UDC 004

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MODELING REAL-TIME INTERACTION BETWEEN GIS DATABASE AND MARINE RADAR

Interacting between Geographic Information System (GIS) database and an image generated by the maritime radar sensor is a challenging task. In this paper two methods of possible real-time interaction between a radar signal and GIS will be described. Marine radar sensor can be placed on the moving platform, such as an object floating on the sea or can be positioned on the land for the coastal surveillance. The result of the radar sensor work is a bitmap produced by the original DSP based radar processor. Both mentioned methods could be considered as intelligent filters. One-method implements the filter like a surface mask based on GIS data, which splits raw radar signal in two categories (from land or from sea). Another method is focused on classifying detections, which are the results of the point-like detector. Commercial PC-based equipment is used. Both methods are implemented in a real system and can be used while the radar is operating.

Keywords: *video image processing, radar image processing, Geographic Information System*.

Introduction

We are the witnesses of the fact that almost all modern marine radars have the option to present integrated Geographic Information System (GIS) [1 – 3].

The GIS information is typically stored on memory media in the format of a bitmap, a coastline vector, the areas of closed polygonal lines, the characteristic points etc. In the modern radar implementations with GIS option, it is usually possible to selectively display the offered GIS content on the radar screen as given in the more detailed explanation [4-7]. Usually, there are no interactions between the GIS and radar sensor produced image.

The image on the display is obtained by overlapping images of preprocessed radar signal and the image based on GIS. The GIS image is formed through the selected objects from the database taking into account the current position and one reference angle from sensor aligned to the north. In this paper, an effort is made to make some level of interaction between the raw radar signal and GIS system, with the focus on work in real time.

In practice, there are lots of problems, which cause that engineers avoid mixing radar signals with the GIS in real time. When we speak of the conventional marine radar operating in a pulsed mode (carrier frequency, amplitude-modulated pulse), the resulting image is the outcome of the received part of the reflected energy, which is a function of geometry of the object, the antenna radiation pattern, the rotation speed and the pulse frequency.

The resulting image is quite distorted compared to the real situation. In recent years the need for a commercial began to appear, such as implementing Frequency-Modulated Continuous Wave (FMCW) radars with the less distortion of actual natural scene. There has been a problem in determination of the position of the radar sensor, in addition to the nature of reflecting, geometry, composition and angle of exposure to EM energy of the observed object. Those problems are related to the level of position precision, the longitudinal and lateral angle of the platform, when the radar is installed on mobile platforms - ship, plane, and direction of antenna radiation pattern.

Regardless of these problems, this paper will propose two new methods of the interaction of raw radar signals and GIS. Those methods are introduced in [13, 14]. The test platform is used in the form of stationary radar sensor where in one case we consider an area near the radar sensor (Figure 1) and in another the entrance to the harbor of one Mediterranean town (Figure 2).

In Figure 1 the location of the radar sensor is in the center of the white circle. Despite DSP processing, there can be seen a remaining non-linearity near the sensor (the white circle in the center). On Figure 2 the distance between the sensor in the second case and the observed region is about 13 nautical miles (24km). From the raw radar signal (logarithmic video, the rotation angle of the antenna and the sync signals) the original DSP-based system generates a bitmap that corresponds to the conventional radar image.

The radar signal processor forms a series of images like on Figures 1 and 2, for each new antenna rotation. The reflections obtained from radar are placed in the two-dimensional matrix (bitmap) where each location (x, y) is colored gray, representing intensity of the reflected signals from white to black from objects in the environment.

The database for GIS used in this work was obtained by manually tracing the visible coastal edge on the Internet application with Goggle Earth.

The coastal line is perceived in this way, which is an imaginary line, which represents the margin between the water (sea, rivers, and lakes) and the mainland. On the marine charts, the line between water and the shore is delineated during the lowest water level (low tide).

