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Industrial Trends in Development of Target Mapping Interface for Passive Radar Systems

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ABSTRACT

Passive emitter location systems have a wide range of applications most importantly in military due to its stealth and precise location capability of threats. Two approaches are followed for emitter location estimation, either to use a single mobile detection system or to use multiple static platforms for signal reception. Direction/angle of arrival and various range estimation techniques allows target localization. Mapping interfaces are used to provide a visual interpretation to the mathematical results. In case of multiple platform systems the mapping module also provides triangulation capability. In this paper we have discussed various trends that are persisting in the form of features incorporated in the target mapping modules, different techniques to extract the information from the Passive emitter location system and to bring it on the visual panel. Various passive emitter systems have been considered and their target mapping modules are compared with respect to different benchmarks.

Index Terms: Passive Radar, User Interface, RF Signals Triangulation, Electronic/ Communication order of battle

I. INTRODUCTION

THE passive emitter location systems are used to find position, heading and nature of the emitter utilizing electromagnetic waves generated by the target. The main advantages being the capability of passive operation with hidden receiver with the reason that now a days it is becoming more and more dangerous to locate and track moving targets by means of active radars due to the development of Electronic Counter Measures. Moreover it is designed in such a way that it is difficult to visualize it as radar compared to the conventional active radars making it suitable for the use as a sensor providing surveillance and security in the sensitive infrastructure. The active radars being expensive are also venerable to detection thereby compromising the sensitive locality. The properties of passive radar make it ideal candidate to provide surveillance in the area of sensitive infrastructure, detecting all movement in the protected area. [1]

The position of a transmitter or a radiating emitter can be estimated from passive measurements of the arrival time, Doppler shifts or directions of arrival of electromagnetic waves received by the observation stations. [2]

After calculating DOA for the detected signals the goal is to estimate the position of the received signals for which each passive emitter locator is provided with a Geo-Mapping module. The module allows triangulation under the geographical coordinate systems and to display the results on geographical base maps. This provides a practical and on ground information about the target with the provision of adding symbols for identification and various overlays providing valuable information.

Various schemes are followed in the composition of mapping interfaces. They depend on the application of radar along with the kind of information needed to be extracted.

This paper covers trends in the composition of currently developed geographical or mapping user interface. These trends are analyzed among various commercially available systems. Further basic modules that form the mapping interfaces are also being discussed in detail.

II. SIGNIFICANCE OF MAPPING INTERFACE IN PASSIVE EMITTER LOCATION SYSTEMS

The emitter location systems are designed to pin point the EM transmitter location with respect to the receiver stations. The RF receiver part of the system intercepts EM waves and based on its algorithmic processing calculates direction from which signal is intercepted along with the power of the signal. Based on this information from minimum two and preferably three receiving stations, the target can be triangulated for its location using the simple trigonometric equations for planner geometry. Generated results can then be plotted on simple graphing displays with distance units as axis parameters.

But simple triangulation has limitations because;

1. It cannot provide geographical distances of the target from the receiver stations;
2. It doesn't take into account the curvature of the earth in its calculations

In addition for the display of information using simple radar plots will not allow;

1. In depth information of the target area for command and control
2. The tactical situational picture of the area
3. The creation of EOB(Electronic order of battle) and COB(Communication order of battle) schemes

So for display and triangulation part of the passive radars each commercially available system is provided with a Geographical Mapping module. This module is developed with the aim to provide the geographical features in calculations as well as in user display.

A. Role in Aerial Target Localization and Tracking

In case of aerial targets intercepted by the passive emitter locator, the main role of Geo-Mapping module is to triangulate its inflight position based on 3D- Global geometry. For this the flight path is calculated based on earth curvature and to further elaborate the picture DEM and DSM (Digital Elevation and surface Models) models are included as shown in Fig.1. This allows the monitoring personnel to have a holographic situation of the target and to predict its path in case of low flight e.g. UAV case using the terrain models.

