A Nuclear Plume Detection and Tracking Model for the Advanced Airborne Early Warning Surveillance Aircraft

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Introduction

- It is important to detect and track the radiation plume from a nuclear detonation.
- Traditionally, the detection of radiation from a nuclear explosion is by using the Geiger counter.
- This technology is only useful at short range.
- For radiation detection from long distance and high altitude, a new technology is needed.

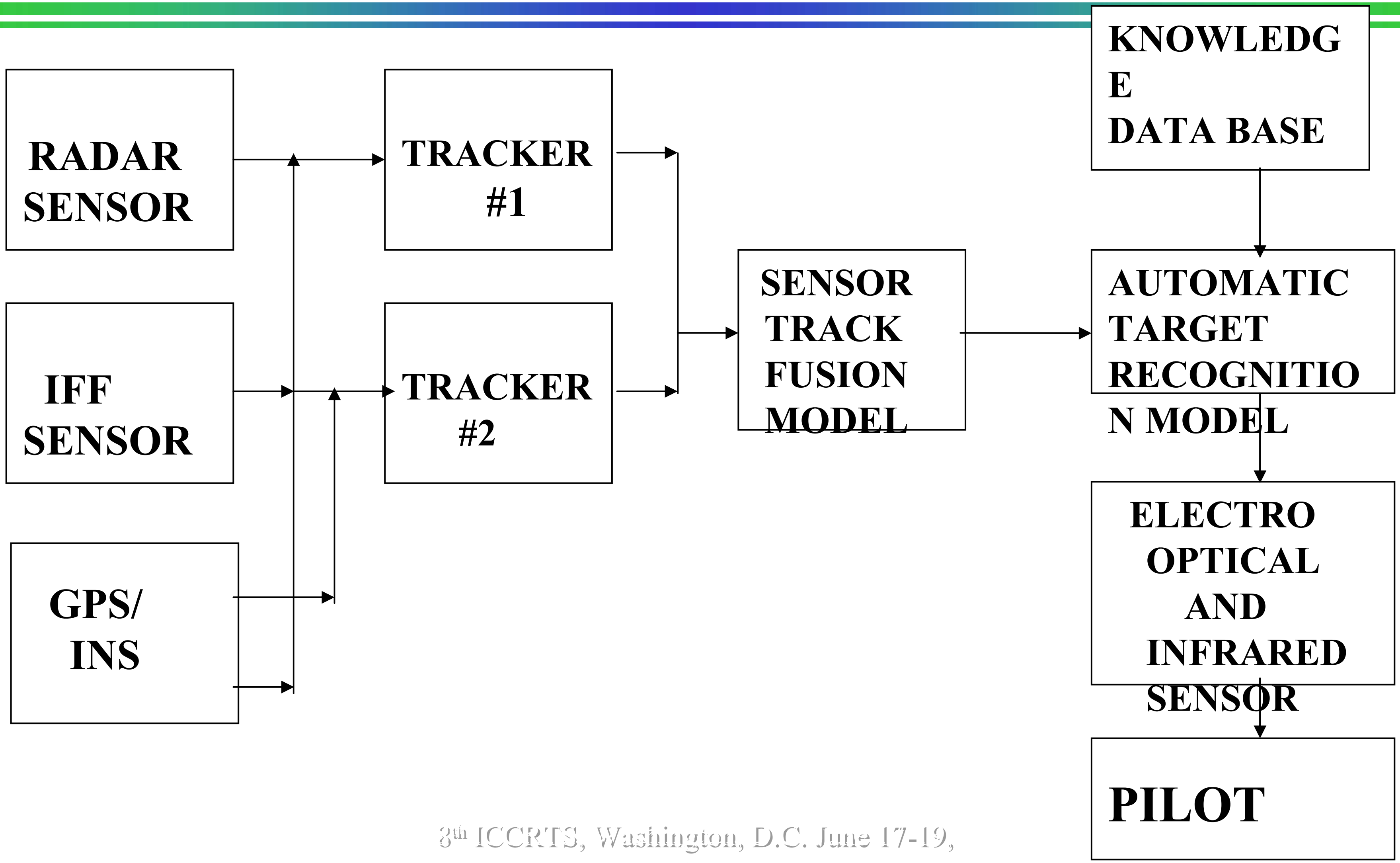
Introduction …

- A new concept and means of nuclear plume detection and tracking (NPDT) model for the advanced surveillance aircraft is introduced.
- The model consists of three major components:
  1) Detection and tracking of multiple targets by using a radar sensor and IFF sensor fusion tracker, such as the widely used Extended Kalman Tracker with Multi-sensor Track Fusion technology,
  2) Use of a Knowledge Data Base to store air target characteristics, and

Introduction …

3) Use of statistical pattern recognition technique with the modified Bayesian model to classify target tracks and identify the nuclear plume.

