Project 5: Aerial Video Processing in Support of Disaster Response

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Overview

- Problem Statement
- Bottom Line Up Front
- Background
- Requirements
- High-Level System
- Operational Scenarios
- Recommendations
- Future Work
- Summary
Problem Statement

• The U.S. Air Force lacks capability to quickly process large quantities of video in support of disaster relief
• Current solution is to have UAV fly over terrain following disaster to gather up to 12 hours of video
• Human analysts watch this video continuously for the duration of video in effort to identify anomalies and/or areas of interest

• Current solution:
  ○ “...death by video” ~ Ms. Biernesser

• Big Data Problem!!!
Existing technology has not advanced to the level required to meet performance metrics for the functional specifications desired by sponsor.
Scope

- Project will focus on developing the high order conceptual design of software that can process 12 hours of video for damage detection
  - “Tell me **how** this could be done” ~Ms. Biernesser
  - “The Air Force has been flying around the forest of this problem and keeps getting smacked in the face with branches” ~Ms. Biernesser

- Project will only concern deriving the feasibility of imagery analysis algorithms and software design
  - No hardware solutions
**Approach**

- **Met with sponsor**
  - Defined problem and scope
  - Developed high-level requirements
  - Identified system restrictions & constraints

- **Literature research**

- **Separated system into 4 stages**

- **Identified project risks and mitigation strategies**

- **Sponsor approved deliverables**
  - Conceptual System Design
  - Feasibility Study
Operational Concept

- Communication Satellite
- Disaster Management Center
- Data Processing (scope of this project)
- Analyst

Air Vehicle

Geographical Terrain
High-Level System Design

Input Stage

Processing Stage

Pairing Meta-Data Stage

Alert Stage

Video Recorder

EO Sensor

Geographical Terrain

Collapsed Structure

Analyst

receives video data

apply damage detection algorithm to detect structural damage

prepare data for analysis

compare to repository of images of damaged structure

compare with prior video footages of same location

identify areas-of-interest and prepare result for analyst

alert analyst
Functional Capabilities

- The system shall accept electro-optical (EO) and infrared (IR) video feeds.
- The system shall process up to 12 hours of video.
- The system shall be able to detect anomalies in video footage.
- The system shall be able to alert users when an anomaly is detected in the video feed.
General System Function

Input:
- Frame grabbing
- Image enhancement

Processing:
- Featured layers
- Define threshold

Output:
- Identify areas-of-interest
Mitigatable Disasters

- **Definition:** Can be forecasted with a certain amount of accuracy before they occur and action can be taken

- **Types:** Hurricanes, Monsoons, Floods, Snowstorm, Human-inflicted

- **This means there’s warning to collect prior-imagery**
Canny Edge Detection Algorithm

- Developed as a means to detect edge lines and gradients for image processing
- Developed in 1986 and still considered state-of-the-art
- Main stages
  - Noise reduction through gaussian filtering
  - Determining gradients of images
  - Relate edge gradients
  - Trace valid edges
  - Hysteresis thresholding
Canny Edge Detection Algorithm
Canny Edge Detection Algorithm

- **Pros**
  - Can run in real time
  - Proven and tested approach
  - Works with color or monochromatic video

- **Cons**
  - Requires tweaking of parameters to get right
  - Requires large amount of processing power
  - Needs previous image for comparison
Un-mitigatable Disasters

- Definition: Cannot be forecasted with accuracy before they occur
- Types: Earthquakes, Wildfires, Drought, Tsunami, Tornadoes, Sinkholes
- **No warning: cannot collect prior-imagery**
Segmentation is one of the most important problems in image processing
- Partitioning an image into a small number of homogenous regions
- Highlights important features to analyze

Applications in geospatial target detection

Region based vs Edge based
- Region methods: Mumford-Shah & Chan-Vese
- Edge methods: Image snakes
Boundary Tracking & Segmentation

- **Learn parameters**
  - Update mean and variance of each region as new points are sampled
  - Sampling Gaussian noise
Boundary Tracking & Segmentation

• **Pros**
  ○ Allows for accurate boundary tracking even in highly noisy images
  ○ Can be used in conjunction with other types of algorithms
  ○ Do not need prior knowledge for image detection

• **Con**
  ○ For high-resolution images, computational times can be long, which can be overcome by doing sub-sampling
Genetic Algorithm
Genetic Algorithm

- **Pros:**
  - Flexible
  - Requires no prior imagery

- **Cons:**
  - Extremely dependent on object definition and characteristics
Algorithm Summary

- **Canny Algorithm**
  - Can run real-time
  - Requires large amounts of hardware and processing power in order to do so

- **Boundary Detection**
  - Can run in real-time however accuracy is 0.62 on f-scale (precision recall)
  - Humans are 0.79

- **Genetic Algorithm**
  - Takes 5-10 seconds per frame - would take 150-300x time of human
Recommendations

- Keep human analysts until technology and cost reach desired levels
- Processing time and accuracy still too slow to compete with speed of humans
- No single algorithm is good for all situations.