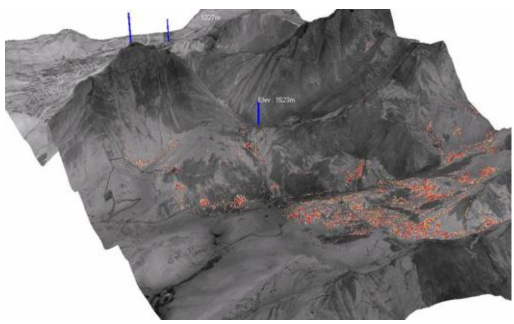

Fig. 1. Three dimensional view of the terrain for aerial targets localization [13]

B. Role in Ground Target Localization and Tracking

For ground based target localization, the role of Geo-Mapping module is emphasized by the shear amount of reflections that exist causing errors in the triangulation. To handle this issue, use of signal power analysis along with the terrain information and surface models used in the mapping applications proves a valuable source.

Additionally in case of ground based locators the sheer number of communication links active at a time is immense. Keeping a track of all the communication nodes with signature analysis suggests the need of a separate logging and mapping module.

III. MAIN MODULES IN MAPPING SYSTEMS

The mapping Modules incorporated in the emitter locator systems have some common parts which are used by most developers. These parts serve the basic functionalities of geo-processing and user interface.

A. Navigation Controls

These controls are the tools for operator to interact with the user interface. They include *PAN Control* for moving the current view of basemap in any direction, *Zoom Control* for changing the scale of view of the basemap; *Direction Control* for keeping the view referenced to the north; *Scale Indicator* showing the current scale of the map. [3]

B. Map Layers

Map Layers hold different information in it and are stacked together to be displayed at once with the provision of removing one or more layers from the stack as shown in Fig. 2.

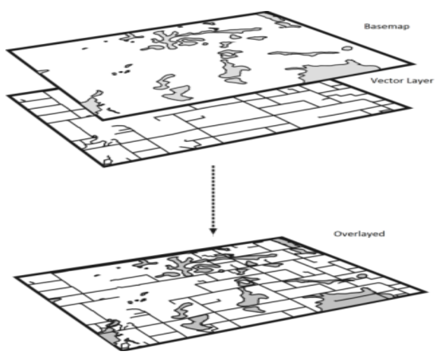

Fig. 2. Map Layers overplayed to give comprehensive information

Basemaps form the lowest layer in the stack, while other layers are placed on precedence basis. Layers listed below are placed according to the hierarchy in layering architecture of GIS systems.

1) *Base maps*

The first layer is composed of geographical maps that form the reference for all the layers stacked as shown in Fig.3. The base maps vary according to its requirement,

application and locality.
In the case where localization is intended in an urban terrain street maps are mostly used while in case of sub-urban and rural areas topographic maps in conjugation with satellite imagery are mostly used. For remote area tracking and localization topographic maps are used. [3]

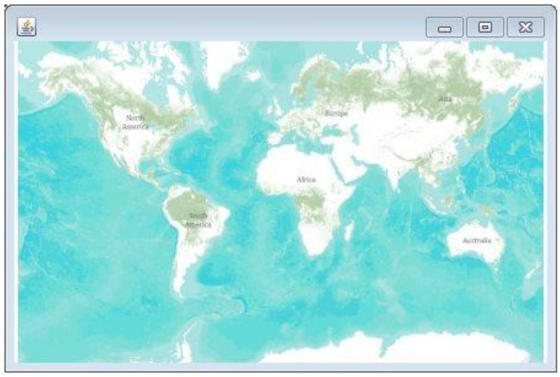

Fig. 3. Basemap deployed for overlaying the information

2) Symbolization and features

Symbolization layer is used to show different point of interest and also to represent various targets that are detected. Most widely used symbol schemes includes NATO [4] symbols and MIL Standard [5] Symbols.
In addition to symbols different features in the form of line/ points and polygons are also used to represent different areas like No fly Zones, restricted areas and sensitive installations. Features are also used in the marking of different movements and placements of EW stations marking their effective ranges.

