Silhouette-Based Target Orientation (STO) Algorithm to Support Aim Point Selection & Maintenance

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Outline

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NAVSEA PMS 405M
Areas of Interest

- Target acquisition (particularly radially inbound) in a high clutter environment. We primarily discussed targets as missiles (both sonic and supersonic); however, there is also interest in detecting and tracking stationary or very slowly moving objects in the water.

- Selection of aim-points on the above acquired target set.

- Maintenance of the aim-point for a period of time to insure a successful engagement. The aim-point must be maintained during the lasing by the high power laser.

- We also discussed image fusion to produce high quality images of objects obtained with data from several low-resolution images

Background

- JPL received NAVSEA to understand if existing JPL technology was applicable to the problem

- Based on our understanding of the areas that were not addressed by the Navy contractor's presentations, JPL chose to examine techniques suitable for determining object orientation (supporting Aim Point selection) as no approach was currently developed by Navy's contractors

Leveraging JPL/NASA Experience

Algorithm techniques similar to other real-time JPL/NASA applications developed for:

- Space Rendezvous effort and

- similar MDA/BMDO funded cruise missile recognition and tracking program (Vigilante) where computation was limited and timing critical Segmented database (of object orientations) used to provide rapid searches

JPL Study Overview

Given an target in a thermal image, identify the object's orientation to support laser aim point maintenance/selection

- **Assumes:**
  - that the target class is recognized
  - the range to target is known either through apparent size in image or alternative sensing (radar, ladar)
  - that the images are generated by a narrow angle sensor at a distance (projection geometry distortion at a minimum)
  - we have an accurate 3D model of the target
  - target is segmented with in the image frame (we know the extent of the object and its location)
- **Produced a Silhouette-based Target Orientation (STO) Algorithm that provides the orientation of the object (Yaw, Pitch, Roll) in the object frame**
- **The target centered outputs (Yaw, Pitch, Roll) can be easily transformed into the sensor frame of reference for pointing and tracking (ie range and center of target along with its orientation give the 6DOF information of the target)**

Objectives Addressed

STO algorithm output can serve as input to modules that control the laser aim-point and tracking

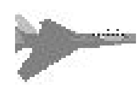
- **Orientation of object (Yaw, Pitch, & Roll) in conjunction with range (based on object's apparent size or by another sensor) serves as input to Aim-Point Selection module**
- **Frame-to-frame orientation changes as provided by STO serve as input to Aim Point Maintenance module**
- **Orientation (bearing) provides information to tracking filters for tracking maintenance**

Target Orientation

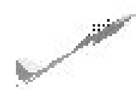
Use the target orientation to find and track components on the target

What the target silhouette looks like in the sensor for different orientations

Yaw, Pitch, Roll: (0,0,0)



Yaw, Pitch, Roll: (0,0,30)



Yaw, Pitch, Roll: (0, 30, 0)

Yaw, Pitch, Roll: (60, 0, 0)

Algorithm Description

1. **Determine "Bounding Box" (perimeter constrained rectangle) of the target in image**
2. **Extract the image in "Bounding Box" and rescale to standard size (we used 40 x 40 pixels)**
3. **Binarize image (target 1, background 0)**
4. **Determine principal axis of target (longest line) and center of mass**
5. **Rotate principal axis to 0 degrees (removing degree of freedom)**
6. **Project rotated image on to n component filters (generated by PCA on object images, we used 10)**
7. **Use rotation information and component results to search database generated from 3D model of object**
8. **Interpolate between k nearest neighbors to determine object orientation**
9. **Output- object orientation and center of mass in original sensor frame**

