Test & Evaluation/Science & Technology Program
Net-Centric Systems Test (NST)
Test Technology Area

Dr. Kofi Nyarko, Clayton Thomas, and Gilbert Torres

Decision Engine for Structured & Unstructured Data

32nd Annual International T&E Symposium

8/20/2015

Acknowledgements

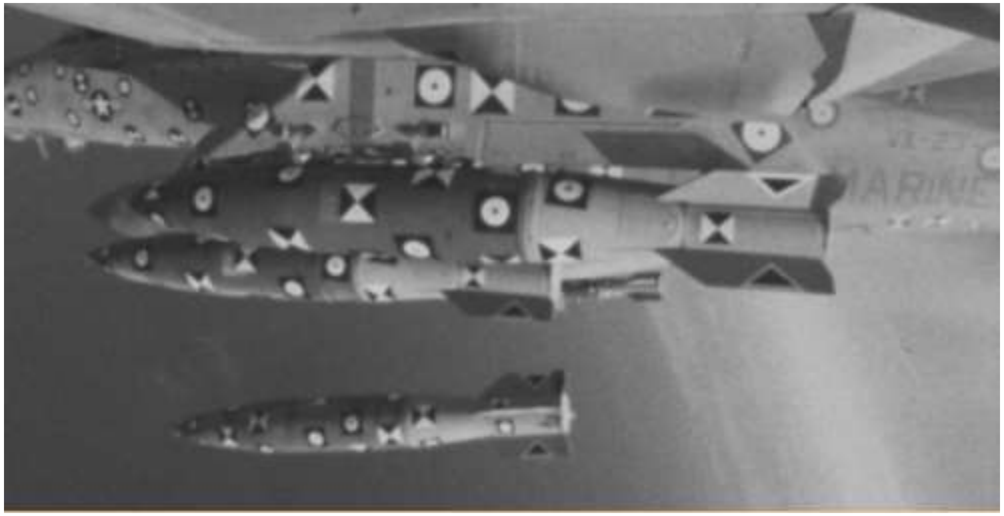
The Decision Engine for Structured and Unstructured Data (DESU) project is funded by the Test Resource Management Center (TRMC) Test and Evaluation/Science & Technology (T&E/S&T) Program through the U.S. Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI) under contract number W900KK-13-C-0017

Agenda

- **Photogrammetrics at the Atlantic Test Range (Photo-G)**
- **Current Photo-G Challenges**
- **Current Approaches**
- **Decision Engine for Structured Data and Unstructured (DESU)**
  - Project Overview
  - Photo-G Target Acquisition
  - Kernel Detection
  - Region Growing
  - Automated Target Acquisition
- **Performance Benchmarks**
- **Conclusion**

Photogrammetrics at the Atlantic Test Range (Photo-G)

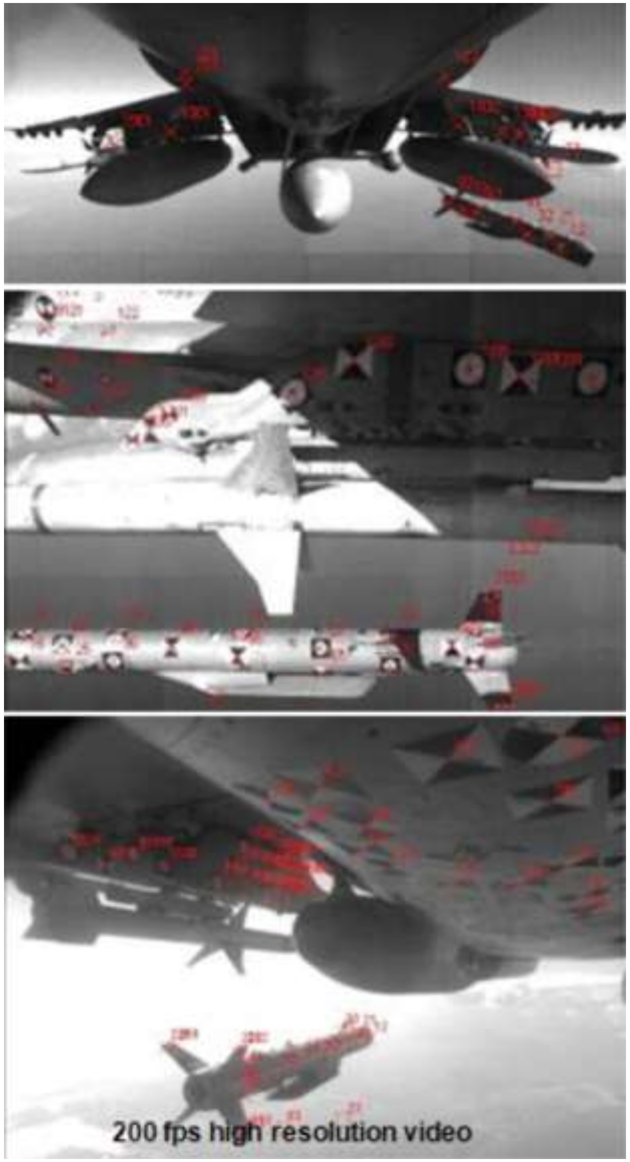
- **Photogrammetrics is a technique to extract reliable measurements from video or file**
- **Technicians at the Atlantic Test Range (ATR) reduce image data from high-speed cameras**
- **Targets placed on aircraft and stores are analyzed to reconstruct optimal 3-DOF or 6-DOF trajectories that best match 2-D tracking data**



