figure 7 is a left side of the camera seen from the test structure, and the structure of the right side of the camera as seen in Figure 7 is symmetrical.

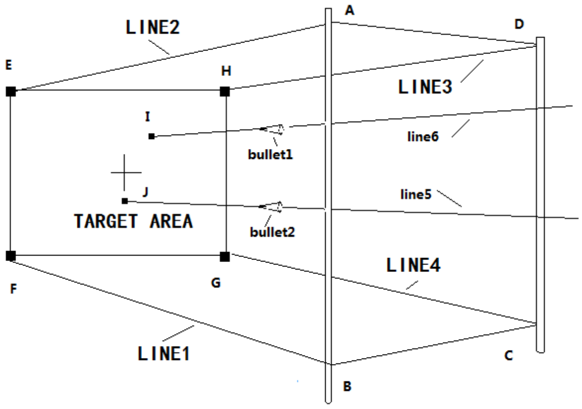
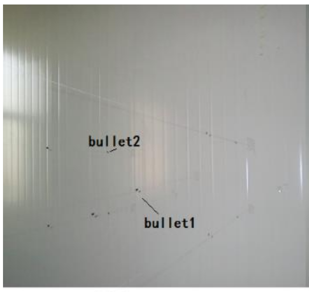


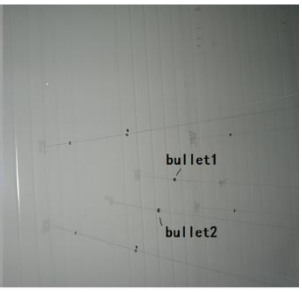
FIGURE 7 Bullet flying through the virtual target surface

This experiment uses a digital camera for two virtual analogue bullets through the process of shooting the target surface, and gets a series of shots left and right view images. Figure 8 and 9 show the left and right camera capture the two bullets images at a time.



Right camera

FIGURE 8 Left camera to capture the two bullets



left camera

FIGURE 9 Right camera to capture the two bullets

3.2 EXPERIMENTAL SIMULATION AND ANALYSIS

Read the collected images in matlab, because the eight landmarks and the two bullets target are small, their coordinates can be manually obtained by selecting the centre of their coordinates. After getting *A-H* the eight landmark coordinates, connect their coordinates in turn. The result is shown in Figures 10 and 11.

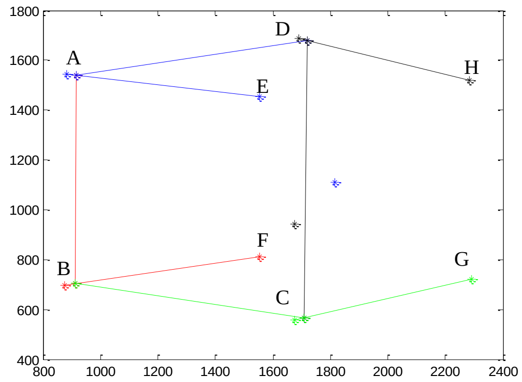


FIGURE 10 Right camera virtual surface composed of eight landmarks

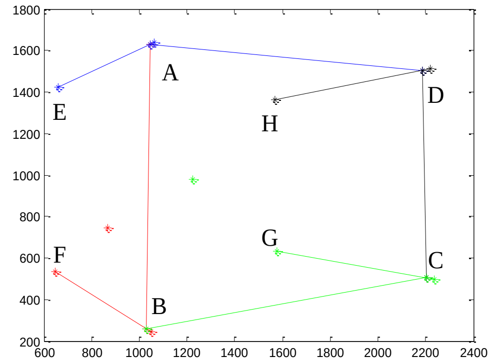


FIGURE 11 Left camera virtual surface composed of eight landmarks

Thus, it can be divided into 20 for *AD, BC, EH; FG* and these points with the same distance are connected in turn, which forming 20 parallel planes. So there is a one-to-one correspondence between the 20 parallel planes and the equidistance 20 planes in three-dimensional space. The result of image segmentation of equidistance is shown in Figures 12 and 13.

