Identification of an In-flight Supersonic Projectile in a Cluttered Environment Using Active Shape Model

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Abstract: This paper focuses on identifying a 155mm non-standard supersonic artillery projectile in an image taken from a cluttered environment. The presence of several objects in the image makes it difficult to automatically identify and segment the projectile shape. This identification is done by training an Active Shape Model with several images of the projectile that captures the variability in shape of the projectile when observed from different directions. The training set of images is generated from a three dimensional computer aided design model. The model is tested with several test images of projectile and non-projectile shapes. The validated model is then applied to identify a 155mm non-standard supersonic projectile in a high speed video.

Keywords—Active Shape Model, projectile identification, shape segmentation

I. INTRODUCTION

Artillery firing ranges use imaging technique such as high speed videography to understand the behavior of the projectile. Several ballistic parameters pertaining to the stability and aerodynamic performance of the projectiles are being determined using such imaging techniques. The basic need in performing such study is to locate the projectile in the image frame. As high speed video has several frames, it is necessary to automatically identify and locate the projectile for further analysis.

The challenge faced in an artillery test range for such automatic identification of an artillery projectile is the highly cluttered environment which could contain several other objects in the image frame. This method overcomes that challenge by using Active Shape Model (ASM) to classify several shapes present in the frame as a projectile or a non-projectile.

An ASM is trained and tested against images of projectile and non-projectile shapes before its implementation in the actual high speed video of fired projectile. Application of ASM for projectile identification in an image is done for standard projectile in [1]. The current study focuses on the applicability of this technique in identifying a non-standard supersonic artillery shell in a cluttered environment. A non-standard artillery shell is used only in testing ranges. A type of non-standard shell with a recovery plug at the nose of the projectile is used in the study.

Projectiles under development and quality assurance stages are required to be recovered to evaluate whether the projectile withstood the load from firing in the gun. Recovery plugs are fitted to the nose of the projectiles to reduce the range covered by the projectile and to reduce the penetration of the projectile into the ground to ease recovery activity. The process of developing the Active Shape Model and its implementation in projectile location is discussed in further sections.

II. ACTIVE SHAPE MODEL

An ASM is a numerical model built by using images of an object in various perspectives. The model captures all possible shape variations of the object. The training and application of Active Shape Models can be understood from [2] and [3]. The training set of images is represented by a set of points present on the boundary of the object to be identified. The set of points are automatically aligned and normalized to have lesser variations in the distance between equivalent points. The statistics of all the points present in all the images are evaluated to build a Point Distribution Model (PDM). The PDM arrived contains data about the mean shape and several other parameters. These parameters correspond to important modes of variation observed from the training set of images. Once this model is built, any new image containing the object to be identified can be evaluated against this model by comparing the difference in parameters that correspond to different modes of variation.

A. Model

A shape is represented by n points placed at equal distance on the contour. The points are generated for a training set of s images. The shapes can be aligned by translating, rotating and scaling them so as to minimize the sum of squared distances between the corresponding points. This alignment procedure makes the shape model independent of the size, position, and orientation of the objects.The points in Cartesian coordinates (x_1, y_1)... (x_n, y_n) are arranged as shape vectors,

$$X = (x_1, y_1 \dots x_n, y_n)^T \quad (1)$$

These shape vectors undergo Principal Component Analysis (PCA) by computing the mean shape,

$$\bar{X} = \frac{1}{s}\sum_{i=1}^{s} X_i \quad (2)$$

the covariance,

$$S = \frac{1}{s-1}\sum_{i=1}^{s}(X_i - \bar{X})\,(X_i - \bar{X})^T \quad (3)$$

and the Eigensystem of the covariance matrix. A matrix $\Phi = (\phi_1|\phi_2|\dots|\phi_t)$ is formed with only t number of eigen vectors corresponding to the largest Eigenvalues λ_i. Any shape is approximately given by

$$X \approx \bar{X} + \Phi\boldsymbol{b} \quad (4)$$

Where **b** is a vector of t elements containing the model parameters.

III. ASM FOR 155MM NON STANDARD ARTILLERY SHELL

For artillery projectiles, the ASM training set consists of images of projectiles of varying yaw angle and pitch angle. The application of the generated ASM is to identify a 155mm artillery projectile with recovery plug as shown in Fig. 1. The image corresponds to a 3D Computer Aided Design (CAD) model of the projectile. The training set of images is generated by placing the 3D CAD model at various pitch and yaw angles. A set of example images used to train the ASM from 3D CAD model is shown in Fig. 2.

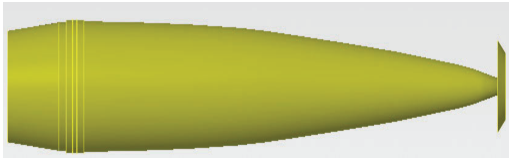

Fig. 1. 155 mm non-standard artillery shell with recovery plug

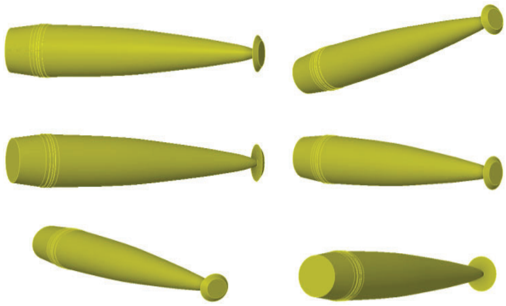

Fig. 2. Images of various views of projectile

Since the training set of images contain only the projectile shapes, the points representing the contour can be obtained using edge detection technique. A segmented projectile shape from a training image appears as shown in Fig. 3.