Store Separation Testing

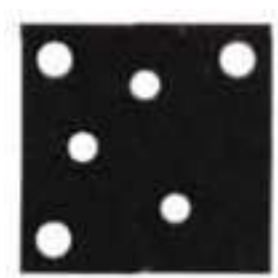
Current Photo-G Challenges

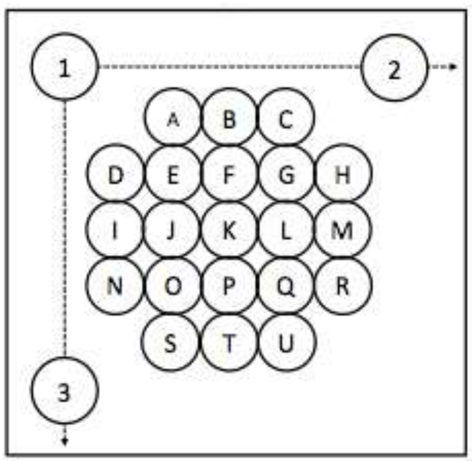
- Efficiently acquire, identify, and track the center of image features in terms of corresponding 2-D coordinates
- Reduce turnaround time from 24 hours to less than 1 hour
- Automatically acquire non-coded targets of varying size
- Automatically acquire non-coded targets of varying shapes
- High performance with limited spatial resolution
- High performance with monochromatic video
- High performance despite potential environmental occlusion



Current Approaches

- **Some manual setup is required for target acquisition and tracking**
- **Technician must conduct manual inspection to initially determine target IDs (could take hours)**
- **Possible to use coded targets**
  - Requires specialized targets (test articles must be refitted)
  - Ideal conditions are needed to reliably locate and decode targets
  - May require cameras with higher spatial resolution than are currently employed
  - Algorithms for coded targets do not translate well to non-coded targets



