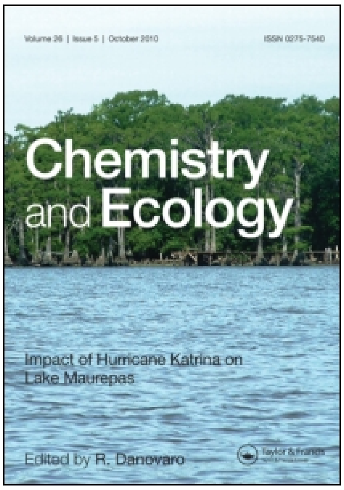

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GIS tools application for risk assessment of toxic waste buried in seafloor sediments

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GIS tools application for risk assessment of toxic waste buried in seafloor sediments

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The paper describes the development of a Geographical Information System (GIS) and related processing tools for handling the data and information acquired in the field to assess the risk of sea-bed dump sites where most of the containers are buried within the sediment. The GIS has been developed as part of the European Project SITAR ('Seafloor Imaging and Toxicity: Assessment of Risk caused by buried waste'). The main innovative aspects of the SITAR GIS system are: a user-oriented graphical interface, allowing end-users to access field data starting from general thematic maps down to finer data details, and integrating environmental, acoustic and biotoxicity data; and the presence of a Decision Support System (DSS) for evaluation of buried containers (shape, dimensions, ...), and based on the development of appropriate 3-D segmentation and classification image processing algorithms. The final version of the system has been evaluated by an independent panel of experts; the procedure and results of the experts evaluation are also reported, showing a clear and satisfactory appreciation for the system and its tools.

Keywords: Geographical Information Systems; Image processing; Underwater acoustics; Environmental monitoring

1. Introduction

Risk assessment of toxic dump sites in shallow water and close seas is a difficult if not impossible task with state-of-the-art oceanographic survey equipment and analysis methodologies. In particular, there is a recognized lack of techniques for two major tasks:

(1) localization and classification of waste containers of relatively small dimension buried within the sea-bed sediments;
(2) analytical methods for in situ assessment of accumulated toxicity in the biota due to prolonged exposure to contaminants slowly released.

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The lack of methods and techniques has so far frustrated thorough attempts at risk assessment of the large number of dismissed toxic dump sites in European seas (as well as in other regions worldwide) [1, 2]. It should be noted that waste dumping in close seas has been prohibited by the London Convention (1975). Before that, dumping was a legal and accepted practice, as had been the case for World War II toxic warfare agents [3]. Most of the material dumped prior to the adoption of the London Convention is now buried in the sediment, and even for known sites it is difficult to estimate the quantity of dumped material and the state of preservation of the containers. It should also be noted that the London convention may not have been sufficient to prevent covert dumping actions even after 1975.

The need for scientific and technological tools for buried dumping assessment has been recognized by the European Union. To respond to this need, the SITAR project has been established, starting in January 2002, with coordination by ISME, the Italian Interuniversity Centre of Integrated Systems for the Marine Environment, a participation of 10 different European partners (including Sweden, Norway, Lithuania, France, UK and Italy, and including Universities, research laboratories, environmental agencies, and industries) and for a duration of 3 yr [4]. The project, being multidisciplinary in nature, has focused its research on acoustic methods for localization and inspection of buried waste containers, biotoxicological methods for in situ toxicity assessment, and Geographical Information System (GIS)-based data integration and presentation. The GIS system, in particular, has to act as the communication tool between the information gathered at a dump site with standard as well as with SITAR-developed methodologies, and the end users with decision-making responsibilities in environmental management.

In this paper, together with a general background on the project and on its field activities, the development and evaluation of the GIS system are reported, including the image-processing tools specifically designed to allow virtual inspection of acoustically imaged buried containers. It should be emphasized that the paper does not aim to provide a case study for risk assessment of a specific site, although field data will be shown throughout the paper. The goal of the paper is to describe some of the technology research for an integrated approach in data processing and data management, in order to present end users (environmental decision-making agencies) with all the available data in a simple, clear, and comprehensive way.

2. SITAR organization and activities

The current major obstacles to a realistic risk evaluation at a given dump site are due to the fact that state-of-the-art technology has been proven to be ineffective at determining the extension and location of buried dumped containers, and potential or already present toxic effects due to bioaccumulation and prolonged exposure to contaminants. The SITAR project has focused on specific scientific and technological tools for the needs of dump-site surveys and investigations; these include the stages of localization, inspection, bioassessment, data integration, and evaluation.

As for the localization of buried containers (as small as a cylinder 1 m in length and 10 cm in diameter), SITAR has developed a bottom-penetrating parametric side-scan sonar instrument. Based on the nonlinear parametric effect of high-intensity acoustic transmission [5], the system operates as a traditional side-scan sonar, but it can yield co-located acoustical images of the seabed surface and of the sub-bottom by using both high- and low-frequency signals. A feature present only on the low-frequency part of the image is then localized as a buried feature.

The instrument is complemented with innovative 3-D synthetic aperture sonar processing [6], to enhance data quality and facilitate image interpretation.

Once localized, a potential waste container has to be inspected to assess its true nature and hazard. Video inspection is ineffective with buried containers. SITAR has investigated, both theoretically and experimentally, an acoustical imaging technique based on Multiple Aspect Scattering measurements (MAS) from the buried container. The buried feature is acoustically illuminated with a directional source at various grazing angles, and the acoustic scattering returns at various azimuthal and elevation angles are recorded. One of the possible geometrical configurations for such measurements is shown in figure 1, where the source is operated from an underwater vehicle (ROV), while a vertical hydrophone array acts as a receiver. The acoustic data gathered from this configuration are then processed, exploiting the knowledge of the source-receiver geometry and the data redundancy, in order finally to obtain a geographically referenced 3-D matrix that associates each (x, y, z) coordinate with an acoustic scattering intensity value [7]. The 3-D matrix thus obtained is the 'raw' input acoustic data to the image-processing technique described below. The MAS technique has been investigated experimentally under controlled conditions, in a scaled laboratory tank, before testing it in the field.