The contour of the projectile is obtained in (x, y) coordinate points. A fixed number of points are obtained from the projectile boundary. The contour shapes of projectiles then undergo rotation, translation and normalization. Rotation of the projectile shape requires calculation of the orientation of the projectile. The centroid of the projectile and the nose region is used to estimate the pitch angle of the projectile with respect to horizontal axis as shown in Fig. 4.

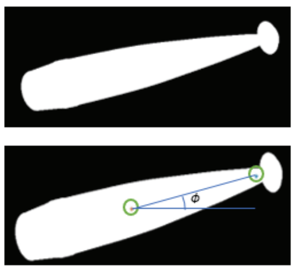

Fig. 4. Orientation of the projectile shape

Fig. 5. Projectile contour points after

All the projectile shapes are then rotated in such a way that the projectile is aligned with the horizontal axis. A rotation matrix R is used to perform this rotation. About 12% of the projectile area towards the tip is considered for estimation of centroid of the nose.

$$\phi = \tan^{-1}\left(\frac{Nose_{centroid,y} - Center_y}{Nose_{centroid,x} - Center_x}\right) \quad (5)$$

$$R = \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix} \quad (6)$$

The projectile contour points are centred at (0, 0) by subtracting each coordinate point on the contour from projectile's centroid. The projectile contour points are normalized by dividing each point with the horizontal length of the projectile observed from the image. After this step, all points of the contour lie with +-0.5.

Once as above steps are performed, the projectile contour appears as shown in Fig. 5. Once the aligned shapes are obtained, PCA is applied as shown in section 2.

IV. VALIDATION OF ASM FOR 155MM PROJECTILE

By using the model obtained by applying PCA, any candidate shape can be classified as a projectile or non-projectile. It is achieved by comparison of the normalized model parameters corresponding to the candidate shape. Let Y be the candidate shape shown in Fig. 6, which corresponds to the projectile in a different pose that was not used to build the ASM. For any new shape Y to be classified, b is computed by

$$\boldsymbol{b} = \Phi^T(Y - \overline{\mathrm{X}}) \quad (7)$$

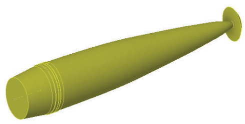

Fig. 6. Test image of projectile

Then a distance F is calculated to estimate the closeness of the new shape Y as given by

$$\Phi = \sum_{i=1}^{t} \frac{\boldsymbol{b}^2}{\lambda_i} \quad (8)$$

Depending upon the model, a particular threshold is decided for the value of F to decide whether to classify a shape as a projectile. For current scenario, the threshold is chosen as 20. For the above test image of the projectile, the value of F is around 4.8 and it is classified as a projectile.

A similar test is done with a set of non-projectile shapes as shown in Fig. 7 to validate the model. The F values for these shapes ranged between 40 and 3000 clearly more than the threshold. Hence these shapes are classified as non-projectiles.

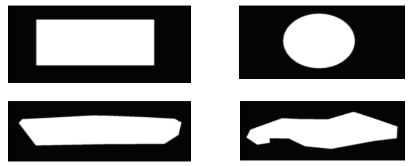

Fig. 7. Non-projectile shapes

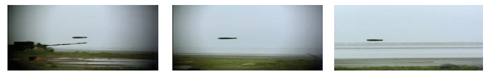

Fig. 8. Example frames from a high speed video of projectile

Fig. 9. Grey scale image

V. APPLICATION OF ASM TO IDENTIFY PROJECTILE IN A CLUTTERED ENVIRONMENT

A high speed video of a projectile recorded in a free flight testing range contains several frames. A few example frames from the high speed video of firing of 155mm non-standard artillery shell with recovery plug could be seen in Fig. 8. From these frames it is evident that several objects and regions are present in the images that complicate the automatic identification of projectile in each frame. So, it becomes necessary to use a shape model to classify all shapes present in the image as projectile and non-projectile.

Each frame in the video undergoes an automatic process that helps in identifying the projectile. Such process is demonstrated here for a single frame as shown in Fig. 8 which is in RGB format. This image is converted to grey scale format as shown in Fig. 9 to reduce the number of calculations to be performed per frame. The edges are detected as shown in Fig. 10.

Fig. 10. Edges detected

From Fig. 11 to 14, the edges are dilated, enclosed regions are filled, shapes in contact with borders are removed and then the image is smoothened respectively. After smoothening, the closed regions with area lesser than 1000 pixel are removed as shown in Fig. 15. Fig. 15 consists of 5 shapes, out of which one is projectile. All these shapes are then evaluated by the ASM built as described in the previous section to classify them as projectile and non-projectiles. ASM is able to successfully identify the projectile. Once the projectile is identified, a segmented image containing only the projectile is created as shown in Fig. 16.

Fig. 11. Edges dilated

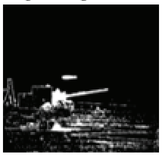

Fig. 12. Enclosed regions filled

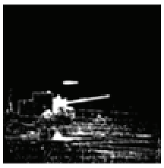

Fig. 13. Shapes near border removed

Fig. 15. Candidate shapes with area more than threshold

Fig. 16. Segmented projectile image after successful classification using ASM

Above mentioned set of operations is performed on all the frames of the high speed video to identify and locate the projectile. For the purpose of visualization, a sample frame from high speed video after the projectile is identified is shown in Fig. 17. Running in MATLAB on an Intel core i5-1155G7 processor, the average time taken for identification of projectile in a single frame is 0.08 s.

Fig. 17. Projectile located in actual frame

X. CONCLUSION

The feasibility of using ASM to identify a 155mm non-standard artillery shell from a high speed video recorded in a free flight range with cluttered environment is established in this study. The ASM is able to detect the projectile in each of the video frame. Once the projectile is identified and located stability and flight performance studies can be performed automatically.

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