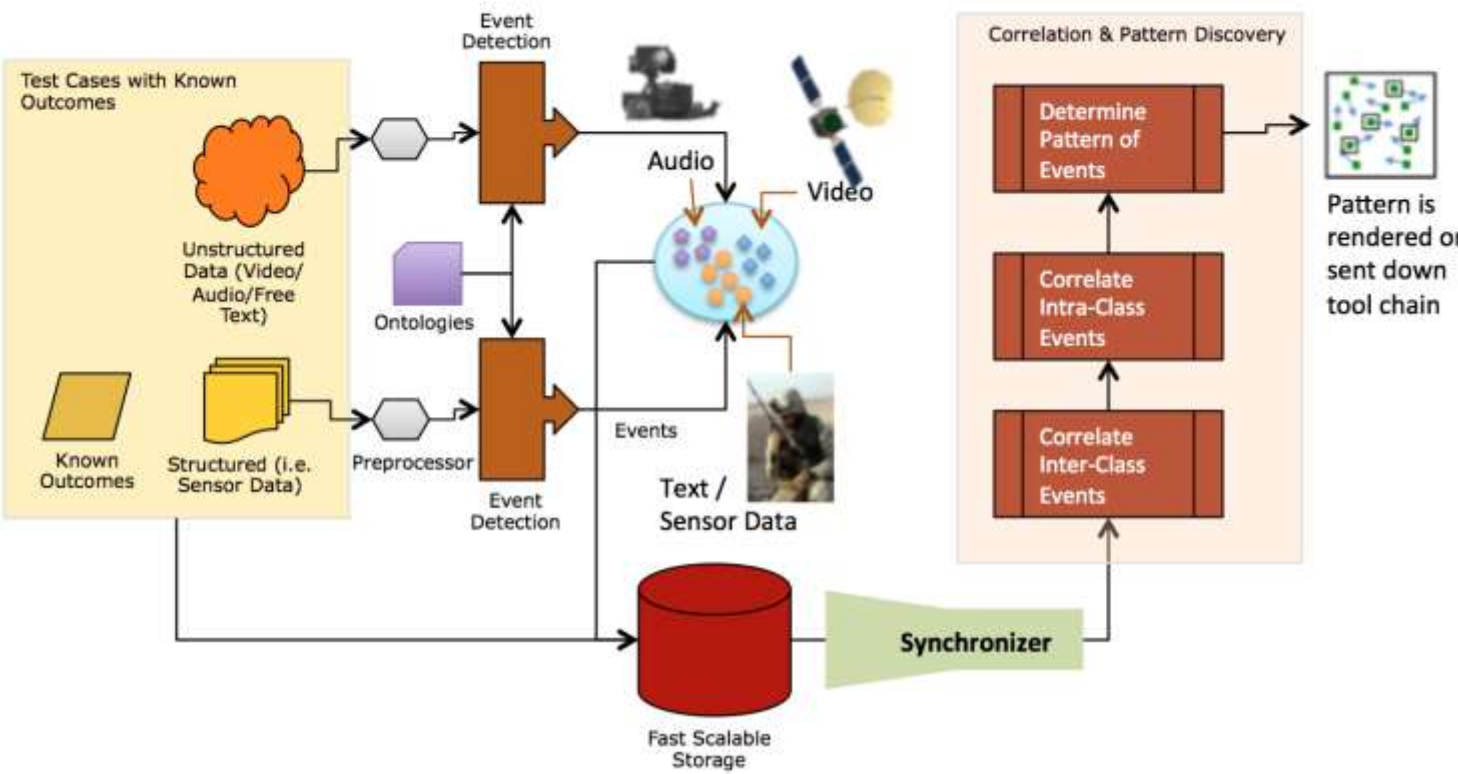


Current Approaches

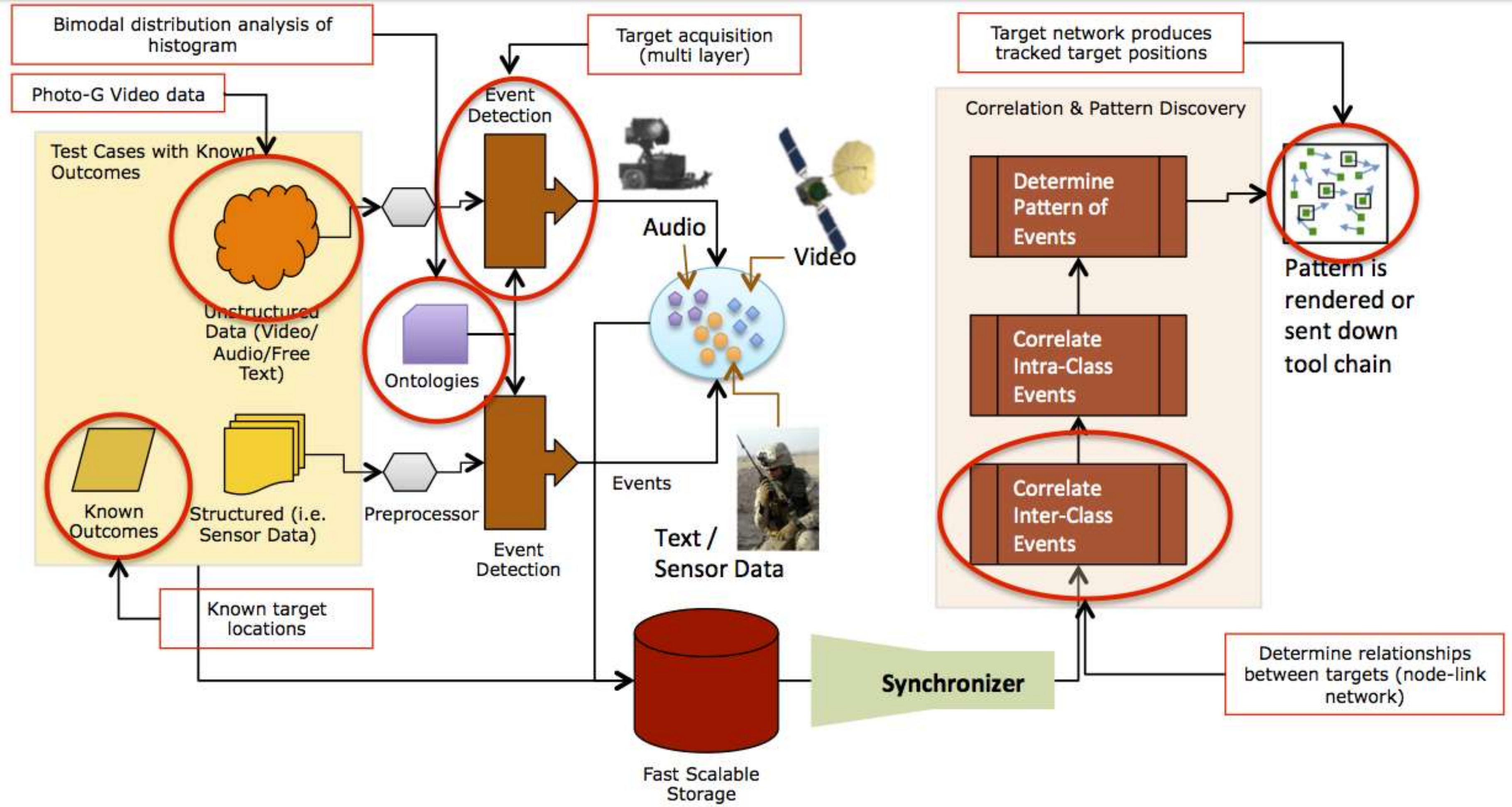
- **General approach used for extracting coded targets**
  - Edges are extracted from images and filtered to produce candidate edges
  - Ellipses are fitted onto candidate edges
  - Parameters of fitted ellipse provide the basis for decoding target
- **This approach is not well suited for Photo-G targets**
- **Algorithms are sensitive to:**
  - noise
  - resolution of central ellipses