3) Operator Markings

These are different from the symbolization layer where symbols are chosen from a predefined library or user can create features of specific shape. In the operation phase the operator needs to make real time spot markings of either temporary nature or just to highlight some local phenomenon; for this custom marking layer is included in the current Geo-Mapping modules. It allows more control and interactive environments to the operator and eases the information display for ongoing events.

4) Tracking

In both ground and aerial applications, the tracking part is the main feature of emitter location systems. The Tracking layer displays the results of this feature as shown in Fig.4. This includes;

a) Tracking the path of all the mobile receiver stations

b) Tracking the mobile targets both ground and aerial and providing their mobility parameters

5) Triangulation Results Display

Localizing the target to a point or an area is done through triangulation of the received signal's DOAs and its result is displayed in the triangulation layer. The results are mostly shown in the form of intersecting lines with estimated position at the point of intersection.

C. Triangulation Processing

It is the core mathematical module which computes estimated location of the target based on the angle of interception of the receiver antennas. Module also incorporates geographical parameters for the area of operation in its calculations.

D. Track Recording and Databases

Information about all the targets is saved in databases for analysis and re-drawing the old scenarios. This allows identifying the unknown signals by comparison with the saved signatures. This is also valuable in quick separation of emitters into friend and foe categories.

E. Offline Analysis Module

Data analysis and knowledge gain is the key in modern world systems. Offline analysis module developed for this purpose provides offline analysis of the interceptions, their nature, either they are friendly or unknown and then to categorize their signatures for reference.

IV. TRENDS IN INDUSTRY DEVELOPED SYSTEMS

In this section we shall discuss the trends in the Geo User interfaces and processing units for various industry products available under the banner of Emitter localization systems. Products from the past three decades are considered in this analysis.

F. Trends in Aerial Target Localization Systems

6) CETC DWL002 Passive Detection System

DWL002 Passive Detection System [6] is used in air-defense or seashore monitoring to perform the detection and location to airborne, ship borne or land based emitters and displays the target flight path in real time. The user interface module of the system as shown in Fig.4 contains,

Fig. 4. Mapping display showing tracks of CETC DWL002 Passive Detection System

i. Simple topographic maps with area markings
ii. No triangulation overlay
iii. No modern military standards implemented
iv. Localization stations symbols overlay
v. Tracking capability and path analysis

7) Lantan/Almaz-Antey Valeria ELINT and Emitter Locating System

The system [6] is intended to detect, track and identify airborne emitters, including radars and support jamming aircraft, from VHF to the Ku/Ka bands. Since the system is from early 90's not much sophistication can be seen in the Geo-Interface module as shown in figure. The module has a simple world boundary vector interface with emitters and targets plotted as shown in Fig.5.

i. No display controls are available
ii. Layering architecture contains just the two main overlays with custom symbols.
iii. Tracking capability is not stated by the manufacturer
iv. No triangulation display as an overlay
v. Offline capabilities are limited to data basing

8) Topaz Kolchuga Systems

The Topaz Kolchuga is a long range direction finding Electronic Support Measures receiver system and can

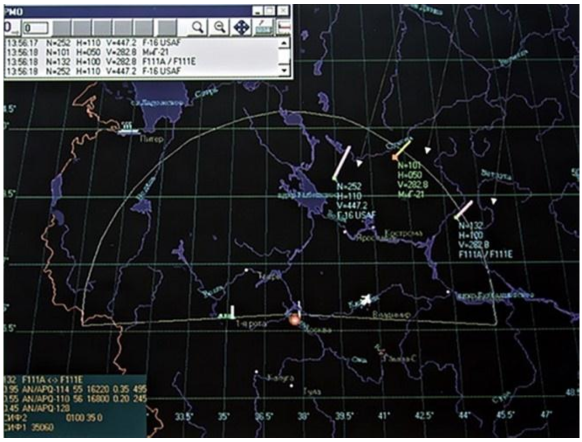

Fig. 5. Mapping display of lantan/almaz-antey valeria elint and emitter Locating System