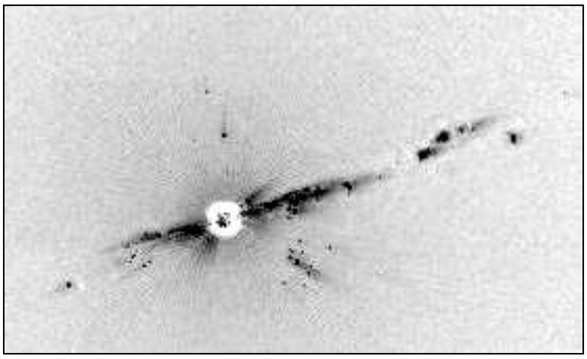

Figure 1: Present selection taken from bitmap near the location of radar sensor

Figure 2: Present selection taken from bitmap at the distance of about 13 nautical miles from radar sensor

In this paper two methods for classification of signals received from radar sensor for observing the sea surface are presented. An attempt was made to make intelligent classification of point objects to identify only the objects that are on the sea. The result of this work makes it possible to carry out mixing preprocessed radar images and GIS. The actual implementation of both methods is made and it works in real time. They can be used while radar is working. Similar image processing methods are used in different area as shown in [7 – 13].

In one method detected features are compared with GIS based bitmap mask in order to find the solution, depending upon whether detected features belong to the sea based objects or to the inner coast.

Another method is based on the estimates of the statistical parameters of the radar image. These estimates help to perform the intentional contamination of the original radar image in order to make the task easier for the feature detector.

Method

Point-like objects detector. Over the bitmap shown on Figures 1 and 2 an attempt is made to detect details that look like points. In pattern matching algorithms, usually the initial task is to solve a problem by minimizing sum of square difference (MSSD) between an image in a bitmap form represented with matrix A (x, y) and template matrix T in well-known form given in Formula (1). The main goal is to find locations with the minimum $\varepsilon\left(p_x, p_y\right)$, which the sum of squared differences.

$$\varepsilon\left(p_x, p_y\right) = \sum_{m_x=-\omega_x}^{\omega_x} \sum_{m_y=-\omega_y}^{\omega_y} \begin{pmatrix} A\left(p_x + m_x, p_y + m_y\right) - \\ -T\left(\omega_x + m_x, \omega_y + m_y\right) \end{pmatrix}. \quad (1)$$

There is normalized form of Formula (1) and is given by (2) and is well known as normalized cross correlation. This pattern/template matching method is commonly used in the feature extraction algorithms for bitmap images processing.

The value of the expression (2) is in the range $-1 < \varepsilon\left(p_x, p_y\right) < 1$, where the maximum negative values of $\varepsilon\left(p_x, p_y\right)$ correspond to the good matching with the original pattern, and positive values match with the inverted pattern.

For the purposes of this paper the template that looks like matrix, shown in Formula (3) with 3D surface as in Figure 1, was chosen. This template roughly resembles a bit mapped point.

$$\varepsilon\left(p_x, p_y\right) = P/\sqrt{Q}, \quad (2)$$

where

$$P = \sum_{m_x=-\omega_x}^{\omega_x} \sum_{m_y=-\omega_y}^{\omega_y} \left(\begin{pmatrix} A\left(p_x + m_x, p_y + m_y\right) - \\ -\bar{A}\left(p_x, p_y\right) \end{pmatrix} \times \atop \times \left(T\left(\omega_x + m_x, \omega_y + m_y\right) - \bar{T}\right) \right);$$

$$Q = \sum_{m_x=-\omega_x}^{\omega_x} \sum_{m_y=-\omega_y}^{\omega_y} \left(\begin{pmatrix} A\left(p_x + m_x, p_y + m_y\right) - \\ -\bar{A}\left(p_x, p_y\right) \end{pmatrix}^2 \times \atop \times \left(T\left(\omega_x + m_x, \omega_y + m_y\right) - \bar{T}\right)^2 \right);$$

$$T(k, l) = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 120 & 120 & 120 & 0 & 0 \\ 0 & 120 & 120 & 120 & 120 & 120 & 0 \\ 0 & 120 & 120 & 120 & 120 & 120 & 0 \\ 0 & 120 & 120 & 120 & 120 & 120 & 0 \\ 0 & 0 & 120 & 120 & 120 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{(Fig. 3)}. \quad (3)$$