Architecture of the NPDT Model



Radar Sensor

- Airborne early warning aircraft must be equipped with a search radar.
  - Detect multiple air targets at long range.
  - Include a preprocessor to provide processed target reports.
  - Target reports must include azimuth, elevation, range, and range-rate of the targets.
  - Reports will be processed by NPDT in real-time.

IFF Sensor

- Airborne Early Warning aircraft must be equipped with an Identification Friend or Foe (IFF) sensor.
  - directional transmit/receive antenna slaved to the search radar antenna to interrogate targets simultaneously with radar reporting.
  - interrogate all targets in the area to provide position, mode code, and altitude.
- sensor fusion technology described below will actually make the determination of which radar and IFF target reports are the same target (determine which target).

Inertial Navigation System and GPS

- Airborne Early Warning aircraft must be equipped with INS/GPS.
  - Provides ownship position and attitude to the NPDT mission system.
  - Provides ownship latitude, longitude, course, speed, and acceleration.
- Information will be used by the NPDT in real-time to translate radar and IFF target reports into ground stabilized position, velocity, and acceleration. NPDT needs this for real-time sensor fusion.

Electro-Optical / Infrared Sensor

- Airborne Early Warning aircraft must be equipped with camera system.
  - Needs both Electro-Optical and Infrared imaging.
  - Provides additional tactical identification capability to the pilot.
- NPDT system is designed to automatically direct the camera to any detected nuclear plume, thus giving the pilot an immediate visual and infrared view of the event.

Radar Tracker

– The radar tracker is based on the extended Kalman filter tracker.
  - It is widely used by surveillance and fighter aircraft.
  - Current radar tracker consists of the following information:
    – initial target state vector.
    – initial state covariance matrix.
    – kalman gain matrix.

Radar Tracker . . .

– chi-sq test.
– updated state covariance matrix.
– updated target state vector.