  - view angles
- **Accuracy drops rapidly when the number of pixels on an eligible edge is insufficient to determine the shape of the fitted ellipse**

Decision Engine for Structured Data and Unstructured Project Overview

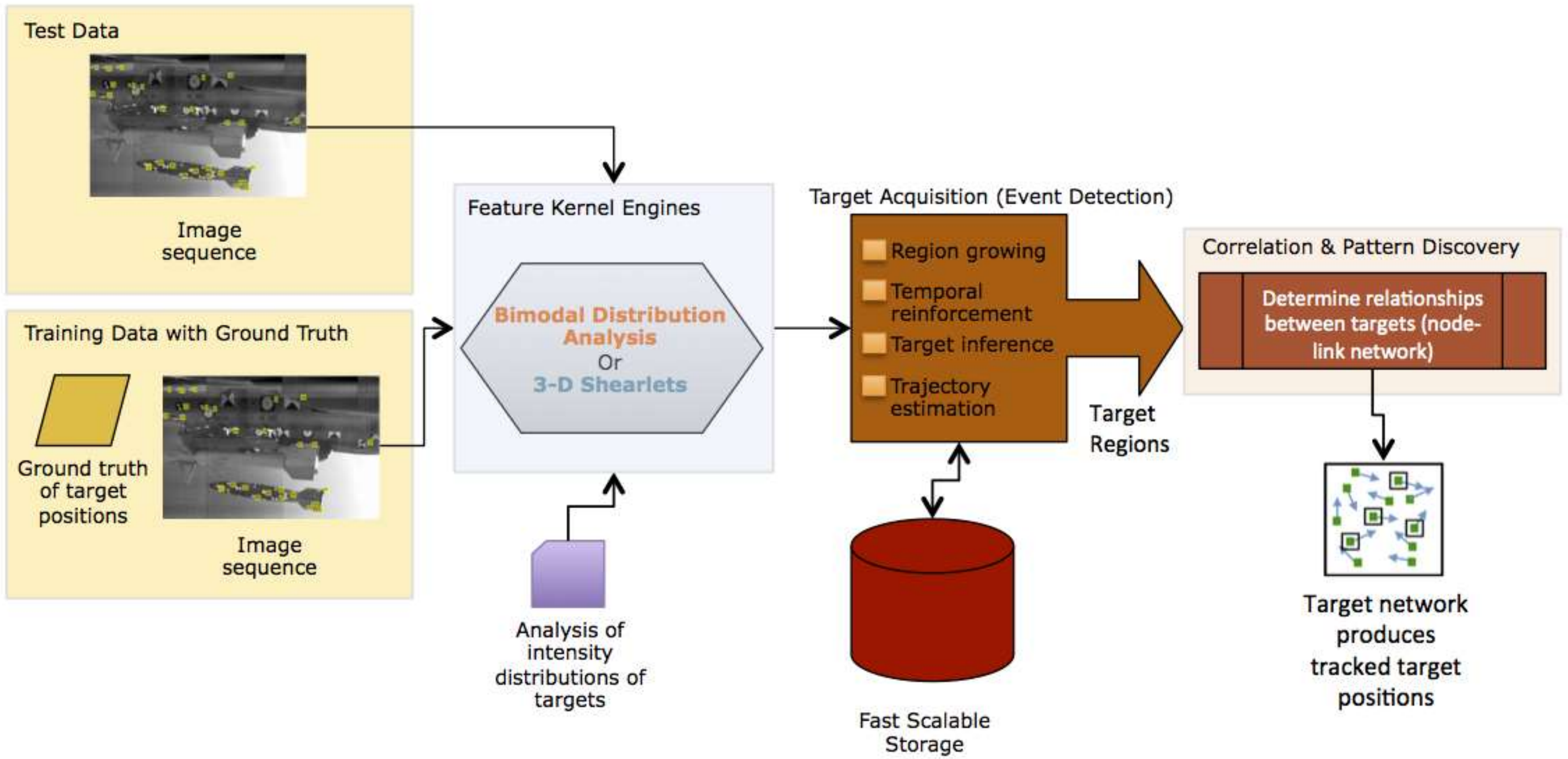
- **DESU is a system capable of rapidly analyzing large amounts of unstructured & structured data to correlate events within and across each stream**
- **Captured events are processed with a graph engine that builds and detects patterns**