In contrast with acute toxicity analysis, SITAR has focused on bioaccumulated toxicity evaluation, by further developing and testing the technique of nanoinjection into fertilized fish eggs of extracts from bottom samples. The observed percentage of growth disorders, when compared with the percentage disorders resulting from extracts of a known reference site, gives a relative measure of accumulated toxicity. The technique mimics maternal exposure and food uptake, and it is species- and pollutant-independent [8].

A GIS-based data presentation system has also been developed, on specification from final end users, to integrate and present the needed data, gathered by the project-developed techniques and/or by standard surveys. The development of the GIS system will be discussed in detail in subsequent sections.

The methodologies and techniques investigated in the project have been tested at sea on a dismissed dump site in the Stockholm archipelago. The experimental activities took

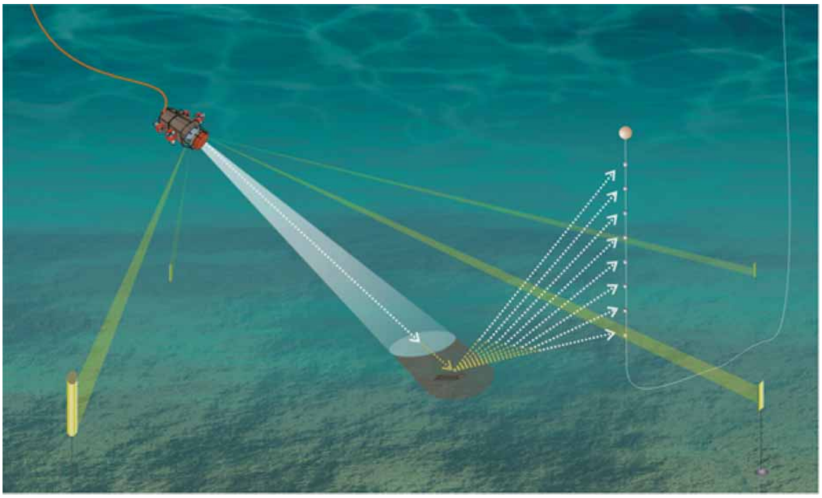


Figure 1. Experimental configuration for the MAS technique. A remotely operated vehicle (ROV) operates a directional acoustic source directed toward the buried feature; the scattered returns are received on a vertical line array; the ROV moves in circle around the feature, in order to illuminate it from different azimuthal angles. Figure courtesy of FOI, Swedish Defence Research Establishment.

place from 22 September to 10 October, involving two ships: one operating the parametric side-scan sonar prototype, in a survey fashion, and the other operating two ROVs and a vertical hydrophone array for video inspection and MAS measurements on potential targets detected by the first ship. The availability of previous surveys and historical background on the site allowed for a comparison of the results obtained with independent 'ground truth'.

3. SITAR GIS system

The integrated application of techniques and methodologies from information and control engineering, such as GIS and Decision Support Systems (DSS), can generate effective and flexible tools to address several types of problems in environmental management. The use of these tools can typically be appropriate whenever it is possible to obtain a quantitative formalization of the problem, adequately supported by engineering and economic evaluations, decision methodologies, and dynamic models of the systems studied. The application of computers to information about the terrestrial surface is widely used and well known [9], while for the marine and coastal environment, the situation is far less straightforward. From the perspective of geographic information science, the growing interest in marine and coastal applications is fascinating. The increased interest in oceans has led to improvements in the analytical potential of GIS, while extending the methodology framework for marine applications [10]. Many challenges remain, such as addressing the multiple dimensionality and dynamism of oceanographic data, and the development of effective conceptual and data models of marine objects and phenomena. Breman [10] reviewed how the GIS capabilities have been used to represent different aspects connected to the marine environment.

Within SITAR, the GIS development has been mainly directed toward the goal of supporting decision-makers in accessing the great amount of information involved in risk assessment of dump sites. The general design guideline is that of allowing the user to start from general thematic maps, where the information is presented graphically in a qualitative and intuitively appealing manner. Upon the user's request, the system can display information at increasing levels of detail, yielding raw data points, should the user wish to inspect them. Economical, social, and political considerations, in particular related to the management of the site, were beyond the scope of the project, and such information is not included in the developed system.

The system architecture (figure 2) is based on the Data Base Management System (DBMS) and the GIS software layers, integrated through the use of a graphic interface. Several data classes can be handled (metadata, maps, videos, images, etc.), and different kinds of queries can be performed on the basis of the end user's requirements. The data that have been collected and that are necessary to describe the status of the dump site can be divided into four main sets:

- environmental data, i.e. oceanographic information and chemical–physical parameters of the water column and the sediments;
- toxicological data, i.e. data from the nanoinjection technique tests;
- sea-bed data, i.e. data from standard bathymetry, side scan sonar, subbottom profiling surveys as well as data from the SITAR-investigated parametric side-scan sonar equipment; and
- object image data, i.e. standard video survey of barrels exposed over the sea bed, as well as SITAR-generated 3-D reconstructions of buried containers (from the Multiple Aspect Survey data).

