Radar GIS for Site Acceptance Testing

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Abstract **- Radar site acceptance testing is a demanding and costly task and requires good planning of the routes for probing aircraft and ships. In this work a preparation for radar site acceptance is presented with use of Advanced Refractive Effects Prediction System (AREPS) propagation model and ArcGIS charting of interesting points detected by the model. This approach enables prediction of radar coverage and significant cost reduction in actual aircraft and ship probing due to optimal route planning. This methodology was applied during recent modernization and optimization of the coastal radar network for the Croatian Navy and Croatian Ministry of the Interior.**

Keywords **- GIS; Radar; Site Acceptance Test; Radio Propagation**

I. INTRODUCTION

The Republic of Croatia has a land surface of 56.610 km^2 and sea surface of 33.200 km^2 and according to these figures it is classified as a medium size country. But a complex shape and developed relief of the Republic of Croatia set a serious problem for designers of electronic systems (radars, radio telecommunications electronic warfare and radio navigation). Croatia has 2.197 km of land border and 1.777 km of coastline, when all islands are excluded, and 4.058 km of the island's shoreline. In Europe, only Norway and Greece have such complex shoreline so there is a need for optimization in border control sensors, particularly coastal radars. These coastal radars must cover sea surface of the Adriatic Sea and airspace of altitudes up to 2000 m, upper airspace is covered by long range surveillance radars used in dual military-civil usage.

This work presents and recommends a two-step method for radar surveillance coverage analysis. The first step is advanced modelling of the radar detection and the second is a GIS analysis using a navigational chart for additional information. This modelling was conducted by Advanced Refractive Effects Prediction System (AREPS) 3.2 application. For the purpose of this work a fictional, not actual, radar site and radar system were used. AREPS computes and displays radar site probability of detection using Advanced Propagation Model (APM) [1]. The APM calculates desired height vs. range coverages for azimuths given with respect to: refractivity environment, diffraction over variable terrain (DTED 1 with resolution of 3" x 3", around 90 m spatially), range-varying dielectric ground constants, interference with surface reflection of radio waves, tropospheric scattering and gaseous absorption. The AREPS calculation is a representative model of radar detection with ability to change radar parameters, scattering of radio waves on target and refractive conditions. These vertical profiles (Fig. 1) of actual radar detections discover interesting points in radar coverage, points worth inspecting during "system acceptance tests" with aircraft. By this mean actual radar testings are in general quicker, cheaper and more accurate. This is particularly important during planning phase of the system acceptance test flights and allows plotting of the optimal flight plans for radar testings. There is a possibility of using multiple regular navigational exercises as a substitute for one thorough and dedicated flight testing.

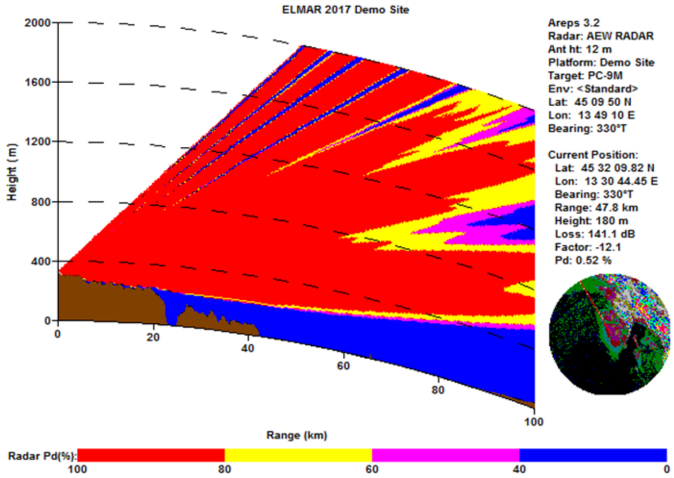

Figure 1. An example of the AREPS output; probabilities of detection for the particular target with detailed model of the radar system.

Long range radio propagation market has many software applications and many of them have been tried over the definition of the preliminary technical requirements: ATDI Radio Planning Software, FEKO, TCS and Ekahau Positioning Engine, Engineer's Refractive Effects Prediction System (EREPS), Advanced Refractive Effects Prediction System (AREPS) and STK. The basis of the AREPS application is the Advanced Propagation Model (APM) inherited from an Office of Naval Research, ONR (former Naval Research Laboratory, NRL) acoustical model. In the very simplest form of the APM it is a parabolic differential equation of the electric field strength in vertical plane $E(x,z)$ as a function of distances in relation to x and z axis, wave number k, curvature of the Earth R and spatial changes of the refraction index in atmosphere (1), j is the imaginary unit. Practically speaking, vertical profile of the refraction index has the most significant influence.