Decision Engine for Structured Data and Unstructured Photo-G Target Acquisition



Decision Engine for Structured Data and Unstructured Photo-G Target Acquisition



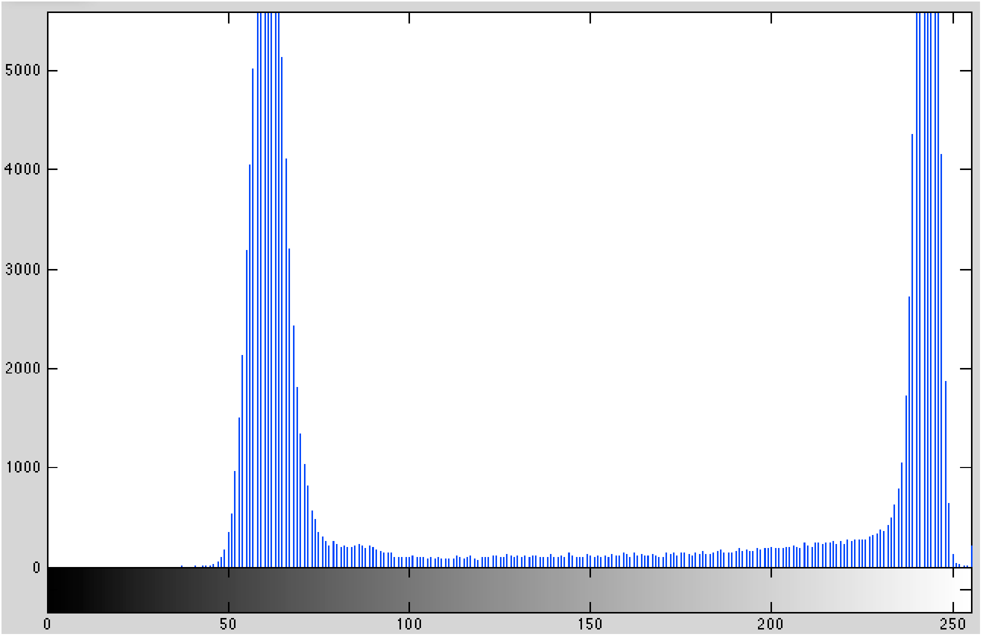
Decision Engine for Structured Data and Unstructured Kernel Detection

