A Geospatial Complex Event Processing Engine for Abnormal Vessel Behavior Detection Suitable for Maritime Surveillance

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## Introduction

<table>
<thead>
<tr>
<th><strong>Current Status</strong></th>
<th>Modern surveillance systems provide a huge amount of data for near real-time processing</th>
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</thead>
<tbody>
<tr>
<td><strong>Need</strong></td>
<td>Handle large amounts of information accurately and efficiently</td>
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<tr>
<td><strong>Solution</strong></td>
<td>Use an advanced computational rule-based engine (TRITON) for analyzing vessel behavior using the Complex Event Processing (CEP) Paradigm</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Support maritime authorities’ surveillance functions</td>
</tr>
<tr>
<td><strong>Capabilities</strong></td>
<td>Analyze ship position reports in real time using data from multiple available tracking systems</td>
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</tbody>
</table>

- Maritime Radars
- Terrestrial-AIS
- VMS
- Satellite Imagery
- Satellite-AIS
- LRIT
TRITON Service \(^{1/2}\)

- Combines geospatial information and detections from different and distributed sources of information to infer events or patterns that describe the current situation.
- Rule based system for identifying and analyzing motion patterns of ships that indicate an ongoing situation that needs attention.
- It includes a wide set of rules to select, and additionally user can combine rules allowing the detection of extremely complex patterns.
- User can apply rules in specific areas, in specific time periods or dates, and filter out ships based on their identity or type.
TRITON Service \(^2/2\)

- Low latency and high throughput
- Compliance with standards
- Light-weighted in terms of memory, CPU and IO-usage
- Real-time, streaming capable
- Provides enhanced situational awareness and fast response in critical situations
- Supports a wide range of rules for detecting different abnormal patterns
- Highly scalable and can be easily extended with additional features

**Suitable for**

- Border Control
- Counter Smuggling
- Counter Human Trafficking
- Counter Piracy
- Counter Terrorism
- Naval and Joint Operations
- Traffic Safety
- Maritime Search & Rescue
- Crisis Management
- Port Control
- Pollution and Safeguarding of Environment
- Protection against Illegal Fishing

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Complex Event Processing

- Is the method of processing large volumes of incoming events in real time and detecting when there is an abnormal behavior using specific rules
- Events are arriving in a streaming fashion
- Pattern recognition is accomplished by applying queries over the streamed data
- TRITON is using the open source Esper platform to provide native CEP capabilities
- Queries are implemented using the Event Processing Language (EPL)

```
 averVelocity := select getAverageVel(window(vessel), currentVessel) 
               from VesselEvent as vessel where vessel.ID = currentVessel.ID

 select currentVessel, averVelocity from VesselEvent(isInArea(currentVessel), 
               isType(currentVessel), hasId(currentVessel), isActive()) as currentVessel
```
TRITON Service Architecture

AIS
Automatic Identification System

Camera

Video Analytics

Maritime Radar

Other

AIS Tracks

Tracks

Radar Tracks

Track Correlation and Fusion

Stored Rules

Suspicious Vessels

Areas of Interest

Fused Tracks

TRITON Geospatial Complex Event Processing Engine

Alerts

HMI

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Supported Rules

- Geofence (entering or exiting area, crossing area or borderline, approaching or moving away from area, borderline, location)
- Contact Lost, AIS Transmission stopped, AIS Spoofing
- Inconsistent Kinematic Attributes, Time-space incompatibilities
- Suspicious Vessel Detection
- Abnormal Course/Speed Change
- Loitering, Drifting

- Vessel’s Domain Violation, Imminent Collision of ships
- Exceeding speed limit, Average velocity over/under threshold
- Vessels crossing routes, Track Splitting
- Vessels sailing in group, small vessel approaching or moving away from larger vessel
- Low or High AIS Transmission Frequency
- Combination of rules
Rule Examples 1/3

Abnormal Course Change

Vessels Crossing Routes

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Rule Examples $\frac{2}{3}$

- Small Vessel approaching larger vessel
- Vessels sailing in group

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Rule Examples $^{3/3}$

- Track Splitting
- Inconsistent Kinematic Attributes

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Simulation using Splines

- Given a set of control points $q$ that form a route
- Estimate interpolated trajectory as a set of cubic splines (polynomials of degree 3)
- Ensuring continuity of velocities and accelerations at control points $q$

\[
s(t) = \{ q_k(t), t \in [t_k, t_{k+1}], k = 0, \ldots, n-1 \}\]
\[
q_k(t) = a_{k0} + a_{k1}(t - t_k) + a_{k2}(t - t_k)^2 + a_{k3}(t - t_k)^3
\]
\[
T = [T_0, T_1, \ldots, T_{n-1}]^T
\]
\[
q = [q_0, q_1, \ldots, q_n]^T
\]
\[
A(T) \cdot v = c(T, q, v_0, v_n)
\]
Simulation Input – Routes and Ports
Simulation Configuration

- Random number of ships inside ports
- Random passenger or high-speed ships in ferry routes
- Random tankers and cargo ships in shipping lanes (100 per direction)
- Additional random fishing boats, pleasure crafts, sailing boats and radar contacts were included in custom routes

2378 Vessels, 294 Passenger, 1130 cargo & tankers, 80 pleasure crafts, 50 fishing boats, 44 radar tracks
Simulation Output – Generated Vessels
CPU and Memory Utilization

CPU Utilization

Memory

Memory Usage (MB)

Commercial in confidence
Events Statistics

- Simulation Duration ~ 6 hours
- Total number of events created: 1,955,548
- Total number of alarms: 129,768
Marisa Project

- Service was demonstrated in the Aegean and Ionian Sea Trials (Phase 1 – Completed, Phase 2 – November 2019)

@EU_H2020 #H2020 @MarisaProjectEU
Conclusions – Future Work

❖ A highly Efficient Abnormal Vessel Behaviour Engine based on the CEP paradigm
  ❖ Robust
  ❖ Real Time
  ❖ Low Latency
  ❖ Scalable
  ❖ Recognize many patterns
  ❖ Easily extended by adding even more rules
  ❖ Supports a wide range of maritime applications

❖ Future Work
  ❖ Use reinforcement learning to build a trainable agent that can recognize specific patterns and can distinguish normal behaviour from abnormal
  ❖ Use historic data to learn and estimate parameters that describe behaviour

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