Over matrix A (x, y) calculated is matrix $\varepsilon\left(p_x, p_y\right)$ for each pixel within the bounds

$$\omega_x < p_x < \max(x) - \omega_x$$

and

$$\omega_y < p_y < \max(x) - \omega_y.$$

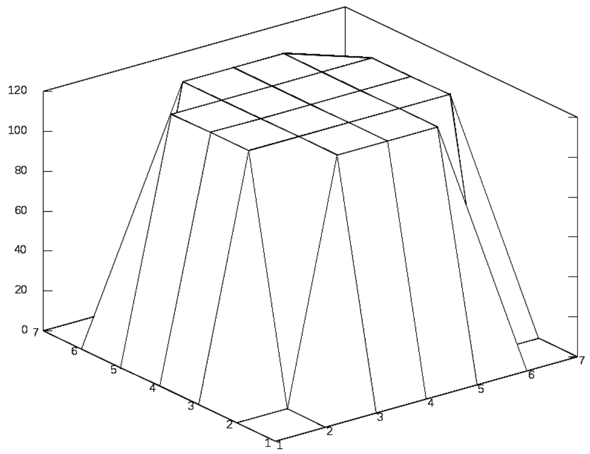

Figure 3: Surface diagram representation of matrix T (k, l)

The results are compared with some predefined threshold T_c. All values lower than T_c are taken into consideration and marked as squares or circles on Figure 4 and 5 respectively.

If the hypothetical human radar operator would be watching for a long time (several days or more), he could note that some of the detected objects are stationary and some not. In this way, we got a lot of detections that do not show the nature.

Intuitive thinking may lead to the conclusion that stationary reflections belong to an object on the shore or a fixed object on the sea level. Non-stationary detections probably belong to some movable objects on the sea level.

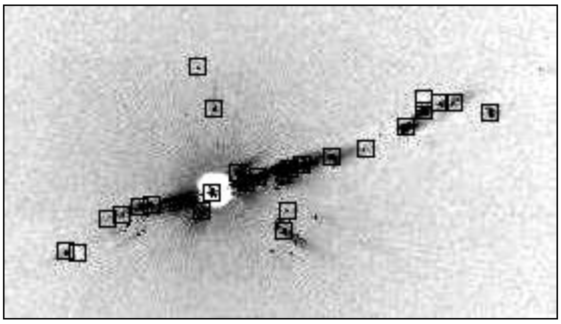

Figure 4: Squares mark positions after point-like detection using Formula 2 over the image on Figure 1

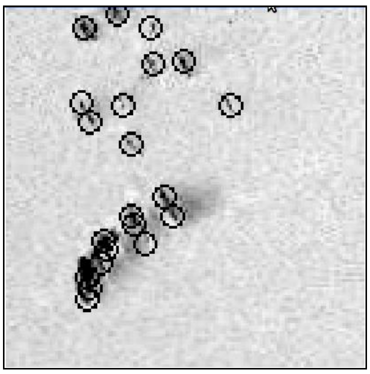

Figure 5: Circles marks positions after point-like detection using Formula 2 over the image on Figure 2

GIS based coastline. If we draw the coastline based on the previously mentioned GIS database we can get the Figure 6 and Figure 7.

Intuitively we know that the upper part above the line belongs to the objects on the sea level, below are objects on the land.

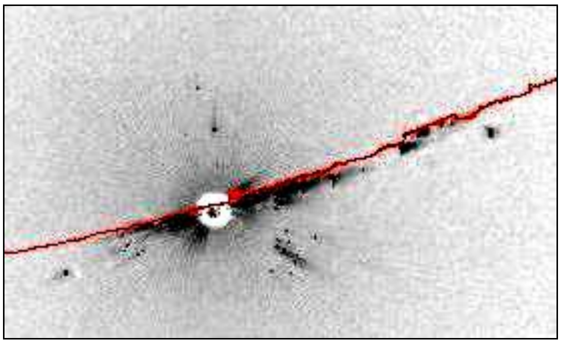

Figure 6: Shows original bitmap like in Fig. 1. With added GIS based coastline. Area above line belongs to sea part below line is coastal part

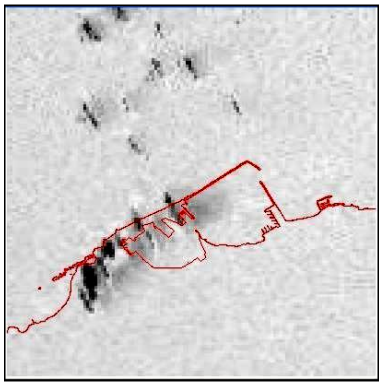

Figure 7: Shows original bitmap like in Fig 2. With added GIS based coastline in harbor area. Area above line belongs to sea part below line is coastal part