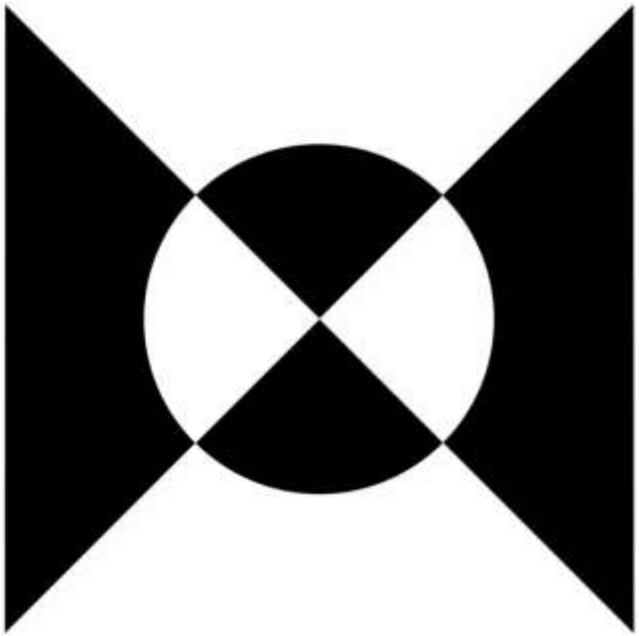
- **Photo-G targets come in three variations (circle, square bowtie and circular bowtie)**
- **Subject to highly dynamic contrast levels**
- **Need approach that doesn't make strong assumptions about target locations and correspondence across images**
- **Identify common feature of all targets**
  - High contrasting adjacent regions
  - Feature kernel can identify bimodal intensity distributions
- **Segment image frame into adjacent cells of s^2 pixels, where each cell meets the condition**

$$(s + 2\frac{s}{l})^2 = \sum_{i=1}^{k} H_i$$

Decision Engine for Structured Data and Unstructured Kernel Detection

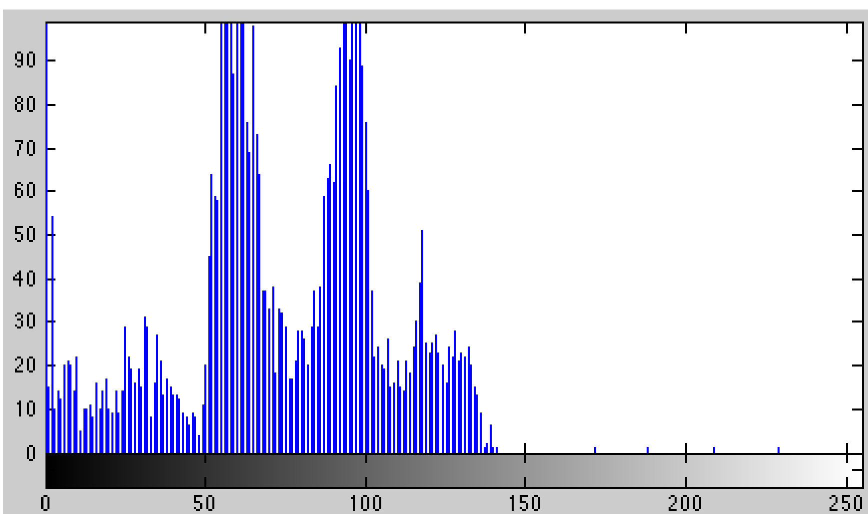
- **Intensity distribution of ideal target**
- **Typical bimodal distribution segmentation assumes distributions are simple mixtures of two Gaussian distributions**

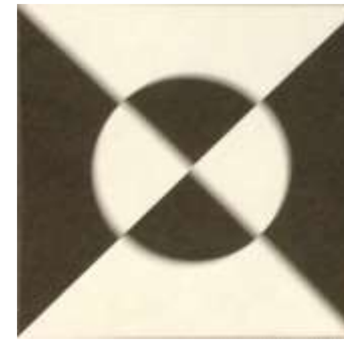


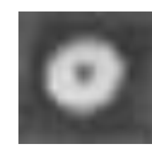


Decision Engine for Structured Data and Unstructured Kernel Detection

- Intensity distributions of actual targets do not fit this assumption
- Kernel smoothing through density estimation is problematic due to finding a suitable kernel bandwidth
- Adaptive kernel smoothing results in unstable modes across all targets (involves a complicated implemented of zero-finding)