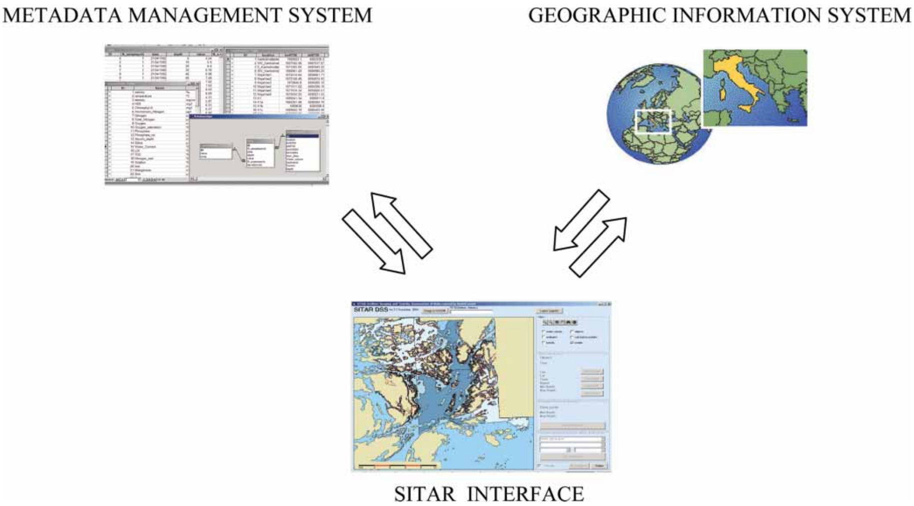
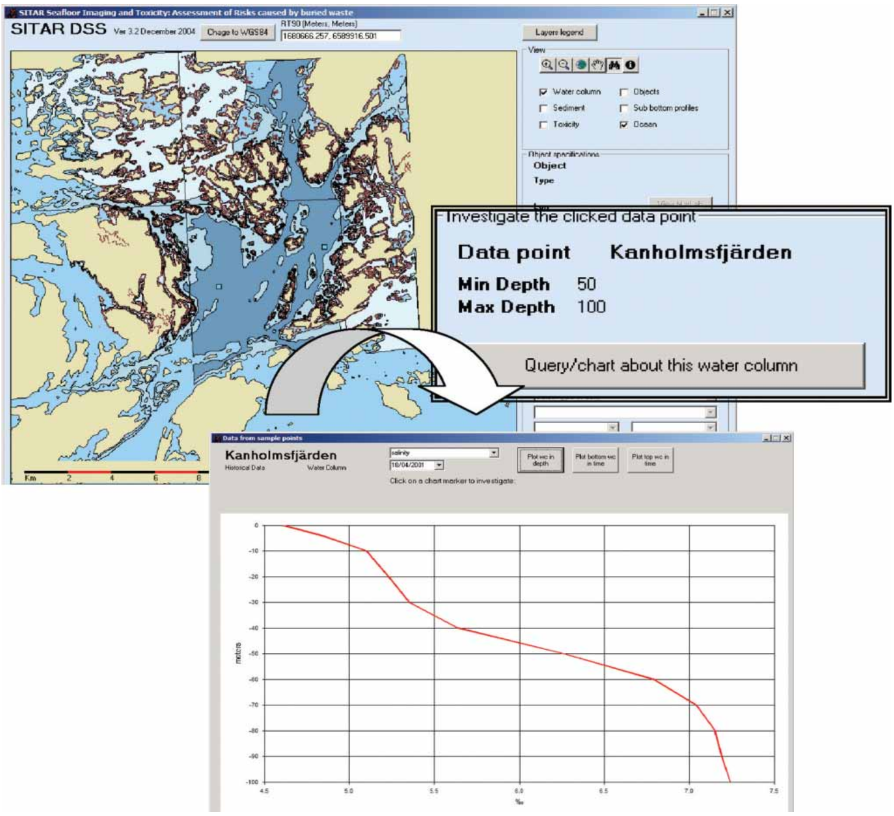


Figure 2. System architecture. A database management system and geographical information are merged in a GIS interface.

The information in the database can be retrieved by specific queries (selected from the end user's specification), and the results are shown in the form of charts. The queries can be easily performed from the developed interface; specifically, it is possible to obtain information on water-column data, sediments, toxicity analysis, and objects on the sea bed. The location of each sample point is displayed in a specific map layer. The data values, as well as the images and videos relative to a specific point or line, are directly accessible by simply clicking on the map layers. An additional pop-up mask allows the user to access, as needed, structured information over time, correlation with other data points, etc. (figure 3).

The layers created in the GIS represent different maps that are viewed through the interface (seen in different projections and coordinates systems: WGS84, RT90). The user can simultaneously or separately see the following layers by clicking directly on the interface: coastline, ocean, bathymetry, side scan sonar, sub-bottom profiles, toxicity sample points, sediments sample points, water column sample points, and object sample points. Figure 4 shows how the objects layer, the side scan sonar layers, and the sub-bottom profiles layer are displayed together on the interface. As an example, interrogating (by clicking) the subbottom profiles lines, the corresponding data are shown.

With the experimental campaigns performed for the SITAR project, different samples on the study area could be analysed. Specifically, several physical, chemical, and toxicity parameters can be associated with different sample points on the area. SITAR thematic maps geographically compare the values obtained in the experimental campaigns and in the laboratory analysis. In particular, for the toxicological data, colour coding has been employed, with 'hot colours' (e.g. red) corresponding to the level associated with higher relative toxicity and 'cold colours' (e.g. blue) corresponding to lower relative toxicity. A legend reporting the quantitative values of the map is always displayed, with the possibility for the user to define the dynamic range of the scale displayed. Thematic maps can thus be constructed for the various toxicity biomarkers; in figures 5 and 6, two examples of these maps are shown, the first for the SITAR experimental area, and the second integrating the SITAR data with additional data made available to SITAR and comprising a wider area in the Stockholm archipelago. In both maps, the represented quantity is EROD activity, where a higher measured level of induced EROD activity in the fish indicates a higher level of toxicity in the total extract injected in the fish eggs.


SITAR Seafloor Imaging and Toxicity: Assessment of Risks caused by buried waste

SITAR DSS Ver 3.2 December 2004

RT90 (Meters, Meters): 1680666.257, 6589916.501

☑ Water column
☐ Sediment
☐ Toxicity
☐ Objects
☐ Sub bottom profiles
☑ Ocean

Investigate the clicked data point

Data point Kanholmsfjärden
Min Depth 50
Max Depth 100

Data from sample points

Kanholmsfjärden
Historical Data Water Column

salinity
18/04/2001

Click on a chart marker to investigate:

Figure 3. Example of a query on data points (water column data, salinity versus depth at selected date). Interrogation is carried out by clicking on the data point on the map. An additional pop-up window allows the user to select among different queries on the data point.