Fig. 6. Topaz Kolchuga direction estimation system consoles

provide the functions of an Emitter Locating System using triangulation and DTOA techniques. The geo-localization module of the system shows considerable improvements as shown in Fig. 6 and provide;

i. Area based maps with cartographic, roads and area markings
ii. The triangulation is provided with overlay on the basemap
iii. Data basing capabilities with log for the tracks
iv. Path tracking of the air borne targets for analysis
v. On screen analysis capabilities for the operator

G. *Trends in Systems for Ground based Application*

9) Rockwell Collins DF-500 direction finder

The DF-500 [7] can provide the bearing to a COSPAS-SARSAT as well as its beacon's latitude and longitude, along with its unique identifier, at ranges up to 116 nautical miles. When the system is used in movement or during short stops, post processing software displays several azimuths on digital map for more precise localization of radiation source.

The user interface in this case is equipped with mapping features as shown in Fig. 7 including;

i. Receiver station movement based target direction plotting
ii. Target localization and tracking
iii. Basemaps with provision of radar display
iv. Receiver station and target symbolization
v. Colored display for DOAs to track the previous results

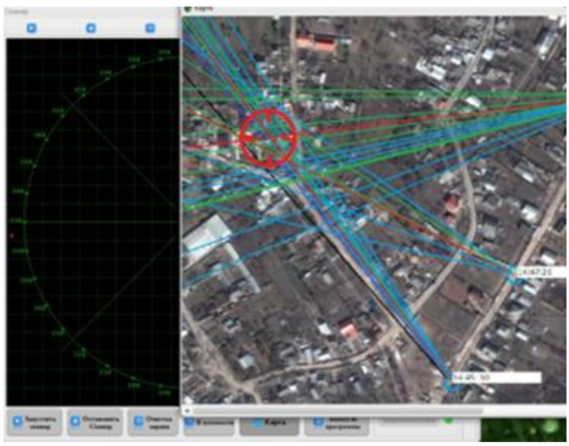

Fig. 7. DF-500 direction finder mapping unit display

10) SwRI's SABER

SwRI's SABER system [8] has been deployed with U.S. troops to provide battlefield situational awareness in support of several operational missions.

The Main features in its mapping unit displayed in Fig.8 include;

i. Terrain based Basemaps with controls for navigation
ii. Tracking capability
iii. Tactical situation picture design capability
iv. Stations and targets symbols
v. Different operator modes for situations

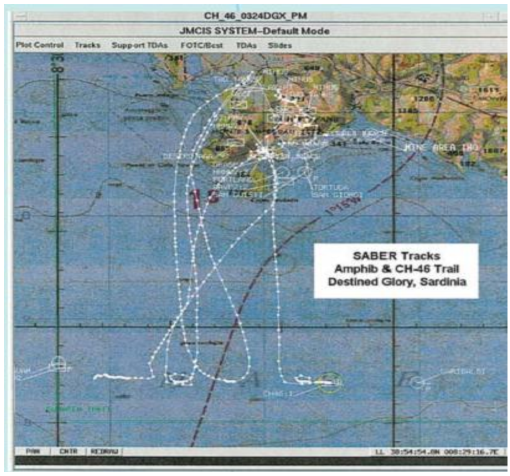

Fig. 8. SwRI's SABER tactical situation analysis software

11) ISOCDF Integrated Surveillance and Observation Center

ISOCDF [9] is a solution designed for radio direction finding (DF) and locating transmission sources. The system may also display transmitters and their location on the map. This works in conjunction with the station information database as shown in the Fig.9. Other main features includes

i. Triangulation display for targets
ii. Receivers and targets symbols view
iii. Area of interest basemap with geo tags and area markings
iv. Tracking capability
v. Data basing capability for offline access