National Aeronautics and
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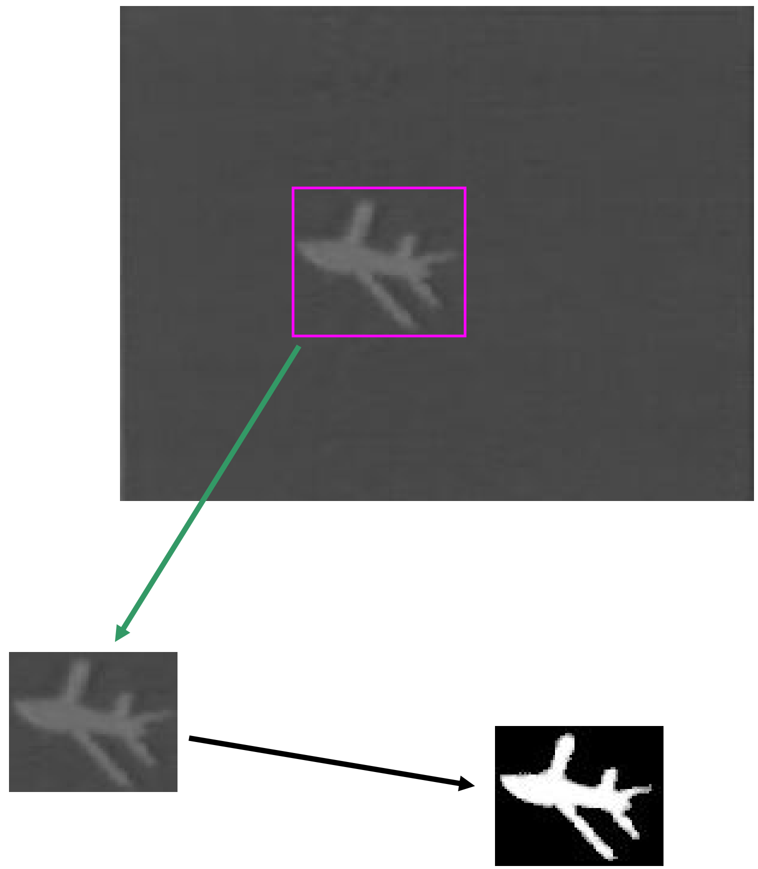
Pasadena, California

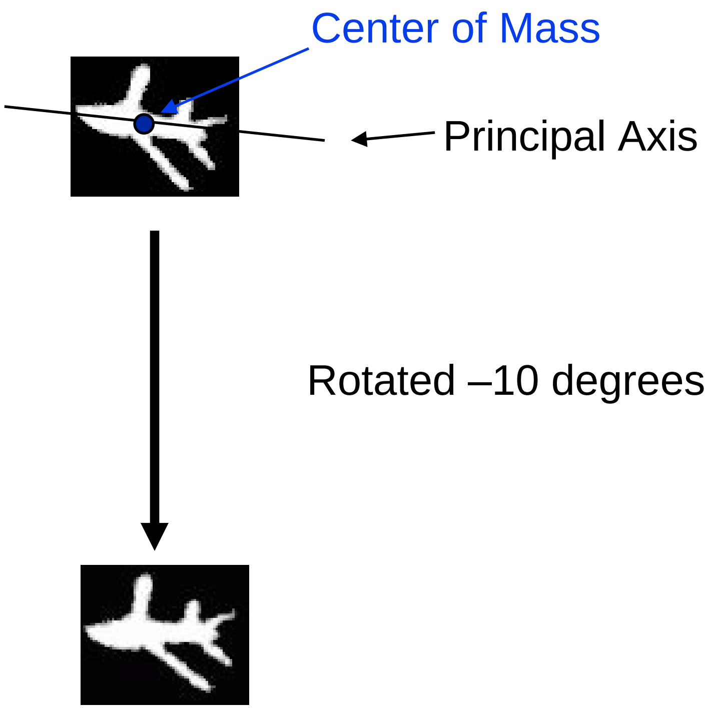
Bounding Box--Binarization

1. Determine Bounding Box of target in image
2. Extract Bounding Box and scale to standard size (we used 40 x 40 pixels)
3. Binarize image (target 1, background 0)