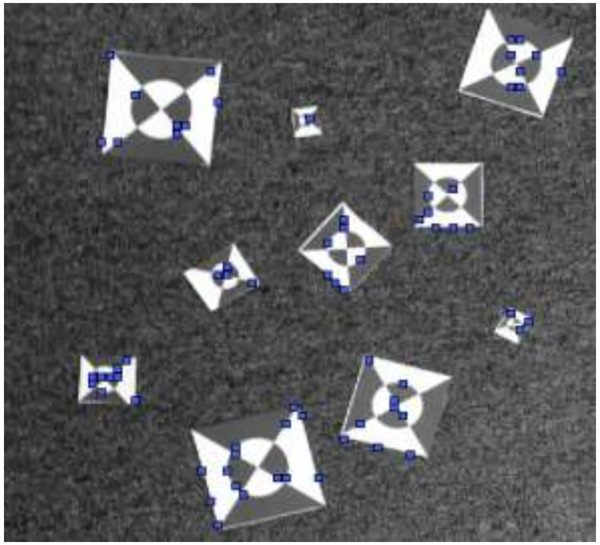
Decision Engine for Structured Data and Unstructured Kernel Detection

- **Following algorithm proved consistent in locating peaks (with mode width and position**

$$I_c = \left\{ i \middle| \begin{matrix} H_i > th \wedge H_{i-1} \le th \\ H_i < th \wedge H_{i-1} \ge th \end{matrix} \right\},$$

$$P_j = \max_{x \in \{H_m | I_c < m < I_{c+1}, c \in 2\mathbb{Z}\}} x$$

- **Feature kernel is defined as a cell that satisfies:**
  - Max(j)=2
  - $PI_1 - PI_2 = th_{sp}$
  - $PI_1 \le th_{p1}$
  - $PI_2 \le th_{p2}$



Decision Engine for Structured Data and Unstructured Region Growing

- **Each region identified by a kernel is grown to find target boundaries**
- **Probability distribution based image thresholding is performed for a sub region of image centered on kernel**

$$T_{x,y} = \begin{cases} 1, & P_2 - a < I_{x,y} < P_2 + b \\ 0 \end{cases}$$

- **Disjointed regions of the same target are connected through a dilation morphological operation**

$$T'_{x,y} = ({T_{x,y}}^c \ominus S)^c$$

Decision Engine for Structured Data and Unstructured Automated Target Position Determination

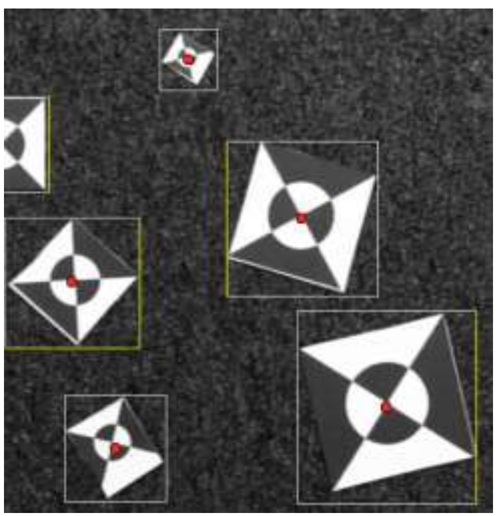
- **Region growing and dilation produce connected regions of a target**
- **Each region is summed and composited to form a binary mask**
- **Mask is processed with 4 neighbor connected component labeling**
- **The centroid method is used to determine target center**
  - Consistent results on smaller targets (size invariant)
  - Resistant to some distortions

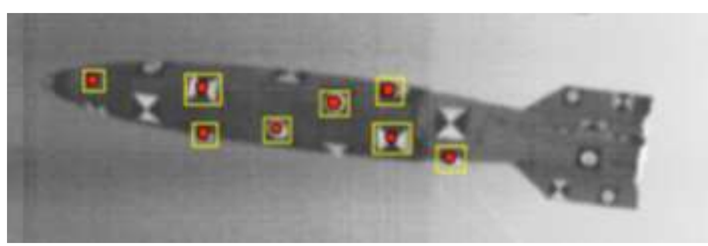
$$x = \frac{1}{M}\sum_{i=1}^{n}\sum_{j=1}^{m} i \cdot I_{ij} \cdot w_{ij}$$