Fig. 9. ISOCDF triangulation module display unit

12) MEDAV Direction Finder-

The mapping package provides an interface for intercept systems (e.g. ARS-8000) to direction finding capabilities (MDF) [10]. Main capabilities as shown in Fig.10 are;

i. Simple basemap with geo tagging
ii. Targets sorting and symbol capability
iii. On screen analysis
iv. Layer control feature
v. Operator view switching capability

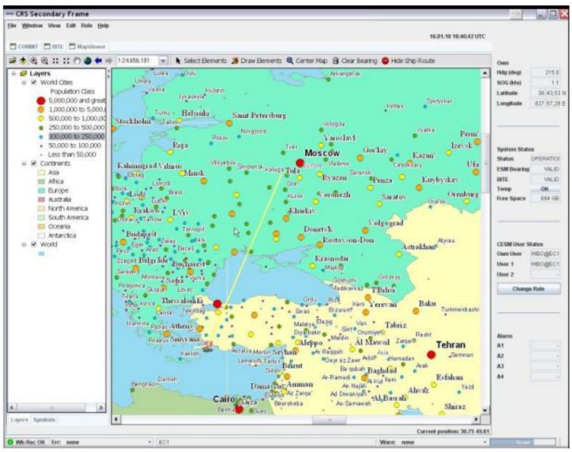

Fig. 10. MEDAV Direction Finder display unit

13) SigMon Transportable Spectrum Monitoring System

SigMon [11] provides RF Spectrum Monitoring, direction finding and geo-location from fixed site, vehicles and portable applications. The mapping module as shown in Fig.11 provides;

i. Street view based base maps
ii. Colored target DOAs for previous results
iii. Layered architecture with layer control
iv. Simulation capability for offline use
v. Operator markings capability
vi. Data basing and retrieving capability
vii. Symbols for on map sites and stations

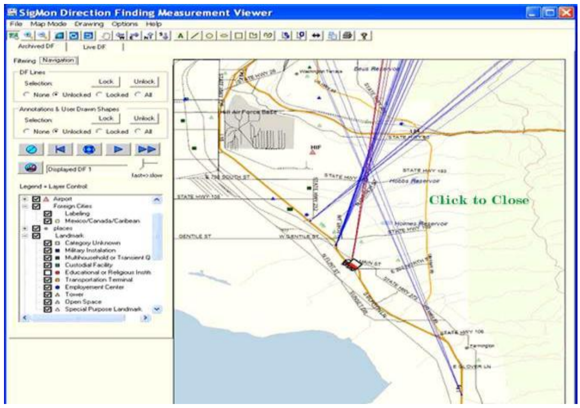

Fig. 11. SigMon Direction Finder display unit

14) Rhodes and Schwartz System R&S Map View

The software [12] is used to display geographic data on digital vector and raster maps. R&S Map View shown in Fig.13 is primarily designed for radio monitoring and radiolocation applications. The module includes,

i. Multiple switchable Basemaps
ii. Navigation controls included
iii. Layer control and layer add/shift feature
iv. Stations and target symbols view
v. Modern military standards integration
vi. Operator marking facility
vii. Data basing and offline access capability
viii. Simulation and tracking features

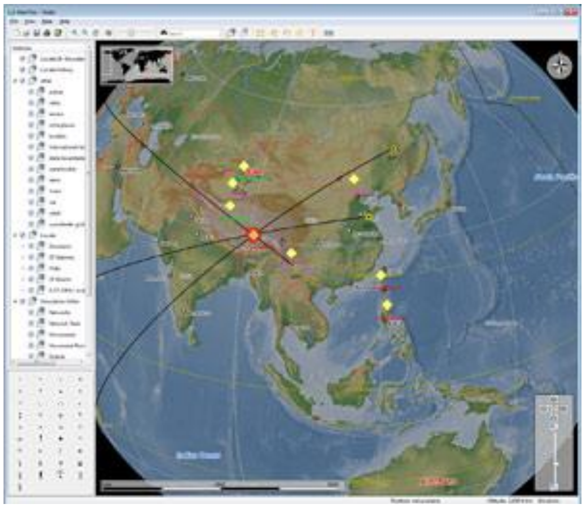

Fig. 13. Map View module for Geographical display of data

TABLE I

COMPARISON OF FEATURES AMONG AVAILABLE PASSIVE RADAR SYSTEMS (AERIAL AND GROUND BASED)