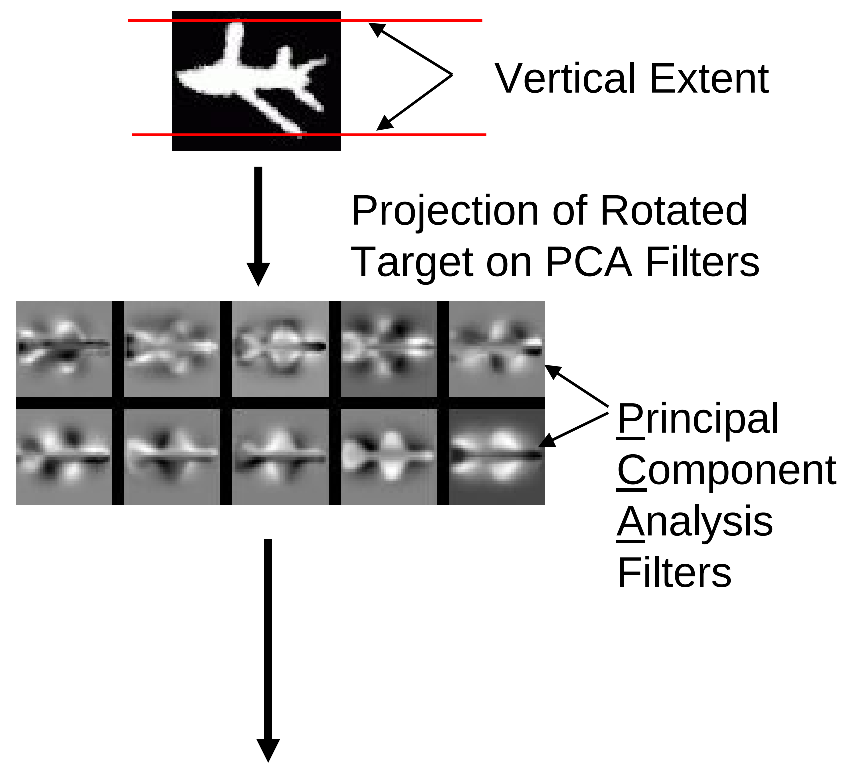
Algorithm Description (cont.)

4. **Determine principal axis of target (longest line) and center of mass**
5. **Rotate principal axis to 0 degrees (removing degree of freedom)**



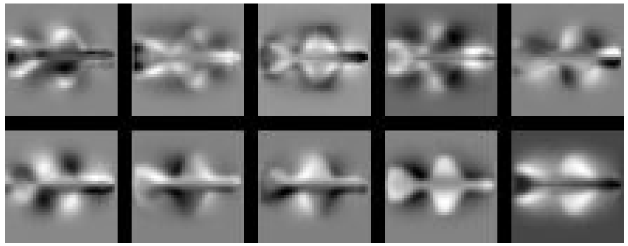
Algorithm Description (cont. 2)

6. Project rotated image on to n component filters (generated by Principal Component Analysis on object images, we used 10)



12 Value Target Signature:
Rotation angle, Vertical Extent, 10 Projection Eigen Values

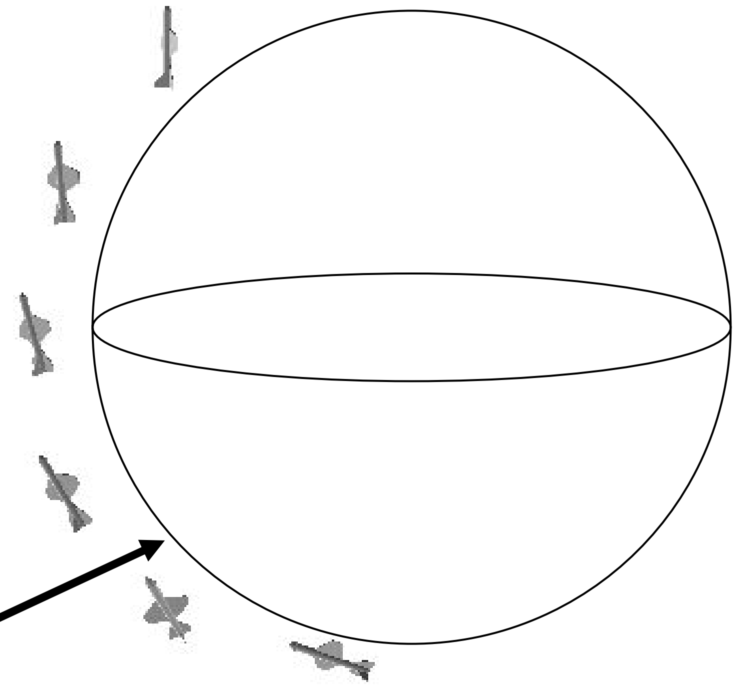
Algorithm Description (cont. 3)



