Ship feature extraction from maritime radar data

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ABSTRACT

In large harbours and long channels where congested traffic and critical weather are present, VTS (Vessel Traffic Service) systems are needed for traffic management and control. The requirements for these systems become more and more demanding because of the continuous increase of traffic and adverse meteorological conditions; reliable systems which can help the operators to avoid accidents which can jeopardise the security of people and goods have to be used to increase safety and efficiency. These systems employ mainly radar sensors, suitably placed in order to have a complete coverage of the area to be controlled, because a 24-hours operation in all weather conditions must be assured.

In this paper a new methodology to process digitised radar images to extract object features (size, heading, etc.) is presented. Considering that ships arriving to, or departing from, harbours are big objects moving in narrow channels or waterway, information such as length and bow position are fundamental to control the ship movements, to evaluate the distance between two vessels, or between the vessel and fixed objects such as buoys or wharves. Results of extensive measurement campaign carried out in Neaples, Leghorn and Genoa harbours are reported.

INTRODUCTION

Traditional elaboration of radar signal, aimed to extract the target's barycentre, is based on 1-D approach; this leads to a lack of information on the objects to be controlled. This effect becomes an unbearable drawback in the monitor and control of vessel traffic in crowded harbour where the distance radar-target is short (some kilometers) and the objects are big enough to extract their main features. Information such as length, heading, etc. can be used to better control the traffic and have to be evaluated with the best precision allowed by the sensor's characteristics.

To extract these features the radar signal is considered as an image on which suitably tailored traditional image processing algorithms are applied. The digitised radar raw data are organised in a bidimensional matrix, whose dimensions are range and azimuth. Each matrix element (pixel) is the level of grey of the quantised radar signal corresponding to the sample time, depending in range on the impulse length and in azimuth on the pulse repetition frequency and radar scan time. Considering the high data rate of radar, the collection and processing of all the radar pixels is a task requiring high computational capacity which can be sustained only by expensive and parallel architectures. To reduce the required processing power an alternative approach consists in collecting and processing only the data around the objects of interest in the scene. The objects can be selected by the system operator with a pointing device clicking on the display, where raw data are presented, in the region corresponding to the objects' image. Then the elaboration is activated as well as an internal tracking which allows the objects to be followed without any further operator's intervention.

Another way to select the objects is to use the information provided by the system tracking device which furnishes a track for each object in the scene; in this way the elaboration start-up is carried out without the intervention of the operator.

In the previous two cases a special radar interface board performs the A/D conversion of the video raw data, collects the data relative to the windows issued by the application software (whose input is received from the operator or from the tracker) and transfers them to a memory accessible by an Image Processor. The interface board has been designed and realised by Alenia.

Instead of processing raw video radar images, sets of strings defining objects can be used as input images. A string relative to a range R (distance from the radar) is defined by two azimuth values (beginning and end of the string) and by a level of grey value (the average value of the string). The beginning and end of the string can be evaluated using classic threshold-based algorithms. A set of range contiguous string defines an image to be processed. In this case a string extractor must be used whose outputs (strings) are sent through a LAN to the Image Processor.

In all the previous cases the elaborative chain below described can be used to extract object's features.

ELABORATIVE CHAIN

The application software carries out the following elaboration on the window containing the object whose features are to be extracted:

- *radar data correction and binarization:* the object's shape is distorted due to various effect such as the different range and azimuth resolution, the azimuth beam width. These effects must be correct by suitably algorithms in order to have a correct estimation of the object's features. In particular a pixel quadrature process is carried out which, by means of linear interpolation or decimation algorithms, produces an image with equal range and azimuth resolution.
An adaptive threshold is then evaluated computing the bimodal histogram of the image: the threshold is chosen as the value which separates the peak corresponding to the clutter pixels from the ones corresponding to the object pixels.
Furthermore the effect of the radar beam width, which enlarges the objects in the azimuth dimension, is eliminated thinning the shape of the objects of a number of pixel equal to the one contained in the radar beam width.

- *image regularisation:* morphological mathematical operations are applied to regularise the binary image: the objects can contain holes (zero values) which must be filled and small objects or even isolated pixels must be eliminated. To perform this task the Minkowski's algebra is used, in which images are analysed in terms of their size and shape, by using elementary patterns known as *structuring elements*. The elementary operations are analogous to the discrete convolution, with the structuring element representing the kernel; the main difference is that the convolution involves addition and multiplication, while the morphological operations execute on the image data the equivalent of "set" operations.
To regularise a binary image, the Minkowski *closing* operation may be used. Intuitively, this operation consists of a first step of dilation, which expands the image set, followed by an erosion process which contracts the expanded regions. The expansion process, as function of the structuring element, retains roughly the shape of the image regions; however, holes of dimension depending on the structuring element size tend to be filled. The subsequent shrinking or erosion operation, therefore, rescales the regions, while retaining the smoothing results (holes do not reappear). In the implementation of the elaborative chain a modified *closing* operation has been implemented: it consists of two consecutive dilation steps followed by two erosions steps.