$$\frac{\partial^2 E(x,z)}{\partial z^2} + 2jk\frac{\partial E(x,z)}{\partial x} + \\ + k^2\left(\left[n(x,z)\right]^2 - 1 + \frac{2z}{R}\right)E(x,z) = 0. \quad (1)$$

AREPS have been the software choice because of very detailed refraction model for long distances (APM) and ability to cope with anomalous propagation conditions (so called “anaprops”) which are quite common over the Adriatic Sea [6]. Such anomalous propagations can be detected using standard aeronomical balloon probing reaching up to 40 km above surface with sufficient temporal resolution for operational use. For example, Croatian aerological station at Zadar airport, along with Italian aerological station San Pietro Capofiume have balloon launching twice a day and Italian stations Udine and Brindisi have four launchings a day. For the particular radar testing balloon probing is a prerequisite. With vertical profile of the refraction index in the atmosphere, *n(x,z)* in Eq. 1, accurate model for long distance radar detection probability is possible. Practically, during planning of the radar test flights both standard refraction and actual refractions were used. Standard refraction is good for long-term flight planning in advance when orography masking is the main concern. The standard refraction modelling discovers interesting points for test flight planning. Without this model, practice is to choose flight paths according to experience of the radar expert and pilots, ensuing standard navigation and approach procedures.

Additional value of the radar modelling is detection of positions of expected or not expected detections with the true coordinates in space. The Low flying chart (LFC), which is currently in use for aeronautical and naval tasks, is used as a background for interesting test points. The scale of a map is 1:500 000 and data are representing altitude above mean sea level measured in feet, datum WGS 84. Interesting points were transferred to GIS software, ArcGIS in our case, inside the UTM grid, and were visualised with dotted signature, labelled with altitude measured in feet as a thematic layer over the LFC (Figure 2.). This approach allows easier perception which simplifies the use of results. The map does not show all points calculated in AREPS program, it shows just the characteristic ones, interesting for users.

We are very aware that the interesting points are frequently located over restricted or dangerous aerospace, for example at low altitude over tall antennas or wind turbine fields, inside the airport zones, over dense populated areas, over protected wildlife zones or in the vicinity of national borderline.