7. Use the

1. rotation angle,
2. vertical extent,
3. 10 projection values results

to search database generated from 3D model of object



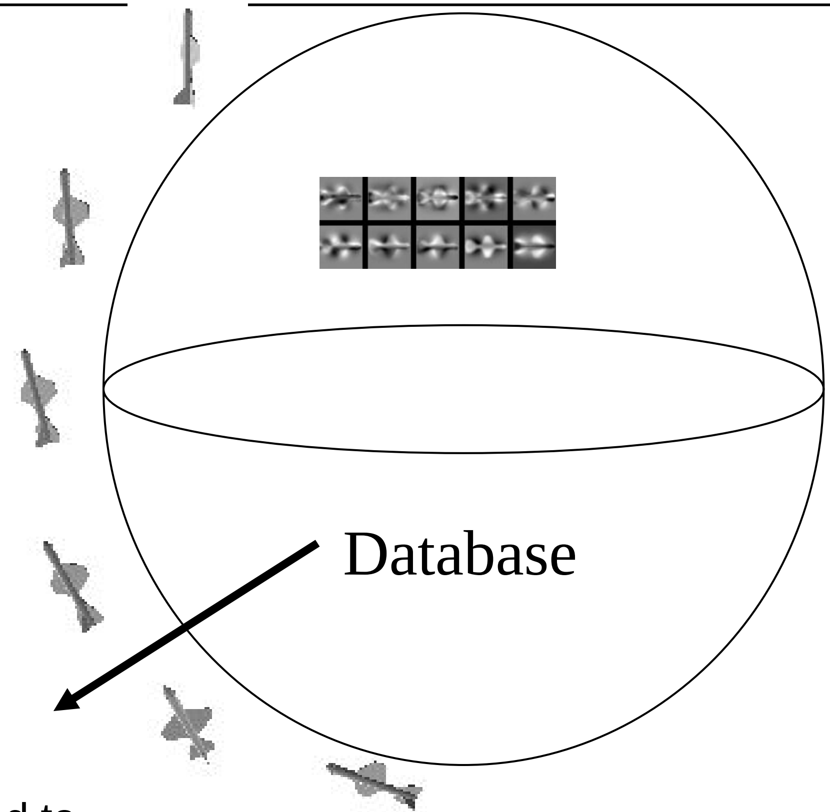
Target Signature Output from step 6
(Rotation angle, Vertical Extent, 10 Projection Values)

How to build a projection database of the 3D Target Silhouettes:

- Generated target silhouettes at 5 degree increments of Yaw, Pitch, Roll
- Run PCA to generate the silhouette Eigen filters
- Over 100,000 silhouettes target signatures outputs in database processed by steps 4-6

Algorithm Description (cont. 4)

8. **Interpolate between k nearest neighbors to determine object orientation**
9. **Output - target orientation and center of mass in original sensor frame**



k closest neighbors (we used 4), interpolated to provide sensor object's estimated Yaw, Pitch, Roll in body centered frame

- Generated target silhouettes at 5 degree increments of Yaw, Pitch, Roll
- Run PCA to generate the silhouette Eigen filters
- Over 100,000 silhouettes target signatures outputs in database processed by steps 4-6

JPL Study Approach & Results

1. Used data from TRW to demonstrate segmentation and normalization routines

2. To provide quantitative results, used cruise missile model for database development and testing

3. Pictures of 3D cruise missile model were generated at 5 degree increments of Yaw, Pitch, and Roll (Yaw and Pitch uniformly placed on unit sphere with 5 degree rolls at each spot—115200 images)