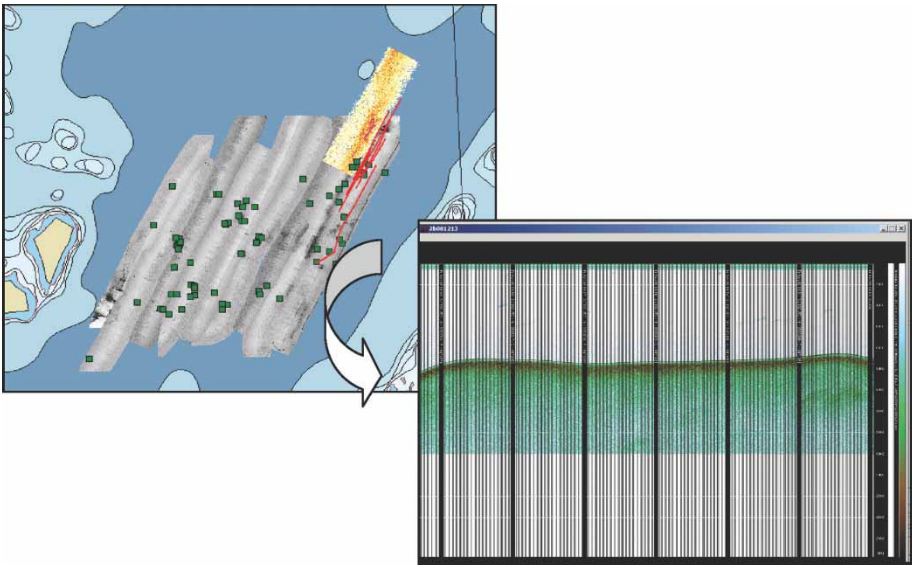


Figure 4. Thematic map displaying simultaneously bathymetry, object distribution, side scan sonar (standard side-scan in grey levels, SITAR-developed parametric side-scan data in color), and sub-bottom profile lines in red. Interrogation of a sub-bottom profiling line displays the raw data in a separate window. All data displayed are field data.

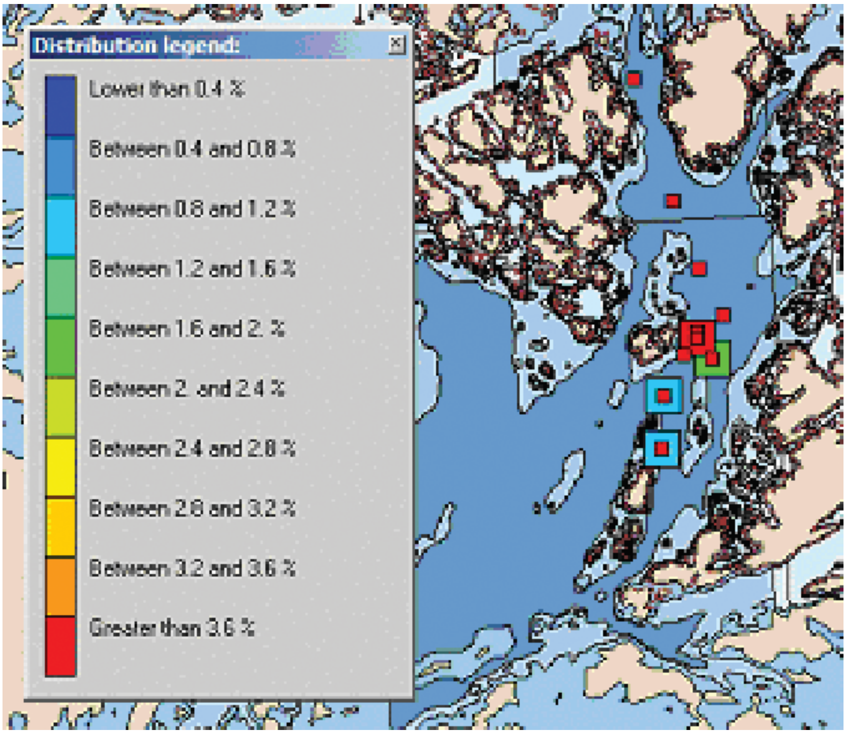


Figure 5. Thematic map of relative EROD-induced activity as measured from SITAR study-site samples. The map is shown as an indication of the capabilities of the data presentation system; environmental implications of the map presented are beyond the scope of this paper.

Finally, with the SITAR system, it is possible to display the identified object distribution, for both proud objects on the sediment surface and buried objects (figure 7). Interrogation of each object point (again by mouse-clicking) allows object information to be displayed, which may include a verbal description plus a video of the object, in the case of proud objects, or

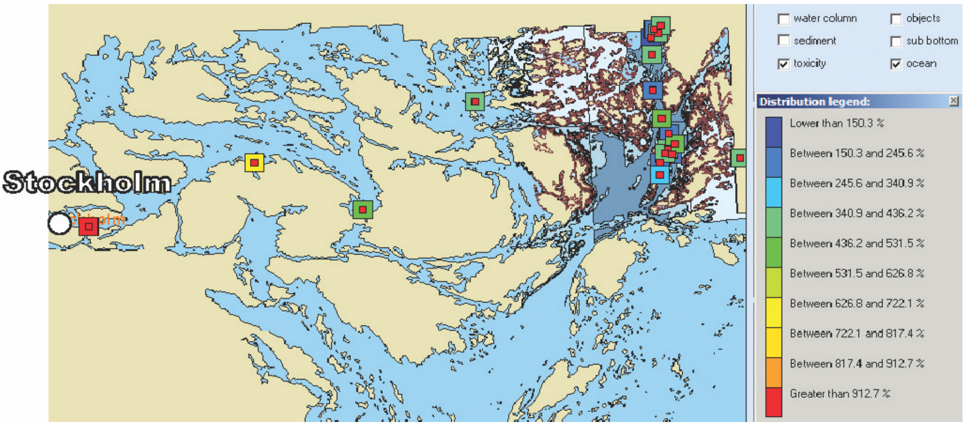

☐ water column ☐ objects
☐ sediment ☐ sub bottom
☑ toxicity ☑ ocean

Figure 6. Thematic map of relative EROD induced activity as measured at several sample points in the Stockholm archipelago (from the city of Stockholm eastward), including the SITAR study site. The map is shown as an indication of the capabilities of the data presentation system; environmental implications of the map presented are beyond the scope of this paper.