Filtering of detected objects according to GIS based mask. One solution to make system that has interaction between GIS and the radar-based bitmap is to make pixel-oriented memory based mask with one-color pixels and to cancel all detections located over pixels with this color. For the purpose of this paper, the choice is made to use white colored pixels over the land area. Figure 8 shows the situation where the land area from Figure 2 is colored white and then added to the results of detections shown on Figure 5.

The common characteristic of this approach is that the resulting detections are filed into memory set. The number of detections over the land is relatively high. The problem is that the border between land area and sea is too sharp, so that the detected or undetected objects near the coastline are unclear. Anyway with this solution, the number of detected objects over the land is significantly reduced. With this step of reducing the number of detections, within other blocks inside the radar processing system, which are responsible for tracking, filtering and kinematic parameter estimation, working task is easier. In other words, there is lower chance to saturate radar-tracking system.

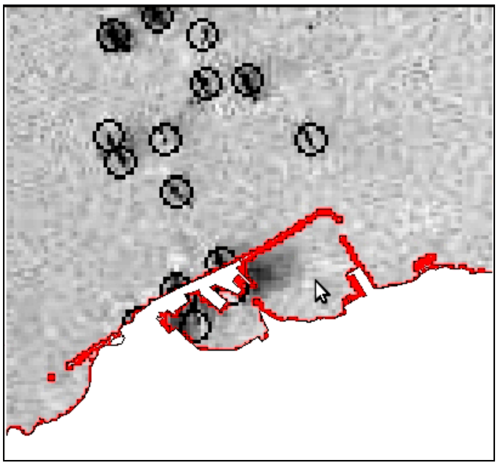

Figure 8: GIS based masking – shows canceling detections over land (colored white)

Masking original signal. Another solution suggested in this paper is based on the methods of statistical analysis of the bitmap based on a radar image.

Over the entire input, bitmap has to determine the mean signal value like function of distance from the sensor by Formula (4).

$$\hat{\mu}(r,k) = \\ = \hat{\mu}(r,k-1) + k^{-1} \cdot \left[A(r) - \hat{\mu}(r,k-1)\right]. \quad (4)$$

In formula (4) r is the (hypotenuse) distance from the sensor position like in Formula (5) and k is the pixel position index.

$$r = \sqrt{(x - x_{sensor})^2 + (y - y_{sensor})^2}\,. \quad (5)$$

Using Formula (6) we calculate the overall image variance.

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(A(i) - \mu_{total}\right)^2}\,. \quad (6)$$

In formula (6) Number N corresponds to the total number of pixels A(i), the value of pixel at index i and μ_{total} mean value over the whole bitmap.

To all pixels, which are below the coastline including the line itself, assign a value using a pseudo random generator with normal distribution, Listing (1).

In this way we will get a picture on Figure 9, which still has the dynamics of the original radar images but with the deleted reflections from the coastal-based objects.

If we try again the detection of point-like objects as in the previously described method, we will get the result like in Figure 10.

```
double randn (double m, double s)
{
  int i;
  double ret;
  double sum=0.;
  for (i=0;i<12;i++){
    sum+=rand();
  }
  sum/=RAND_MAX;
  sum-=6.;
  ret=s*sum+m;
  return ret;
}
```

Listing 1: Model to generate pseudo-random variable with normal distribution, where m is the mean value and s variance.