4. Random orientations of the cruise missile were generated for testing purposes

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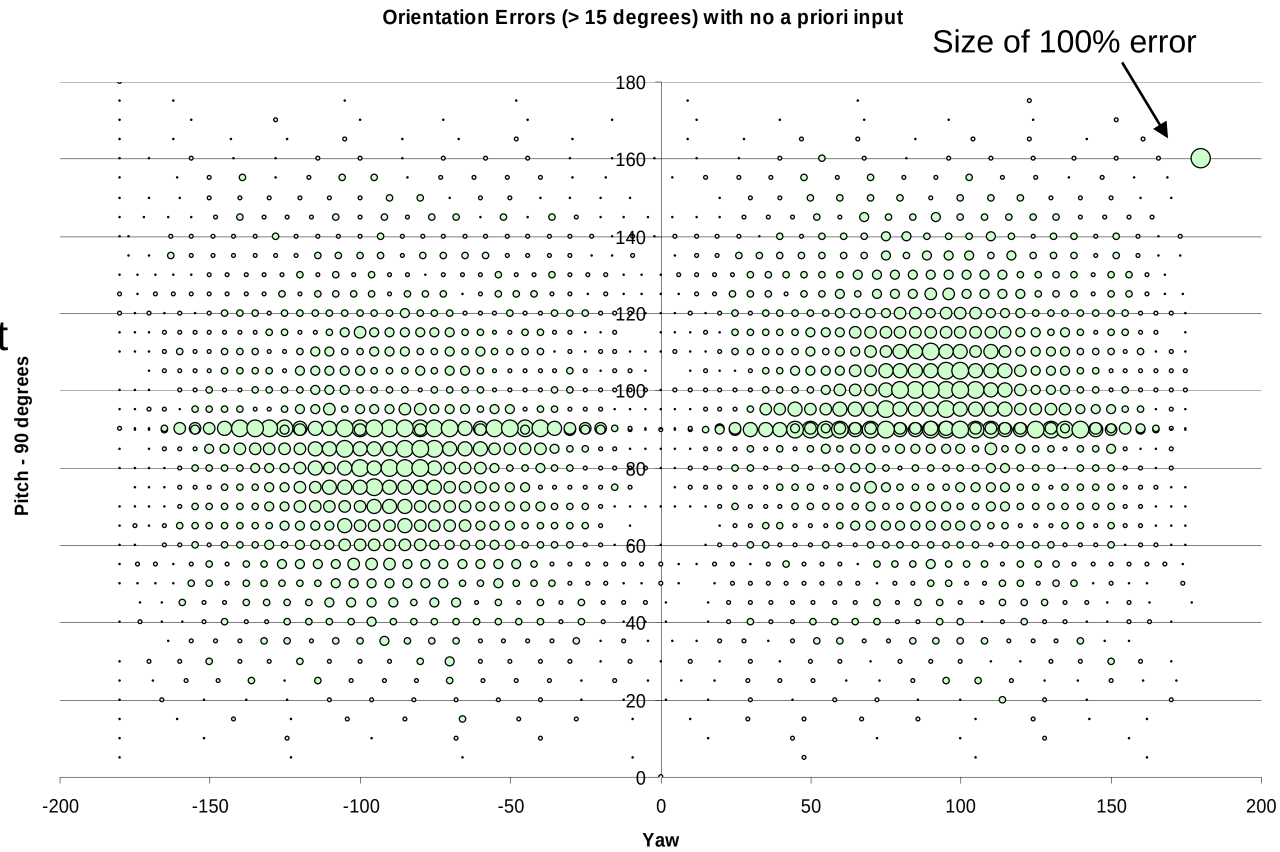
Results (with no a priori input image)

Errors associated with orientation determination

Most errors occur while the object is heading directly at the sensor

Some asymmetry due to the differing visibility of the control surfaces of the cruise missile

Each point represents 50 trials



Improved Results

1. 81 % of the orientations presented were within 15 degrees of Yaw, Pitch, and Roll when evaluated (no a priori information about heading)

2. When the orientation of the object was known , given prior input to with in 15 degree each axis, the next target input in time results in reduced errors dropped to 2.88 degrees (Yaw, Pitch) and 6.5 degrees (Roll), 1 sigma (standard deviation)

3. Database resolution (5 degrees) can be more finally populated (e.g.. 2 degrees) if tracking/aim point selection requirements demand better accuracy at the cost of longer associated search times

Conclusions

Applied JPL machine vision technology to a problem space (object orientation for aim point selection) identified by NAVSEA as critical for operation

Algorithms examined (STO) performed well on synthetic missile targets demonstrating an 81% success rate for placing target object within 15 degrees of actual orientation.

Algorithms obtained +- 2.9 degree (Yaw, Pitch error) and +- 6.5 degree roll error when object orientation was within 15 degrees

Speed up issues would need to be addressed in future work

A complete performance (accuracy) picture would need to be addressed in future work