Which kind of data do you wish to visualize?

Figure 7. Zoom on the SITAR thematic map on object distribution at the site superimposed with side-scan sonar information and an image of one of the object, accessed by interrogating one of the object data point.

virtual visualization in the case of acoustically imaged buried objects. The methods and tools developed for the visualization of buried objects are the subject of the next section.

4. Analysis of buried objects in 3-D acoustic images

The development of DSS for image processing/analysis embedded in the data-integration system has the objective of analysing 3-D acoustic images of the sub-bottom and extracting salient characteristics of the buried objects. Investigation of man-made objects proud on the seafloor or buried into the bottom can be carried out by acoustic imaging techniques and subsequent data processing. A processing chain, starting from a 3-D acoustic image of the object (as obtained from the MAS experimental technique of Section II) and requiring a minimal interaction with the user, resulting in an augmented reality model, has been developed. Essentially, the chain includes blocks devoted to noise reduction, statistical 3-D segmentation, semi-automatic surface fitting, extraction of measurements, and Virtual Reality Modeling Language (VRML) modeling. A multi-resolution data representation based on an octree approach can be applied along different steps of the chain, if necessary.

When a volume is organized as a 3-D regular grid of voxels (volume elements), it can be very efficient to build a multi-resolution structure. Hierarchical data representations make it possible to decide at which level of spatial resolution an algorithm can be applied. The same operation (e.g. a segmentation procedure or a rendering method) can work at the first level of a hierarchical structure when the finest resolution is required, or it can be made simpler and sped up at a lower-resolution level. In particular, the octree is a multi-resolution pyramid for representation of three-dimensional spaces [11]. A 3-D image with a one-degree lower resolution in an octree scheme contains eight times fewer data, so it can be processed approximately eight times more quickly. The octree is built, starting from the base of the pyramid, i.e. from the finest-resolution level, and the resolution is iteratively reduced by spatially smoothing the available data (see figure 8 for a 2-D illustration of octree construction); using this procedure, it is possible to decrease data noise and to eliminate gaps in the data. In addition to the spatial smoothing performed through the octree data representation, a 3-D recursive median filter can also be applied in order to reduce speckle noise, which is typical for acoustic data.

To obtain useful information on the buried objects, a 3-D segmentation step is the key action to separate the voxels belonging to an object from the voxels belonging to the sea water, the seafloor, and the sediments. Image segmentation consists in identifying in the volume image

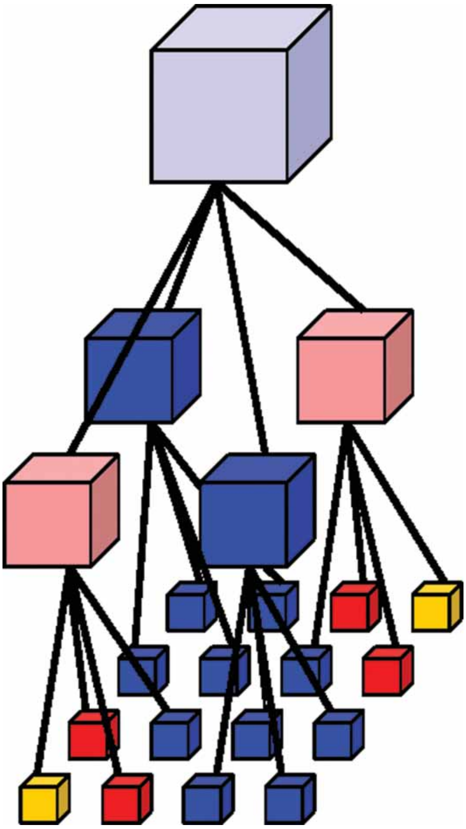
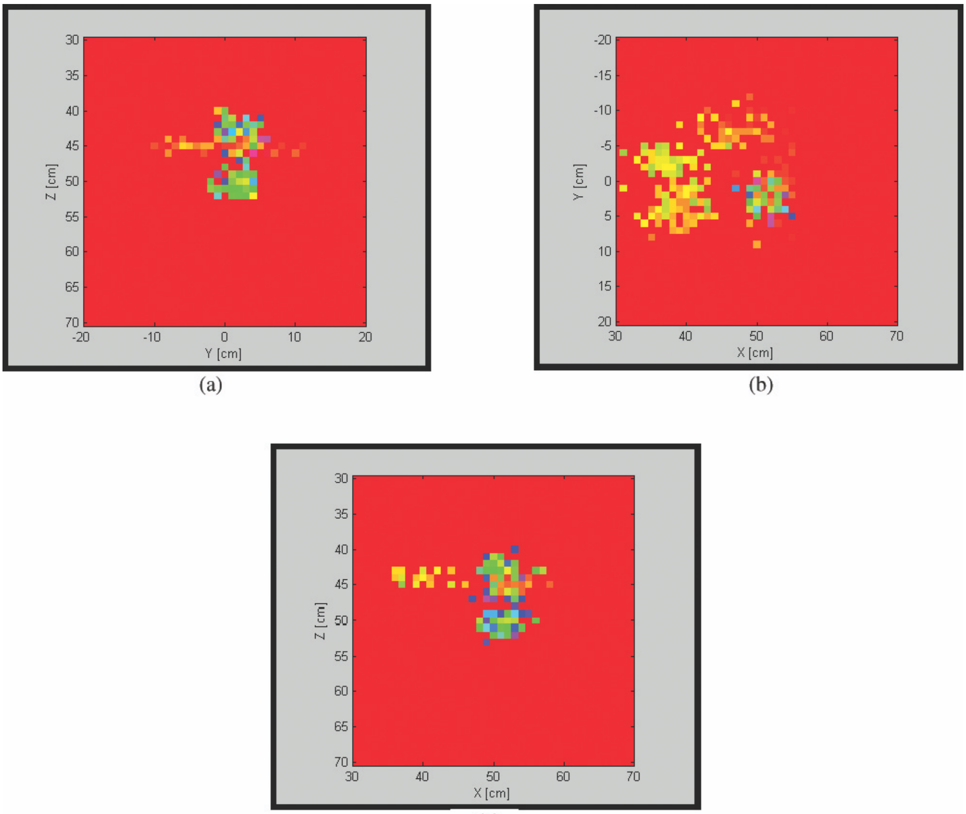