$$y = \frac{1}{M}\sum_{i=1}^{n}\sum_{j=1}^{m} j \cdot I_{ij} \cdot w_{ij}$$

Where

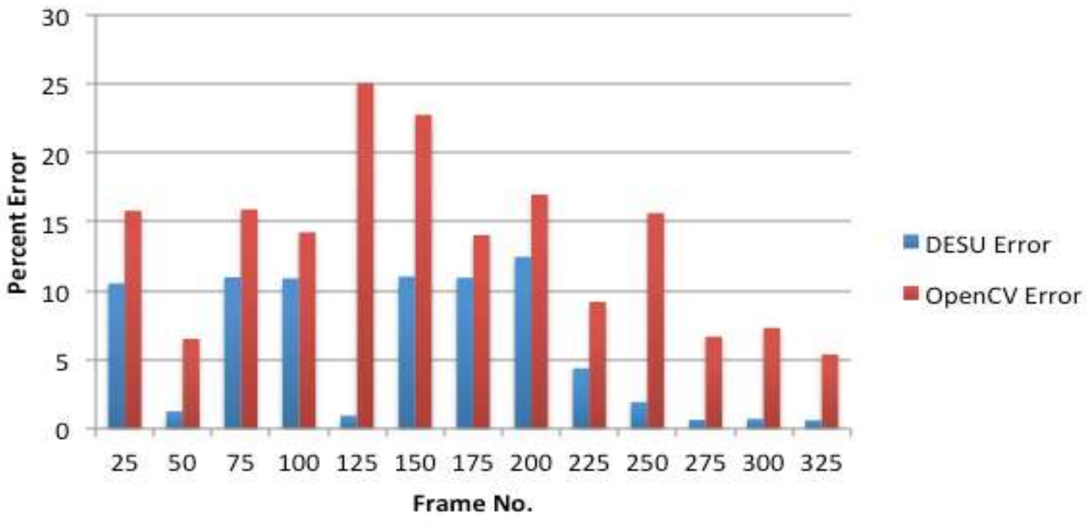
$$M = \sum_{i=1}^{n}\sum_{j=1}^{m} I_{ij} \cdot w_{ij}$$





Performance Benchmarks

- **Performance was benchmarked against Haar classifier**
- **Haar Classifier was implemented with OpenCV**
  - Trained 60 positive targets as ground truth
  - 15 human operators inspected 325 video frames to locate target centers
- **Benchmarking program determined percent error from difference between user input and derived center points for both algorithms**
- **Average improvement in detection accuracy from Haar classifier was 46%**



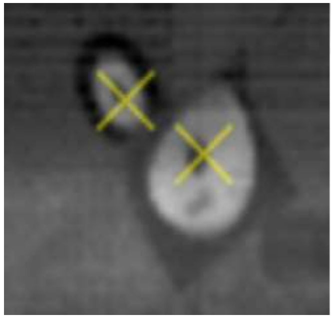
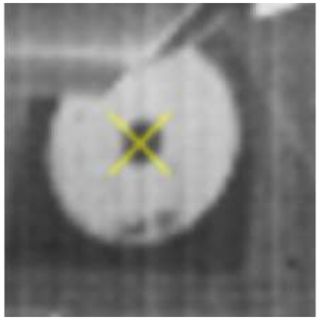
Ongoing Work

- **For close range photogrammetric analysis of varying target types at varying sizes, prior knowledge about targets can boost performance for automatic target acquisition**
- **Sub-pixel accuracy is difficult to accomplish with this technique, but it can serve as preliminary stage in a multi-stage analysis**
- **Signature based analysis can extends this approach**
  - Improve accuracy
  - Detect target type
  - Detect target size

Ongoing Work

- **Centroid based target positioning may result in inaccuracies**


- **Multi-layer analysis that considers temporal gradients and graph analysis can significantly mitigate these inaccuracies**

Ongoing Work

- Layer 0: Kernel detection ✓
- Layer 1: Region growing ✓
- Layer 2: Temporal reinforcement and target detection (acquisition) ✓
- Layer 3: Target identification ✓
- Layer 4: Target inference through motion estimation
  Layer 5: Target inference ✓ through graph analysis
- Layer 6: Target identification through graph analysis (partial)
- Layer 7: Target tracking (partial)

NST & DESU
Points of Contact

- **NST Executing Agent**
  - Mr. Gil Torres
  - 805-989-9521
  - gilbert.a.torres@navy.mil

- **DESU Principle Investigator**
  - Dr. Kofi Nyarko
  - 443-885-3476
  - kofi.nyarko@morgan.edu