Features	CETC DWL002	Almaz-Antey Valeria	Topaz Kolchuga	RC DF-500
Navigation controls	N	N	N	A
Map layer architecture	N	N	Basic	A
Layer Control	N	N	N	N
Basemap	Basic	Basic	Simple	Adv.
Symbolization	Basic	Basic	A	A
Operator markings	N	N	N	N
Tracking	A	A	A	A
Geo-Processing	N	N	N	N
Offline analysis	N	N	A	A
Data basing	N	A	A	A
Tactical Picture	N	N	N	N
On-Screen Triangulation	N	N	A	A

TABLE II

COMPARISON OF FEATURES AMONG AVAILABLE PASSIVE RADAR SYSTEMS (AERIAL AND GROUND BASED)

Feature	SwRI's SABER	Isocdf	Medav	Sigmon	Map View
Navigation controls	A	N	A	A	A
Map layer architecture	A	A	A	A	A
Layer Control	N	N	A	A	A
Basemap	Adv.	Simple	Simple	Adv.	Adv.
Symbolization	A	A	A	A	Adv.
Operator marks	N	N	N	A	A
Tracking	A	A	N	A	A
Geo-Processing	N	N	A	N	A
Offline analysis	N	N	N	N	A
Data basing	A	A	A	A	A
Tactical Picture	A	N	N	N	A
On-Screen Triangulation	A	A	A	A	A

Basic (Basemap): Vector Basemap or Area Lines
Basic (Layer Architecture): A simple one overlay layer
Adv. (Basemap): Terrain, satellite maps
Basic (Symbols): Point or polygon graphics
Adv. (Symbols): Military Standard
A: Available
N: Not Available

V. CONCLUSION

Target mapping module being a key part of the industry of emitter localization systems is a major area of research and innovation for enhancement of localization results. The trends in the industry are not divergent in the basic functionalities but in advanced functionalities shear customization can be observed. Future trends towards virtual 3D environment and better use of geographical parameters can be a significant jump towards a more innovative and error free systems.

VI. FUTURISTIC TRENDS IN MAPPING SYSTEMS

With the advancement of technology new techniques and algorithms needs to be introduced in the geographical calculations of emitter locators. They serve mostly in the analysis of detected signals and probability of event occurrence for various scenarios. Some foreseen future trends are listed:

H. Path Prediction

It is a major requirement especially in the aerial applications where path tracking needs to be equipped with the path prediction and mission planning. Due to complexity of path prediction algorithms and their runtime working limitations, they are not commonly included in the current breed of emitter locator; but futuristic military and non-military requirements needs the systems to be upgraded with the feature.

I. RF PATTERN ANALYSIS

In the dense urban environment where multiple emitter locators use is not feasible. RF pattern analysis using a single receiver can be useful. This uses the highest power level and angle of arrival of the signal to estimate direction of the emitter. With mobile receiver and continuous RF intensity plot analysis the position of the emitter can be estimated with considerable accuracy.

J. RF Terrain Analysis

The idea is to scan the area of installation for emitter locators under view shed analysis. This allows the system to recognize the reflected signals in its analyzed region and to use only non-reflected signals in the processing of angle of arrival. This will considerably increase the sensitivity of system and errors that are incorporated due to multiple copies of the original signal from immediate environment.

K. Data Analysis for trending results

Analysis of data from previous missions can be valuable in understanding of trends and nature of signaling used in the monitored emitters. This can also be used in distinguishing future communications and intercepting them. Path tracking data analysis of targets can be useful in finding the camouflaged and hidden sites.

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