Figure 8. Octree pyramidal hyerarchical structure for data representation: the base of the pyramid represents the data-representation level with a higher resolution (each cube represents a single data voxel); each higher level is built by spatially averaging a group of nearby voxels (2^3 voxels for 3-D images, 2^2 voxels for 2-D images, as in the figure). As the pyramid grows, fine spatial details are lost, but data-storage requirements and processing times are reduced.

regions which are considered homogeneous according to several criterion. Segmentation is achieved in our case through a seeded volume growing procedure. The procedure needs to be initialized by a human operator, whose task is to select a (usually small) number of voxels belonging to different classes present in the image, according to the operator judgement. The selection of the voxels is fast and user-friendly: starting from a 2-D slice of the raw data (see figure 9), the operator must identify different regions corresponding to the different classes to be segmented. These initialization voxels are called ‘seeds’. Starting from the seeds, at each step of the algorithm each region grows by adding connected voxels with similar scattering intensities, where similarity is evaluated according to a measure of distance. The output of the volume grower is a set of labelled volumes, where the label indicates the membership of a voxel in a segmented object. Let us suppose n seeds have been selected, each corresponding to a class $A_i, i = 1, \ldots, n$. At each step of the algorithm, new voxels are added to some of the classes A_i by the following procedure:

(1) The unallocated voxels which border at least one of the regions are examined and are labelled according to the measure of distance.
(2) If the considered voxel x has more than one neighbouring region, a decision is made as to which region the voxel x should be added to. The distance from all its neighbouring



(a) (b) (c)

Figure 9. Bidimensional slice of 3-D acoustic scattering data as obtained from the MAS experimental technique. Each pixel (voxel) in the image corresponds to a scattering intensity, spatially referred. The background (no scattering) is red, progressively colder colours indicate a progressively higher scattering strength from the correspondingly located scatterer. (a) Slice parallel to plane $x = 0$; (b) slice parallel to plane $z = 0$; (c) slice parallel to plane $y = 0$. Data from tank test experiment conducted at the University of Bath.

> regions is calculated, and x is added to the region to which it is the closest. The algorithm ends when all the voxels have been allocated to a class, and the classes do not grow anymore.

The choice of the aggregation criterion is critical for the success of the segmentation task. Two different criteria have been applied to the segmentation procedure: the first based on the intensity mean value of the current regions; the second based on a fitting of the current volume histograms with an adequate probability density function. In the first case, the distance is a simple measure that states how far the intensity (i.e. the scattering strength) of the considered voxel x is from the intensity mean value of the current region. In the second case (statistical volume growing) at each step of the algorithm, for each region: (1) we calculate the current histogram; (2) we compute the parameters of the chosen probability density function (pdf), e.g. Gaussian, Rayleigh, Poisson, ..., that 'best' fit the histogram; (3) for each voxel connected to a region, we add it to that region if its intensity value satisfies the threshold condition based on the intersections of the current densities. If a considered voxel x, connected to a region A_i, has an intensity level g, accordingly to the estimated densities, it will be assigned to that region if pdf $A_i(g)$ is higher than pdf $A_k(g)$, $\forall\, k \neq i$.

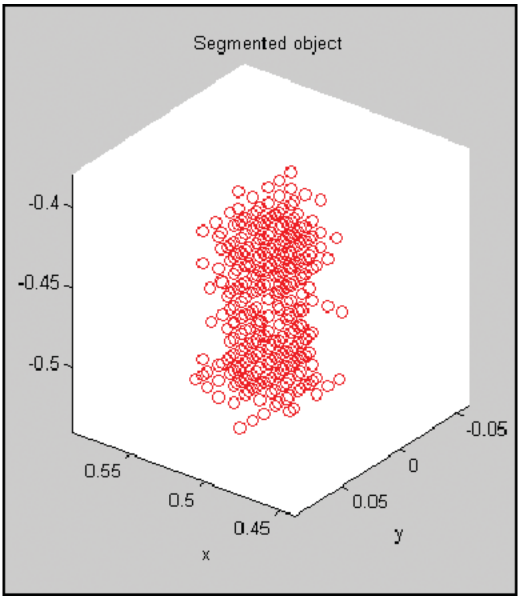
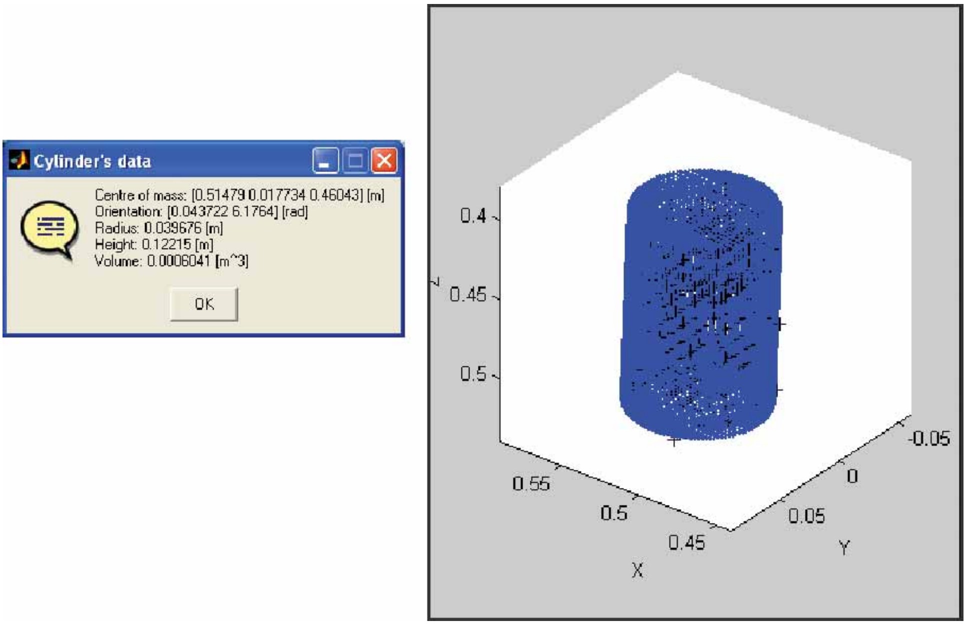