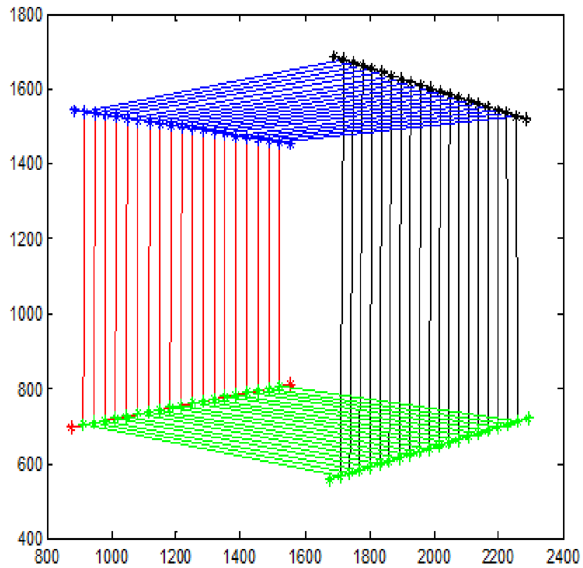


FIGURE 12 The uniform cutting plane of the right view

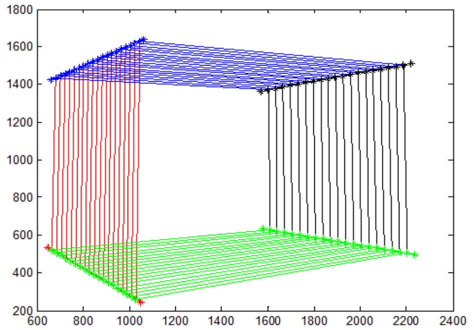


FIGURE 13 The uniform cutting plane of the left view

First assumption, two bullets bullet1 and bullet2 imaging are in the same plane *ABCD* at the same time. By formula it can respectively calculate the perspective transformation relations function about the left, right image plane and the uniform size of the front view. Then, applying the function to the left image and right as the recovery of the bullet point coordinates. Figure 14 shows the two bullets bullet1 and bullet2 in the left view image by perspective transformation to get the two bullets coordinates b1 and b2 in front view image. Figure15 shows the two bullets bullet1 and bullet2 in the right view image by perspective transformation to get the two bullets coordinates b2 and b4 in front view image. By comparing the coordinate size, b1, b2 and b3, b4 the coordinates of the points are not the same. Through the analysis of Equations (11) and (12), the two bullets are not on the plane *ABCD* at the moment, as it not find the bullet into the actual plane at the moment.

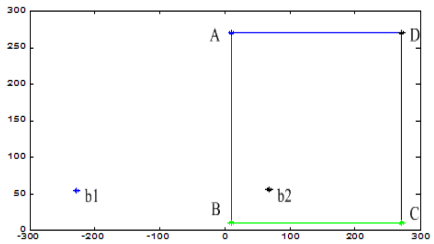


FIGURE 14 The bullets' coordinates b1 and b2 by the left image ABCD conversion

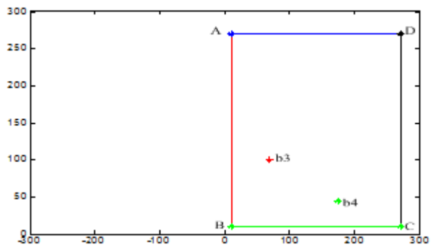


FIGURE 15 The bullets' coordinates b3 and b4 by the right image *ABCD* conversion

Through to the next image plane of the same algorithm, iterative until it finds the coordinate of a bullet is same on the front view image by restoring the left and right view image. Through iteration, it gets a front view of the uniform image plane *MNOP*, and the result is shown in Figures 16 and 17. Figure 16 shows the left view image bullet11 coordinates through transformation to get the coordinates c1 in front view, at the same time, bullet2 coordinate is converted to coordinate c2. Figure 17 shows the right view image bullet11 coordinates through transformation to get the coordinates c3 in front view, at the same time; bullet2 coordinate is converted to coordinate c4. From the coordinates of the results shows that c1 and c3 is the same, coordinates c2 and c4 are not equal. Through the analysis of Equations (9)-(12), the bullet11 into the plane *MNOP*, the bullet12 is not on the plane *MNOP* at this time, which can be found through the recovery of left and right view the coplanar planes, is to determine the bullet points around the image matching.

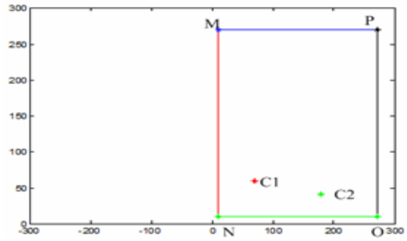


FIGURE 16 The bullets' coordinates C1 and C2 by the left image *MNOP* conversion

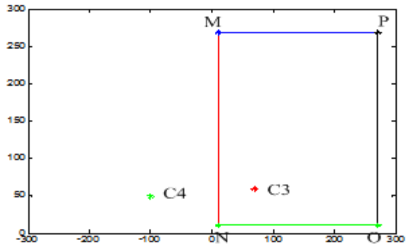


FIGURE 17 The bullets' coordinates c3 and c4 by the right image *MNOP* conversion

Through the above algorithm, multiple iterations around until it finds the coordinates of the bullet is consistent, that is sure to know the same bullet's imaging point in the left and right view. About as long as it can find a set of matching bullets coordinates, then the continuity of the trajectory of the bullet image may be used for matching judgment, then can realize the bullet match in each moment.

Determine the internal and external parameters of camera by camera calibration and combining the Equation (13) that can calculate the bullet's three-dimensional coordinate. Connect the three-dimensional coordinates of the bullet that can get the bullet's three-dimensional trajectory. Figure 18 shows the simulation results of the three-dimensional trajectory.

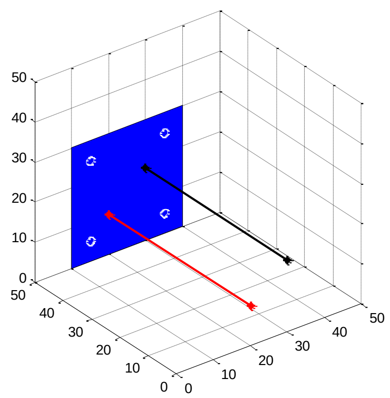


FIGURE 18 Three-dimensional trajectory of the two bullets

4 Conclusions

In order to obtain the flight trajectory of the bullet diagram is the three-dimensional coordinates of different points in time, the need to solve a major problem is that the presence of multi-target, so the camera one by one to the bullet point target pair. This process as the bullet flying through the numerous virtual planes parallel to each other in the process, and the left view image converted by the perspective transformation is a front view of the image. Through multiple iterative methods to find the corresponding coordinates in a front view of time consistent with the target point is about the same time the same target in the viewpoint of a real space in the same plane. This method is an iterative search to find the target by multiple coordinators' consistent elevation view, while the left and right camera will determine the corresponding match point in the bullet. This method is convenient and feasible experimental procedure. The image processing from the surrounding environment can quickly and accurately find the corresponding matching point and thus, can create a three-dimensional bullet trajectories.

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