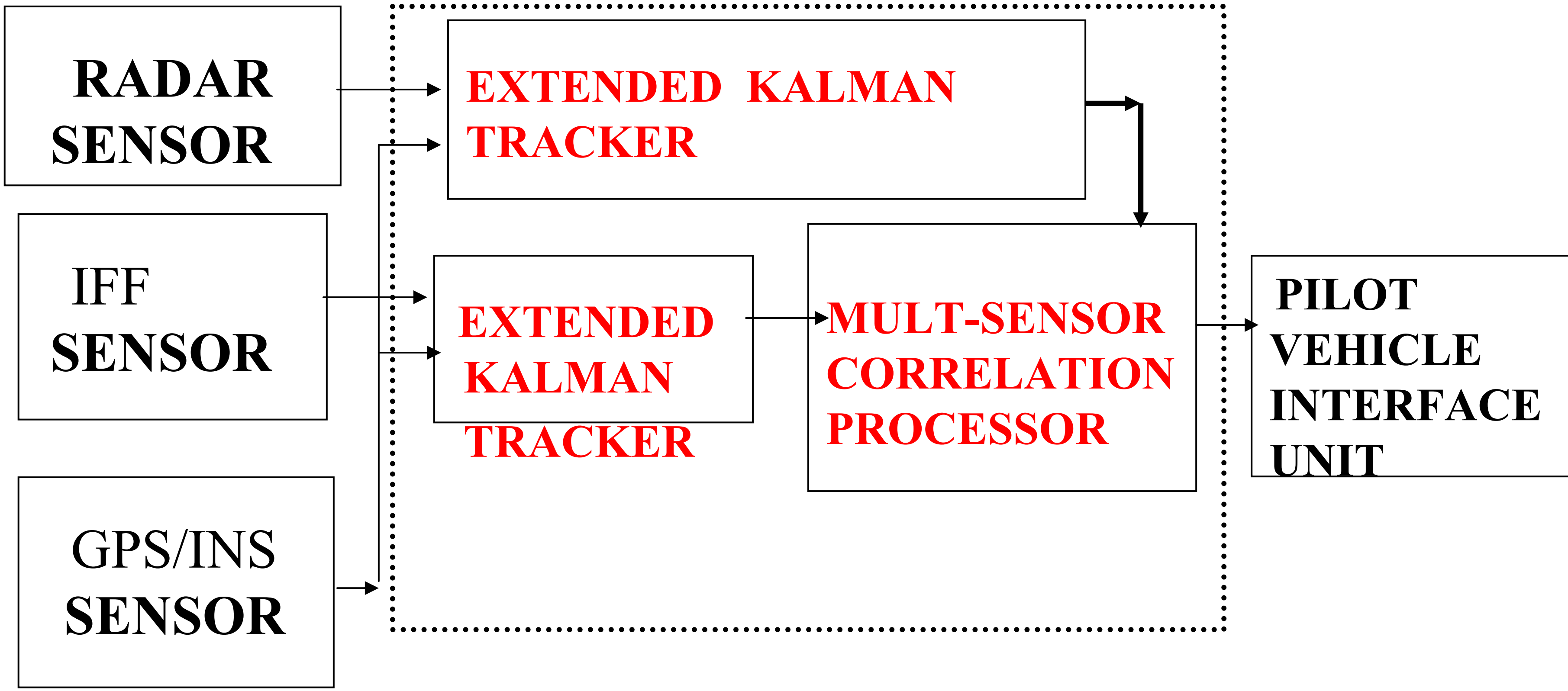
IFF Tracker …

- The IFF tracker is a digital tracker:
  - different from the traditional tracker.
  - does not rely on any particular frequencies.
  - input to the IFF tracker is azimuth angle and range.
  - output of the IFF tracker is the target state vector.

Extended Kalman Tracker

- The Extended Kalman Tracker expects an input vector extracted from a radar report by pre-signal processing.
- The input vector generally contains target elements such as range, range rate, azimuth angle and elevation angle.
- In general, radar reports provide very accurate target information.
- The output vector generated by the Extended Kalman Tracker contains very accurate target information, such as three dimensional target position, velocity, and acceleration

Sensor Track Fusion Model



Multi-Sensor Track Fusion Model

- The objective of the Multi-Sensor Track Fusion Model (MSTFM) is to generate the fused track from the radar tracker and IFF tracker. The fused track is the integrated target track from the radar and IFF track.
- The Multi-Sensor Track Fusion Model consists of (radar sensor, IFF sensor, and GPS/INS sensor), Extended Kalman Trackers, and Multi-Sensor Correlation processor.

Multi-Sensor Correlation Processor

- The Objective of the Multi-Sensor Correlation Processor (MSCP) is to estimate the relationship between target state vectors X and Y.
- Suppose that one target state vector X is detected by radar sensor and the other target state vector Y is detected by IFF sensor. The Multi-Sensor Correlation Processor will calculate the correlation coefficient between target state vector X and target state vector Y.
- If the correlation coefficient between X and Y is one, then the target X and target Y can be identified as the same target. If the correlation coefficient between target X and target Y is zero, one can conclude that target X and target Y are different types of target.

Statistical Pattern Recognition Model

- How can one discriminate a nuclear plume from an unknown air target? This is a typical statistical pattern recognition problem and the object identity can be found by applying the Bayesian probability model.

Knowledge Data Base

- Any database containing true information about target parameters can be defined as the Knowledge Database.
- For example, in our particular database, there are two distinct types of target parameters, one is air target characteristics and the other is nuclear plume characteristics.
- In this database, each target parameter contains a target state vector with elements such as Latitude, Longitude, Range, Range-Rate, Bearing, Velocity, Course or direction, altitude and Minimum Detection Yield.

Simulation: Example #1

– Determine if target X and Y are the same target

- Given

  X = { 5.0,10.0,75.0,60.0,1.0,150.0,75.0,20.0}

  Y = { 5.0,10.0,75.0,60.0,1.0,150.0,75.0,20.0}

- Consider

  "X" is from radar tracker.

  "Y"is from IFF tracker.

- Since R_{XY}=1.0
- Therefore "X" and "Y" are the same target.

Simulation: Example #2

– Test if the unknown target X is a nuclear plume

- Given X = { 5.0, 10.0, 75.0, 60.0, 0.0, 150.0, 75.0, 20.0 } ("X" is from STF Model)

– Y = { 5.0, 10.0, 75.0, 60.0, 0.0, 50.0, 75.0, 10.0 } ("Y" is from KDB Model)

– Apply the Modified Baysian Model, we have:

– $D = (X-Y)T*\Sigma-1*(X-Y) = 10100.0$

– Since D is a non-zero number, therefore "X"

– is not a nuclear plume.

Display

- Figures 3 and 4 show some of the fused track results from Radar and IFF tracker.
- These fused information will provide the pilot integrated, real-time technical information which can be used for making decisions.