- *blob aggregation and windowing:* this process aims to segment the image into blobs corresponding to different objects. A method of singling out each component of the picture as a separate object consists in labelling all the elements of the object using the same value.
A simple way to do it is through a propagation process, see Rosenfeld (1). A raster scan of the binary image is executed, until an element (1 value) is found; to this pixel a label is assigned. Then a local operation is performed in which any pixel in the picture which has a labelled pixel as neighbour is itself changed to the value of the same label. If this is iterated until no further changes occur in the image, the same label is assigned to every pixel that belongs to the same object. At this point the image raster scan is resumed, until another pixel, which must belong to a different component, is found, and the above process is repeated.
After all the blobs are clustered, the one to be elaborated is identified. A window is opened around this blob in order to carry out all the further elaboration in this window, thus reducing the elaboration time.

- *perimeter point extraction:* a method of coding binary image boundaries has been defined by Freeman, see Freeman (2). It is known as *boundary chain code* and it is very advantageous for applications which are primarily shape oriented, that is, applications in which the main interest is in the shape of the contour itself. In the elaborative chain an algorithm, proposed by Pavlidis, see Pavlidis (3), for contour tracing has been chosen. It considers a line as represented by a sequence of octal digit, each one indicating the direction of the next point, according to 8 predefined direction. In the chain coding terminology these straight-line segments (or the integers with which they are labelled) are referred as *links*, and a sequence of links representing a line structure is called a *chain*.

- *barycentre evaluation:* the barycenter abscissa x_b and its ordinate y_b are given by the following expressions:

$$x_b = \frac{1}{n}\sum_{k=1}^{n} x_k \qquad y_b = \frac{1}{n}\sum_{k=1}^{n} y_k$$

where the sums can be limited to the object boundary points or can be extended to all the object blob elements. The number of computation is lower in the first case, but in the second case the use of a larger number of points can give higher estimation accuracy.

- *heading and length extraction:* various approaches are available to extract the object's heading and length; in the following the principal ones are described:

a) the blob is thinned with the Hilditch's algorithm, see Rutovitz (4), thus obtaining the skeleton points (the set of points that are equally distant from the closest points of the figure boundary). To evaluate the direction of the skeleton, that is the heading of the object, the Hough transform is used, see Pratt (5). In this trasformation a straight line is mapped into a point in the parameter plane, taking into account that:

$$\rho = x \cos \theta + y \sin \theta$$

is the normal representation of a line where ρ is the normal distance of the line from the origin of the reference system and θ is the angle of the normal to the line with respect to the x axis. The Hough transform of this line is the point (ρ,θ) in the parameter plane. A point $(\overline{x},\overline{y})$ maps into a sinusoidal curve in the ρ-θ plane. The adopted quantisation on the parameter plane is 0.5° for θ and 3m for ρ.
Considering the Hough transformation of the skeleton points, suitably algorithms have been developed to identify in the parameter plane the straight line which these point lay on. The optimal way is to find the maximum of the local averages performed in the surroundings of the local maxima in the parameter plane.
The length is evaluated as the distance between the points belonging to the perimeter and to the barycentral line whose direction is the one evaluated by the Hough transform
b) the centroidal map is evaluated. Let be the perimeter point coordinates expressed in meters with respect to a reference system centred in the object's barycentre, thus describing a close line which is the object's contour. The centroidal map is a function C(q), where q is in the range [0°,180°), which expresses the distance between the intersections of the straight line y=xtan(q) and the perimeter. In the following figure a ship perimeter and the relative centroidal map are reported. The function C(q) is filtered and the maximum is evaluated. It is then straightforward to obtain the ship's length and heading.