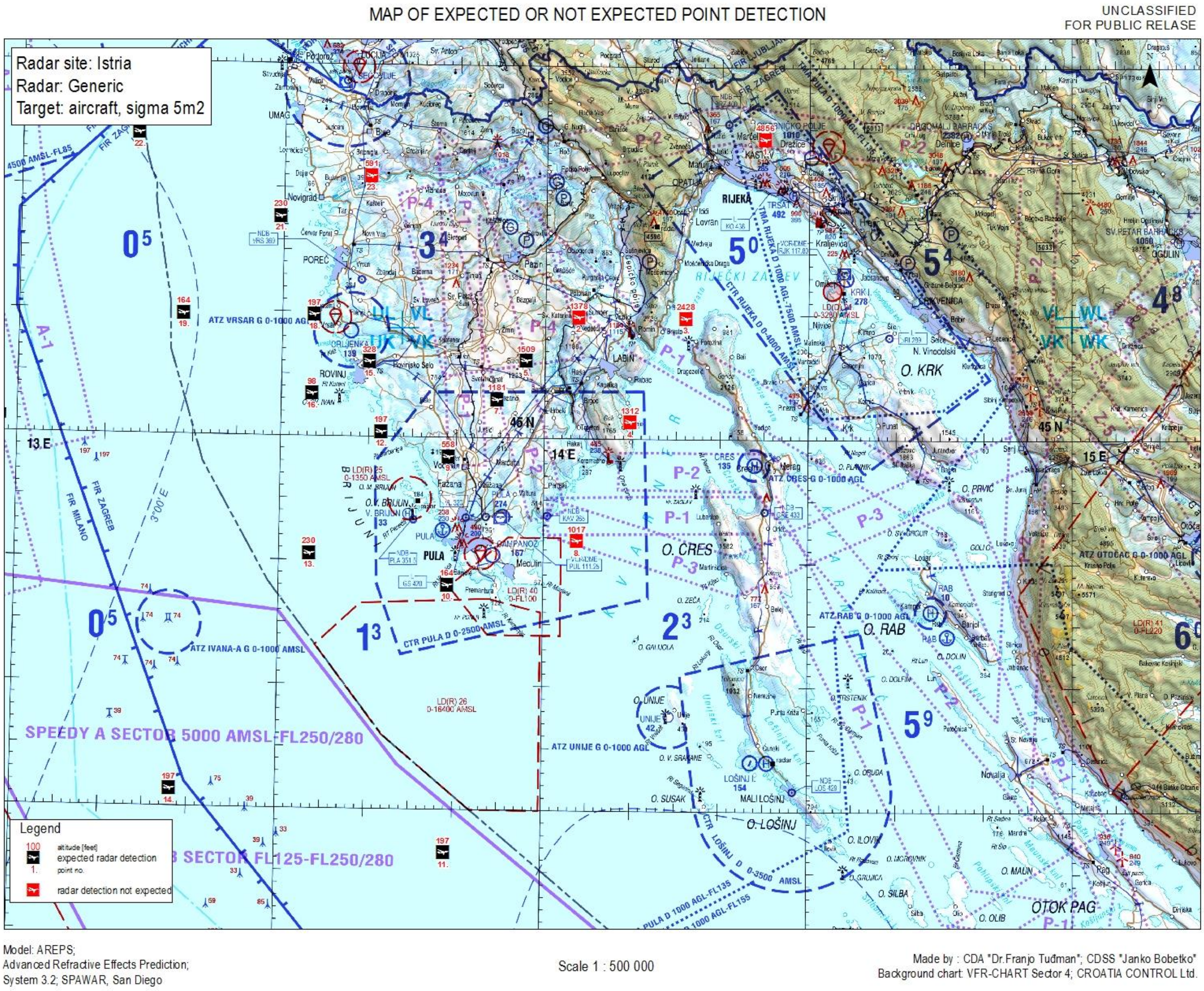

Figure 2. The map of expected or not expected point detection.

II. METHODOLOGY

Spatial accuracy of the AREPS model is constant and depends on spatial resolution of the DTED1 digital elevation model. Spatial resolution of 3”x 3” is equal about 90 m x 90 m and determines the resolution of the model. Radar spatial accuracy is more complex and depends on measurements errors in distance and azimuth (we have used 2D radars so the accuracy of target altitude will not be discussed in detail now).

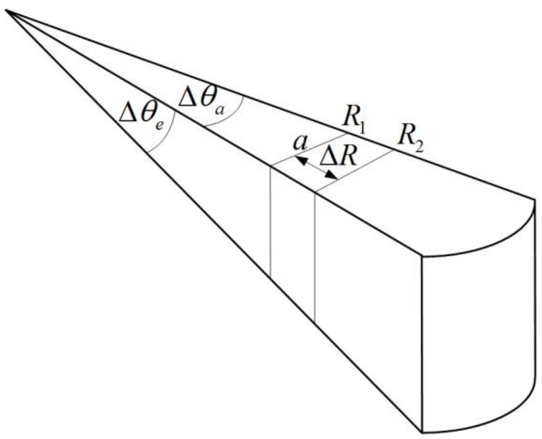

Figure 3. Positional error as a function of range and angle measurement errors.

Radar range RMS error (σ_R) is composed of three components, but in many practical circumstances only one prevails [2,4]:

$$\sigma_R = \sqrt{\sigma_{RN}^2 + \sigma_{RF}^2 + \sigma_{RB}^2} \approx \sigma_{RN} \qquad (2)$$

where σ_{RN} is signal to noise (SNR) dependent random range measurement error which usually dominates over the other two components, σ_{RF} is fixed random error mostly originated form multipath and propagation errors (this component is much more emphasized in vertical beam error θ_e than in the horizontal beam error θ_a, see Fig. 3), the third component is σ_{RB} bias error component which originates in imperfection of radar system (usually minimized during system design). At the end we have to estimate σ_{RN}

$$\sigma_{RN} = \frac{\Delta R}{\sqrt{2SNR_{dB}}}. \qquad (3)$$

SNR_{dB} is signal to noise ratio for the particular radar system and ΔR is range gate, the difference between R_1 and R_2 (Fig. 3) range estimations. For impulse radars the range gate is

$$\Delta R = R_2 - R_1 = c\frac{\Delta t}{2} \qquad (4)$$

where time interval of the range uncertainty is limited by pulse width, with minimal time difference of a radar pulse width τ, practically $\Delta t = \tau$

$$\Delta R = \frac{c\tau}{2} = \frac{c}{2B} \qquad (5)$$

so range uncertainty could be considered as a function of pulse width, or bandwidth B of the particular radar system. In our cases, range error was much smaller than DTED1 resolution except on very close ranges.