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Figure 3

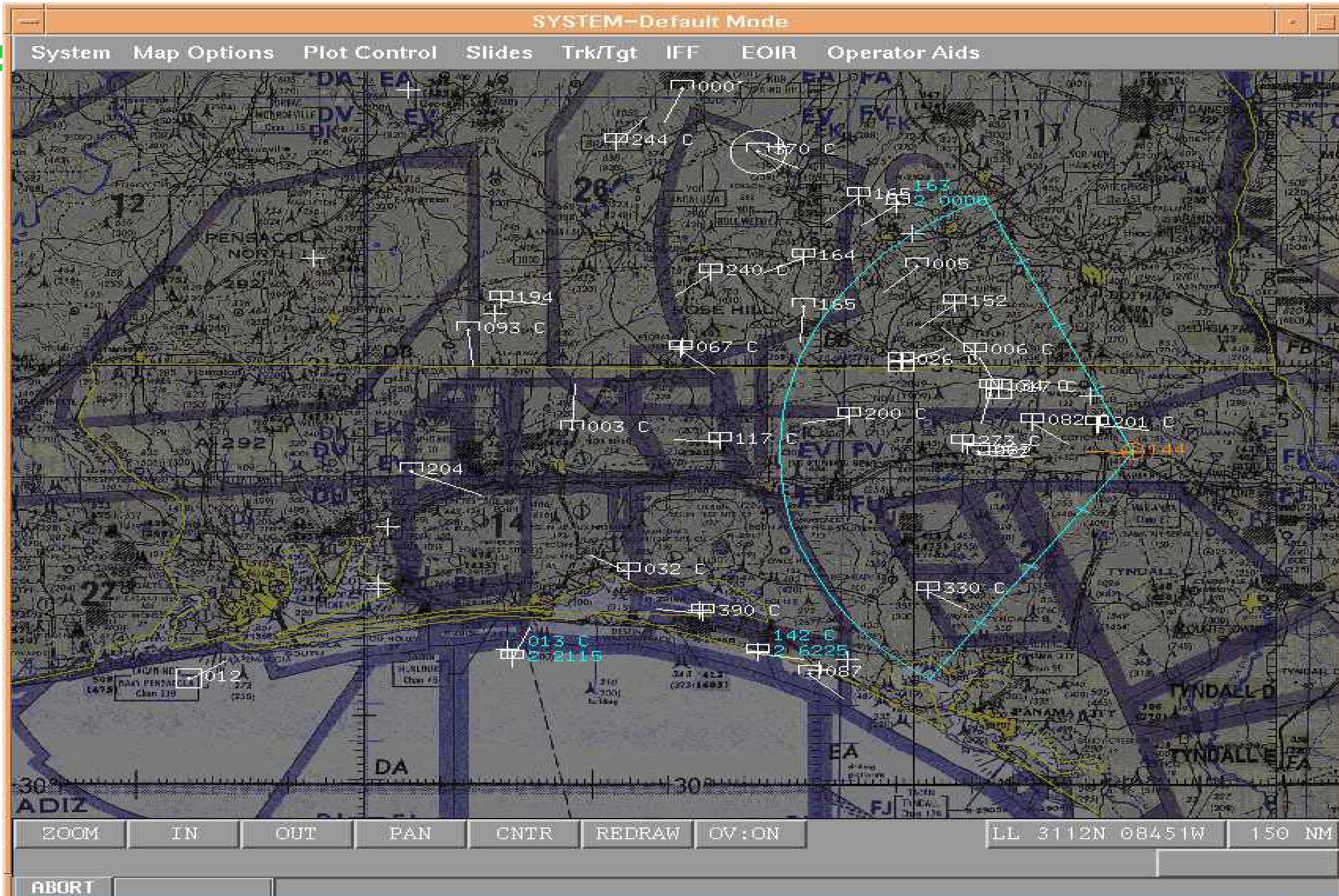

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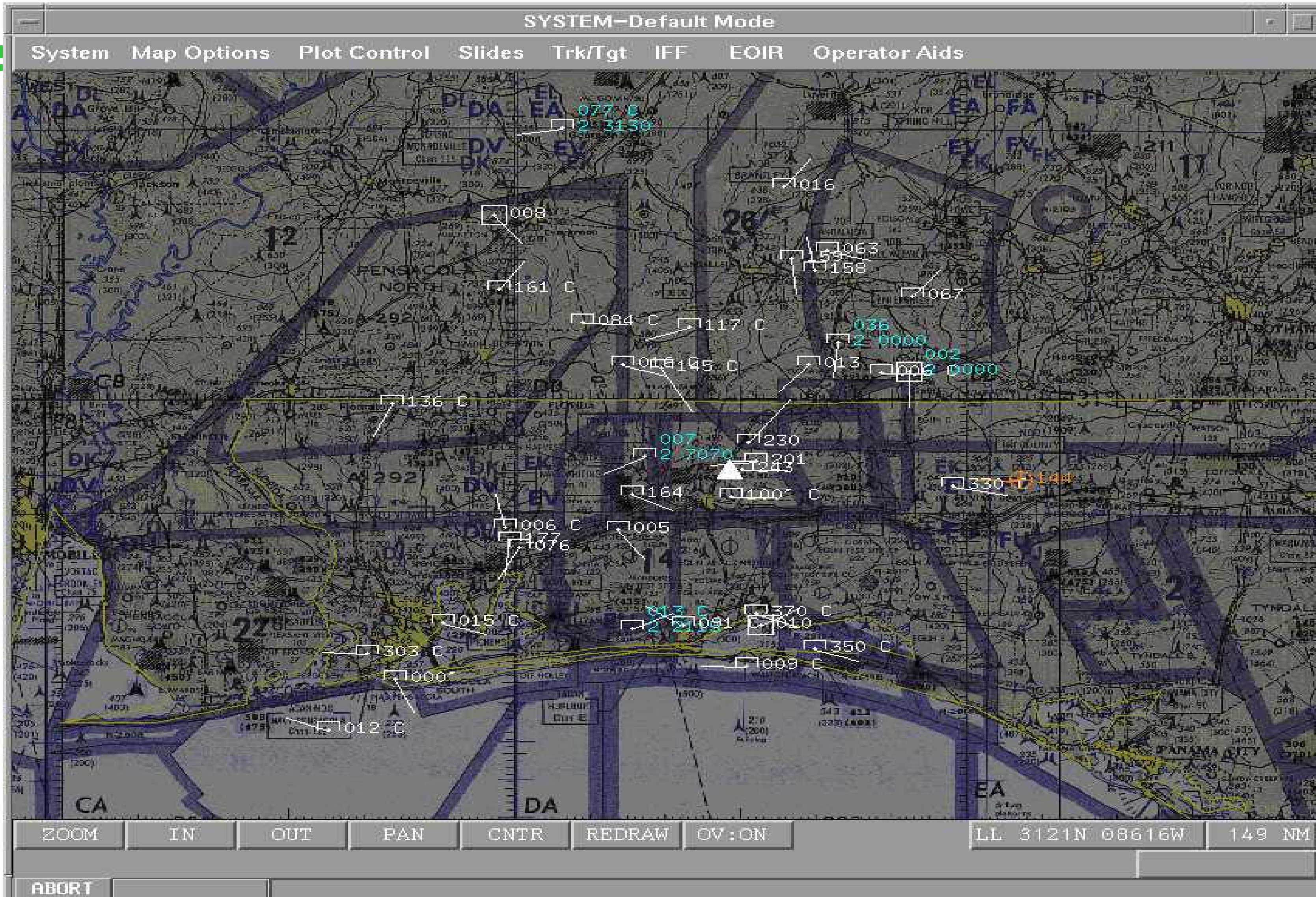
Figure 4



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Conclusions

- The new technology introduced in this paper, consists of three distinct concepts:
  - (a) multiple target detection and tracking with IFF sensor, Radar Sensor and GPS/INS sensor, and Multi-Sensor Track Fusion;
  - (b) discriminate nuclear plume from general air targets by using Statistical Pattern Recognition techniques with Knowledge Data Base; and
  - (c) EO/IR sensor provides visual information to the pilot who will have the power to make the final decision.

Conclusions …

- The sensor track displays verified the concept of target detection and tracking and sensor track fusion.
- The four simulation cases verified the concept of nuclear plume discrimination. According to the International Monitoring System (IMS), the measurable characteristics of the nuclear plume is the Minimum Detectable Yield , which is a function of the Minimum detectable concentration of Xenon-135 and Barium-140.

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Conclusions …

- The release of these Radio isotope radionucleides during the nuclear explosion, makes the nuclear plume detection and tracking from the advanced surveillance aircraft at 200 nmiles and 40000 feet is feasible.
- We only explored a concept of detection and tracking a nuclear plume, and provided simulated information. There is no real time data to support our claims, because nuclear explosions are a rare event, no one wants to see it happen.

Conclusions ...

- More research work should be concentrated on how the characteristics of the nuclear plume are measured in addition to the feature vector with elements such as latitude, longitude, range, range-rate, bearing, MDY, ground speed and altitude.
- New parameters such as temperature, and size of the plume should be included. The new feature vector for the nuclear plume may enhance the detection and tracking of the nuclear plume.

Questions & Comments

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