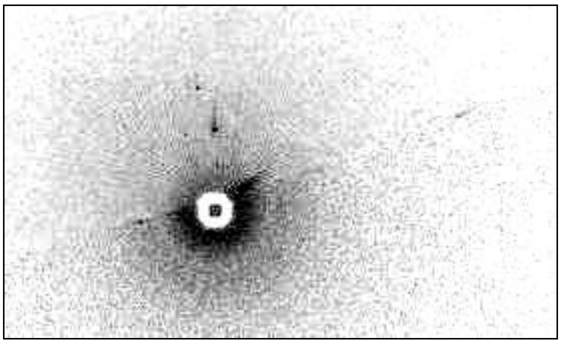

Figure 9: Presents the resulting picture after the original signal has been masked with normally distributed pseudo random noise

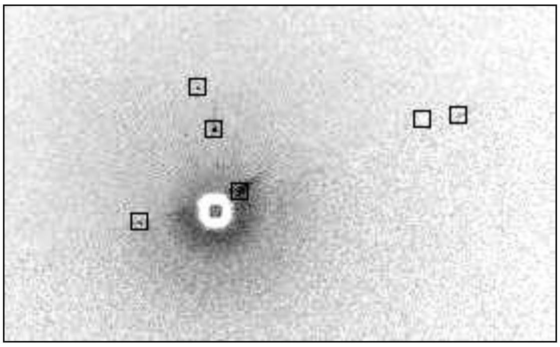

Figure 10: Squares marks detected positions, which corresponds to the required pattern like on Figure 3

Conclusions and discussions

Two possible approaches to organize interactions between radar image and GIS are presented.

Both methods are realized and tested on an experimental platform. An image like the one on Figure 8 presents the result of one method. The other one is shown on Figure 10.

The first method introduced too sharp border between the coast and the sea. In practice, this is not always the case. It is possible to avoid problems with border points that disturb the quality of detection, based on the method of normalized cross correlation, by introducing noise masking.

Both methods show that the number of point-like detected objects is drastically reduced. Both methods can include the preparation phase at the beginning of the radar processing work for the stationary sensors (fixed positions). If the sensor is moving, then we have to set a special working task in the background of the main task or in a parallel processor.

Another problem is the definition of the previously specified threshold. Intuitive setup includes engagement of an expert in the given field.

The change of the parameters in the environment (rough seas, no homogeneity, humidity, rain, rain clouds) can significantly degrade the model that was obtained by an expert participation.

Problems are the objects that are close to the coastline. These problems objects are the subject of further research in this area.

For the future work, one can consider application of fuzzy methods, e.g. in [12].

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МОДЕЛИРОВАНИЕ ВЗАИМОДЕЙСТВИЯ БАЗ ДАННЫХ ГИС И МОРСКИХ РАДАРОВ В РЕАЛЬНОМ РЕЖИМЕ ВРЕМЕНИ

З. Джорджевич

Организация взаимодействия между географической информационной системой и изображениями, формируемыми морскими радарными датчиками, является сложной задачей. В статье описаны два способа возможного взаимодействия в реальном времени между сигналом радара и ГИС. Морские радарные датчики могут быть размещены на подвижной платформе, плавающей в море, или могут быть расположены на земле для прибрежного наблюдения. Оба описанных метода можно рассматривать как интеллектуальные фильтры. Один метод реализует фильтр, как поверхность на основе ГИС-данных. При этом исходный сигнал радара разбивается на две категории - от земли или из моря. Другой метод ориентирован на обнаружении и классификации на основе точечного детектора. Оба метода реализованы в реальной системе и могут быть использованы при работе радаров.

Ключевые слова: *видео обработка изображений, обработка радиолокационных изображений, географическая информационная система.*

МОДЕЛЮВАННЯ ВЗАЄМОДІЇ БАЗ ДАНИХ ГІС І МОРСЬКИХ РАДАРІВ В РЕАЛЬНОМУ РЕЖИМІ ЧАСУ

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Організація взаємодії між географічною інформаційною системою і зображеннями, зформованими морськими радарними датчиками, є складним завданням. У статті описані два способи можливої взаємодії в реальному часі між сигналом радара і ГІС. Морські радарні датчики можуть бути розміщені на рухомій платформі, що плаває в морі, або можуть бути розташовані на землі для прибережного спостереження. Обидва описаних методу можна розглядати як інтелектуальні фільтри. Один метод реалізує фільтр, як поверхню на основі ГІС-даних. При цьому вихідний сигнал радара розбивається на дві категорії - від землі або з моря. Інший метод орієнтовано на виявлення й класифікацію на основі точкового детектора. Методи реалізовані в реальній системі і можуть бути використані при роботі радарів.

Ключові слова: *відео обробка зображень, обробка радіолокаційних зображень, географічна інформаційна система.*