Currently best used as a System Support Tool
Summary

- Four key components to processing video: input, processing, meta-data pairing, and alerting
- Mitigatable disasters and unmitigatable disasters
- Recommendation: Keep using current process for videos
- Largest problem: humans are still fastest at processing video while maintaining accuracy
- Future work should focus on processing architectures and hardware
Future Work

- USAF needs to invest in feasibility study of their own to determine if it meets their mission requirements
- Extend further research into the specific algorithms described in CONOPS
- Research algorithms that can identify non-areas-of-interest
- Research hardware design
  - Hardware capability
  - Parallel hardware
Questions??
Back-Up
References

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- Ryan Hruska, Greg Lancaster, Jerry Harbour, Shane Cherry, Small UAV-Acquired High Resolution Georeferenced Still Imagery, Idaho National Laboratory, September 2005
Genetic Algorithm

\[ \text{Fitness}(G) = \sum_{g_i} I_M(g_i) + \sum_k \sum_{(g_i, g_j), g_i R_k g_j} I_{R_k}(g_i, g_j) \]

- Optimal solution maximizes fitness equation
- \( G \) is the gene of interest
- \( I_M(g_i) \) is the estimation function of gene \( g_i \) regarding low-level visual similarity
  - Similarity between the region of interest and an object that’s been described
- \( I_{R_k}(g_i, g_j) \) is the estimation function of spatial similarity between \( g_i \) and \( g_j \) in terms of \( R_k \)
  - Describes how well a relation holds between two regions
Dynamic Processing Allocation (DPA)

- A method for controlling processing to manage computing resources.
- Find a balance between SPEED and ACCURACY.
- Employs both “cheap” and “expensive” processing algorithm.
  - Cheap = less accurate, faster
  - Expensive = >90% accurate, slower; may be human analyst
DPA - How

- Employ second-order Markov model with node and state variable for each frame
- Similar to Hidden Markov Model, the observation of each frame depends on the previous
- Cheap algorithm
  - Background subtraction
- Expensive algorithm
  - Face detection
  - Moving object
- Run cheap algorithm on every frame
- Run expensive algorithm on consecutive uniform intervals of frame

DPA PLANS WHERE TO EMPLOY THE MOST PROCESSING RESOURCES - DIRECTS RESOURCES TO THE MOST RELEVANT PART OF THE VIDEO-
DPA - Algorithm

1. Ex. run cheap background subtraction algorithm on all frames to provide clues as to where areas of interest (bridges, buildings, etc.) are.

2. Uses B' observations from total budget B to make uniform interval observations.

3. Note which interval provides the most reward.

4. Allocate remaining B''=B-B budget to intervals with most reward.

5. Future observations are conditionally independent components before and after the observations (Krause and Guestrin algorithm).

6. Ex. run expensive damage detection algorithm.
Detection results on a compressed video: (a) original image, (b) standard deviations, (c) unimodal model, (d) MOG, (e) Kernel, (f) CB

DPA - Examples of Face Detection

- Top-down knowledge-based method – determines relationship between structural features such as eyes, nose, and mouth.
- Bottom-up feature-based method – seek invariant structural features such as eyebrows, hair texture, and skin color.
- Template-based method – compare faces with input image.

SAME ALGORITHM APPLIES TO DAMAGE DETECTION
DPA - Pros & Cons

• Pros
  ○ Employs multiple algorithms – the best of both
  ○ Balance between accuracy vs speed
  ○ Can be applied to videos with large number of frames
  ○ Can set limit to processing resources

• Cons
  ○ Employs multiple algorithms – complicates logic
  ○ Not as fast as some algorithms
  ○ Not as accurate as some algorithms
  ○ Not for simultaneous capture and processing
General Approach
## High-Level Project Risk

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation Strategy</th>
<th>Likelihood</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short duration of the performance period in the event the schedule slips</td>
<td>Redefine scope as needed to account for period of performance</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Availability of sponsor for feedback on deliverables</td>
<td>Utilize both sponsors to review deliverables</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Availability of desired software packages for developing deliverables</td>
<td>Identify additional software with similar capabilities that are more readily available as well as utilize SEOR labs if available and loaded with desired software</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Availability of SMEs to provide information on work</td>
<td>Work early with Sponsor to leverage any contacts that are available; identify SMEs needed early on</td>
<td>Medium</td>
<td>Medium</td>
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