Figure 10. Results from the statistical segmentation process as applied to the data of figure 9. Voxels identified as belonging to the class “object” are displayed. Scales are in metres.

In figure 10, we display the statistical segmentation results obtained by processing the raw data of figure 9 when two regions are selected (object, sediment), and the chosen densities are Gaussian for the object and Rayleigh for the sediment.

The analysis of the segmentation results has the objective of extracting parameters that are useful in identifying the spatial orientation and dimensions of hypothetical objects present in the scene of interest. To estimate such features, a technique that can work with an ample set of object geometrical configurations has been developed. The input to this step is the voxel distribution coming from the segmentation stage representing the natural or man-made objects we want to analyse. The set of parameters to be estimated concerns the attitude of the object in the space: namely, starting from an inertial coordinate system (ICS), defined by the versors $\mathbf{v}_1, \mathbf{v}_2, \mathbf{v}_3$, we want to obtain the coordinate system (OCS), defined by the versors $\tilde{\mathbf{v}}_1, \tilde{\mathbf{v}}_2, \tilde{\mathbf{v}}_3$, fixed with respect to the object and taking into account the eventual object symmetry. Commonly, artificial objects can be assumed as rotational solids, namely, generated by a rotation of a surface about an axis. To obtain information on the orientation of a 3-D distribution of points, it is possible to use a particular tensor associated with such distribution, the Inertial Tensor (IT) [12]. The eigenvalues of the matrix associated with the IT correspond to the rotation inertia of the distribution around the principal axis defined by the directions of the corresponding eigenvectors of the matrix itself. In the case of a symmetric distribution, the eigenvectors of such a matrix, being the principal inertial axes, are symmetry axes, too. To identify the rotation axis among the three eigenvectors, user interaction is required. 3-D data are projected onto the planes normal to the eigenvectors, and the operator must choose the projection orthogonal to the axis of symmetry, identifying in such a projection an object with a circular (or partially circular) symmetry. Now, starting from the symmetry axes, it is possible to obtain the information to describe the orientation of the analysed object. The successive step concerns the estimation of features related to the physical dimensions of the target. This task is strongly dependent on the geometrical shape of the considered object; thus, a surface-reconstruction method has been developed for specific object classes. User interaction is



Centre of mass: [0.51479 0.017734 0.46043] [m]
Orientation: [0.043722 6.1764] [rad]
Radius: 0.039676 [m]
Height: 0.12215 [m]
Volume: 0.0006041 [m^3]

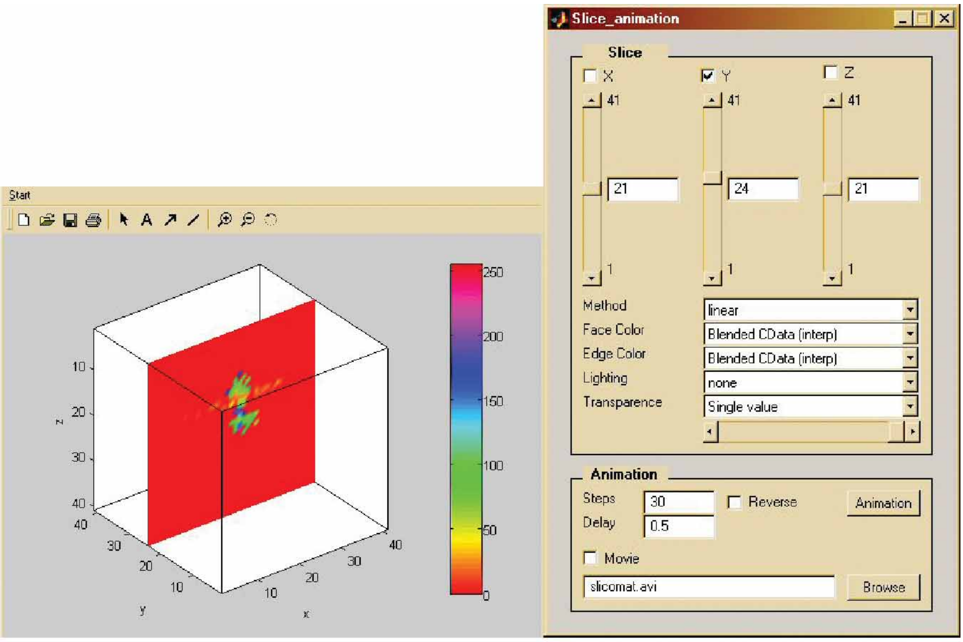
Figure 11. Fit of segmented data (figure 10) with a cylindrical shape, and extraction of relevant geometrical parameters from the estimated object inertial tensor. Scales are in metres.

required to choose from a database the model shape to be fitted on the segmented data. As an example, starting from the segmentation results of figure 10, the parameters obtained by the Inertial Tensor method and by selection of a cylinder model are shown in figure 11.

A free 3-D visualization software package, Matlab toolbox [13], has been partly adapted to our specific requirements. By means of a menu (figure 12), the user can inspect raw 3-D data by choosing the slice of interest (parallel to the plane x, y, z). Moreover, it is possible to visualize a sequence of slices by clicking on the button ‘animation’ of the menu. Figure 12 shows the toolbox interface: in panel (a) a slice parallel to plane y has been selected by the user; in panel (b) the tool menu is displayed. In this way, the user can rapidly and easily obtain information useful for the successive steps (e.g. seeds selection).