RMS angle measurement error σ_a is also a function of three similar parameters

$$\sigma_a = \sqrt{\sigma_{AN}^2 + \sigma_{AF}^2 + \sigma_{AB}^2} \approx \sigma_{AN} \qquad (6)$$

where σ_{AN} is a random angular measurement error dependent on signal to noise ratio and usually the dominant term, σ_{AF} is fixed random error due to propagation and multipath influences and σ_{AB} is angular bias error which should be minimized during radar system design. The dominant term of signal to noise dependent random angular error is a function of

$$\sigma_{AN} = \frac{\theta_a}{k_m\sqrt{2SNR_{dB}}} \qquad (7)$$

θ_a is beam width at 3 dB signal level, $k_m \approx 1.6$ is constant, and SNR_{dB} is signal to noise ratio for the particular radar system. Limitation of the DTED1 resolution and the 3 dB beam width limit the lowest possible range at (Fig. 3)

$$R = \frac{a}{\theta_a}. \qquad (8)$$

Practically, only close proximity of the radar is affected. Knowing these radar parameters, all measurement errors were checked for the particular radar system before actual modelling [5]. We are aware of the relatively frequent anomalous propagations over the Adriatic Sea which is not discussed here [6]. To assure standard refraction conditions we suggest planning of radar tests in times few hours after regular aerological balloon soundings (GMT: 0h, 6h, 12h and 18h) to check actual vertical profile of the refraction index. These data are available within hours of soundings by national meteorological service or regional/global meteorological centres.

III. RESULTS

Target position accuracy depends on actual radar characteristics, according to (3), (5), (7) and (8): radar pulse width, signal to noise ratio, radar beam width and spatial resolution of the digital terrain model (a = 90 m). Recent study for the Croatian Navy and Croatian Ministry of the Interior included 32 radar sites with different radar types. The actual radar characteristics are classified, however we could still illustrate the effects of the critical spatially related characteristics along with DTED1 spatial resolution. For the comparison, we will use four “generic” coastal radars; two long range, and two short range radars with the critical spatial characteristics only estimated, accurate up to order of magnitude (Table 1).

TABLE 1. POSITIONAL ACCURACY OF RADAR TARGET AND THE LOWEST POSSIBLE RANGE

Generic radar types	**Spatially critical radar characteristics**			**Estimated positional accuracy of the target, computed using (3), (5), (7) and (8)**		
	Radar pulse width **[μs]**	***Signal to noise ratio*** **[dB]**	***Radar beam width at 3 dB*** **[°] / [m rad]**	***Radar range RMS error*** σ_R **[m]**	***Radar azimuth RMS error*** σ_A **[°]**	***Lowest possible range R*** **[m]**
Long range L-band	16	14	3 52.36	453	0.354	1719
Long range S-band	12	10	2 34.91	402	0.280	2578
Short range S-band	6	8	1.2 20.94	225	0.188	4297
Short range X-band	2	5	1 17.45	95	0.198	5157

Table 1. was computed by using velocity of radio wave propagation c and length of a DTED1 cell a. As expected, the short range radars are more accurate in both range and azimuth however they are also more susceptible to the DTED1 spatial resolution. Lowest possible range limits application of the DTED1 model at close proximity of the radar. Due to narrow radar beam width, typical of the high frequency and low range radars, the lowest possible range could have unacceptable values and should be verified before actual radar visibility modelling.

IV. CONCLUSIONS

The method applied in this work combines three tasks for radar site testing and validation: radio propagation modelling, GIS charting and actual radar testing using real air and sea targets. Utilisation of the propagation model has enabled us to suggest interesting points inside radar coverage, the points where targets are not expected to be detected due to orography mask or interferential phenomena. It shows that knowledge of these points in advance is a significant advantage during planning process of the radar site testing. Identification of the interesting points in radar coverage is the main guide during route planning for testing aircraft and ships. However, these points are sometimes distributed unevenly, some of them are inaccessible or are located inside restricted areas. Effects of these restrictions on radar test planning could be seen by using GIS charting. Exact locations of the interesting points were put on LFC aeronautical chart to help planning staff to choose the best route for radar testing. A check of actual radio propagation conditions, using aerological balloon probing, was also a prerequisite before radar testing. Interesting points which are quite separated spatially could be accessed during different voyages which contribute to lowering costs of the radar site testing. Also, in the reducing costs effort, testing of interesting points could be planned during regular aircraft and ship tasks. Accurate position of probing vessels is assured using modern navigation equipment for position, navigation and timing: global satellite navigation systems, terrestrial radio navigation, secondary radars, ADS-B etc. [3]. By using the precise timing it is possible to compare actual and detected routes accurately using the same GIS tools as during route planning. Brief accuracy check conducted in this work shows that 3” x 3” (around 90 m) spatial resolution of the digital terrain model (DTED1) and corresponding AREPS modelling resolution is good except for close proximity of the radar site.

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