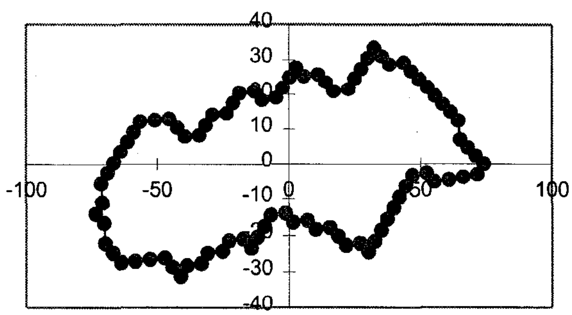

Figure 1. Ship's perimeter (in meter)

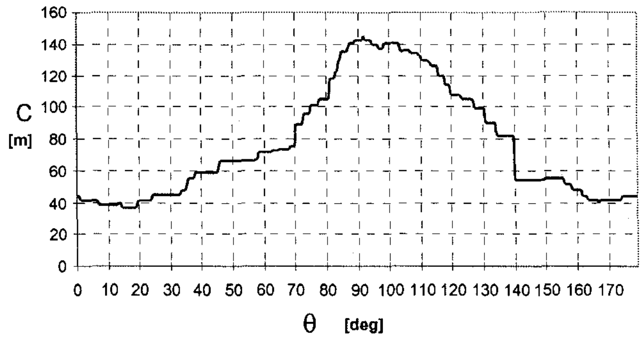

Figure 2. Centroidal map (angles are evaluated from the y axis anticlockwise)

c) the linear regression line is evaluated using the blob points or the skeleton points. This function minimises the quadratic error of the distances between the considered set of points and the line. It is then an expression of the blob's axis, from which it is easily to determine its length and orientation.

- *features extraction:* the perimeter length P and the area A are evaluated using the Freeman code's property to directly evaluate P and A from the code itself. The compactness, defined as $C=P^2/4\pi A$ is then evaluated; this figure gives and idea of the elongation of the target considering the minimum value is 1 for the circle

- *tracking and filtering:* simple $\alpha-\beta$ algorithms are used to filter the barycentre and the heading values. The length measures are filtered with an average based IIR filter.

MEASUREMENT CAMPAIGNS

Extensive measurement campaigns have been carried out in the Naples, Leghorn and Genoa harbours to test and validate the elaborative chain. A suitable tool has been set up to register radar raw data contained in the windows to elaborate. This tool allows moreover a reproduction (playback) of real data in the laboratory so as to perform a tuning of the algorithms and to measure performance figures.
Long sequences of data referred to moored or moving ships have been registered and statistical parameters, such as mean and standard deviation, have been evaluated for each of the above described approach in order to compare the obtained results among them and against the real values, when available.
X-band radars with 50 nsec. pulse length, azimuth beam width ranging from 0.4° to 0.7°, PRF from 0.8 to 3.2 Khz and with revolution time from 3 to 6 sec. have been used.
In the following charts, as an example, the evaluated length and heading of the ship Anastasia entering in the

Leghorn harbour are reported; the ship's real length is 181m.

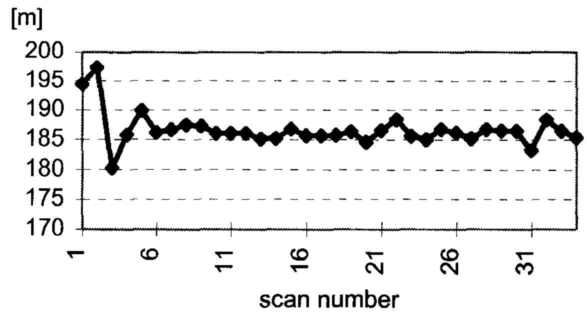

Figure 3. Ship length evaluation

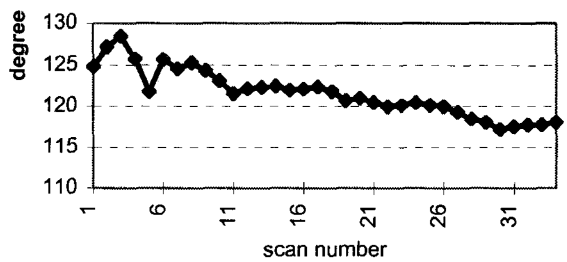

Figure 4. Ship heading evaluation

In these charts the filter effect should be noticed, which smoothes the measurements, when it reaches its steady condition after the initial scans.
Moreover simulated data have been used to reproduce critical situations, such as dangerous ship trajectories or particular bad weather conditions. Simulated data have also been used to study other types of sensor, such as Ku band radar, and to analyse the results obtained with the elaborative chain.

CONCLUSIONS

The elaboration chain described in this paper allows the estimation of ship's feature with a high precision. Elaboration results of real data from the X band radar have a maximum error on the length of 10% and estimated error on the heading ranging from 0° to 5°. Simulation using Ku band radar have shown a maximum error on the length of 5% and on the yaw of 3°.
The features estimated with this new approach can be used in VTS system to perform a more accurate traffic control improving the efficiency of the system.
This approach can also be extended to other application fields, such as the A-SMGCS (Advanced Surface Movement Guidance and Control System), where a surface traffic monitor and control of non cooperative objects must be performed.

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