Last, but certainly not least, the development of an efficient technique of 3-D visualization can be a useful step in the human interpretation of both segmentation results and the respective model reconstructions. The operator can explore the insonified scene and make decisions supported by a better understanding of the objects present in the area of interest. To this aim, we have performed 3-D rendering by means of VRML. The point distribution representing the object segmented region has been described by means of a set of coordinates (x_i, y_i, z_i) with respect to the inertial system and associated with the same representation colour. Figure 13(a) shows the segmented cylinder rendered as a cloud of red points, whereas the water volume and the sediments are represented as blue and grey regions, respectively. Starting from the same virtual world representing the segmentation result, it is possible to add the reconstructed cylinder by a simple mouse-clicking on the button ‘Fitting’ (see figure 13(b)). Once in the VRML representation, the user can zoom on the object, look at it from different angles and orientation, rotate it, etc.

When presenting the data through the SITAR interface, the steps are reversed with respected to the processing chain: starting from the thematic map on object spatial distribution, by interrogating a point on the click of a mouse the user has immediate access to the VRML object reconstruction. However, the user also has access to all the other processing stage results



☐ X ☑ Y ☐ Z

41 41 41

21 24 21

1 1 1

Method linear

Face Color Blended CData (interp)

Edge Color Blended CData (interp)

Lighting none

Transparence Single value

Steps 30 ☐ Reverse

Delay 0.5

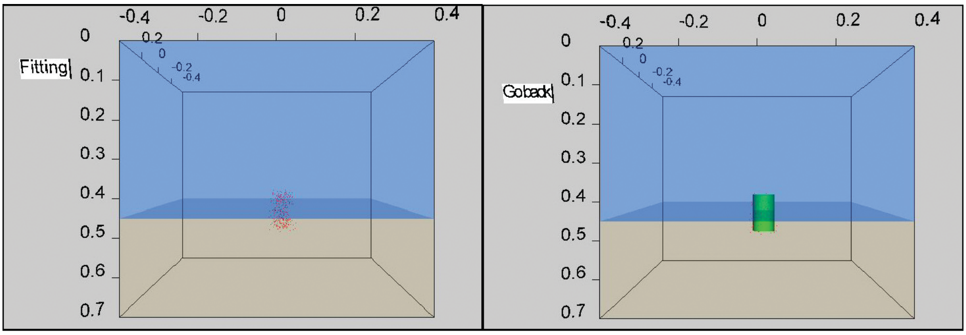
☐ Movie

slicomat.avi

(a) (b)

Figure 12. (a) 3-D visualization of the raw acoustic data; (b) toolbox menu. Scales are in voxel coordinates.

(not necessarily in the same order) and to the raw data. The possibility of visual inspecting the raw data is considered of paramount importance in avoiding erroneous interpretation: the user, in fact, must not be 'cheated' by the system, which may force an interpretation based, for instance, on a poor selection of geometrical classes in the processing steps; on the contrary, it is the end user who finally has to evaluate the credibility of the processing results vis-à-vis the raw data available. It has also been considered important to warn the user of the possibility of processing artefacts from the very moment the virtual inspection is started: for this reason, the VRML panel always includes the segmented points together with the geometric estimated shape, and a menu panel allowing the access to the previous stages output and V3D-based raw-data display.



(a) (b)

Figure 13. (a) VRML rendering of the segmentation result; (b) virtual reconstruction of the target. Scales are in metres.

Regarding the evaluation of the method, although a thorough discussion is not within the scope of the present work, it may be interesting to report that the data displayed in figures 9– 13 have been generated from acoustic scattering data acquired in controlled conditions (in a tank) by University of Bath researchers [14]. In particular, the scattering object was a cylindrical aluminium can, filled with fluid, 10 cm in length and 6.7 cm in diameter, and half buried in the tank silt sediment tray; this object is a scaled version of a standard oil drum of 58 cm in diameter and 88.5 cm in length [15]. The estimated dimensions from the processing of the acoustic data are a length of 12 cm (20% relative error) and a diameter of 4 cm (40% relative error). As can be observed from the figures, the position of the object (half buried) is also faithfully reconstructed.

5. System evaluation

The evaluation of a complex system such as the SITAR data/integration presentation is not straightforward. In particular, from a software-engineering point of view, one of the prerequisites of the final system is that of complying with design specifications (which the developed system does respect). However, compliance with specifications cannot be the sole indicator for system evaluation. The final system must also get through the subjective evaluation of the end-user community for which it has been primarily developed. Subjective evaluation can be performed through a structured procedure and does indeed lead to important indications on the system and on possible future developments. Subjective evaluation of the SITAR system has been organized in the following way [16]: a panel of eight experts has been assembled, with professional competences ranging from environmental decision/policy making (three people), environmental sciences (two people), underwater acoustic and oceanic engineering (two people), and a hydrographic survey (one people). The team was composed of personnel from institutions within the project and personnel from outside the project. After a short introduction of the system, each panelist has been left with the system CD-Rom, a User's guide and a PC, and had to install the system and to play with it exploring its different capabilities. At the end of the exercise, each panelist was asked to anonymously fill a form to indicate their subjective judgement on the following eight topics:

(1) software-installation procedure;
(2) user-interface appearance (colours, organization of information, etc.);
(3) ease of use;
(4) adequacy of all the information presented (as related to risk assessment);
(5) biotoxicity-data presentation;
(6) buried-object presentation;
(7) parametric side-scan sonar presentation (standard and synthetic aperture);
(8) environmental-data representation.

The judgement had to be given on each item accordingly to the following score:

- A = excellent (score: 4);
- B = good (score: 3);
- C = sufficient (score: 2);
- D = poor (score: 1);
- E = insufficient or lacking (score: 0).

The scores obtained on each item are reported as histograms in figure 14. Note that on some items, some of the panelists did not express a score. The mode ('majority vote') on each

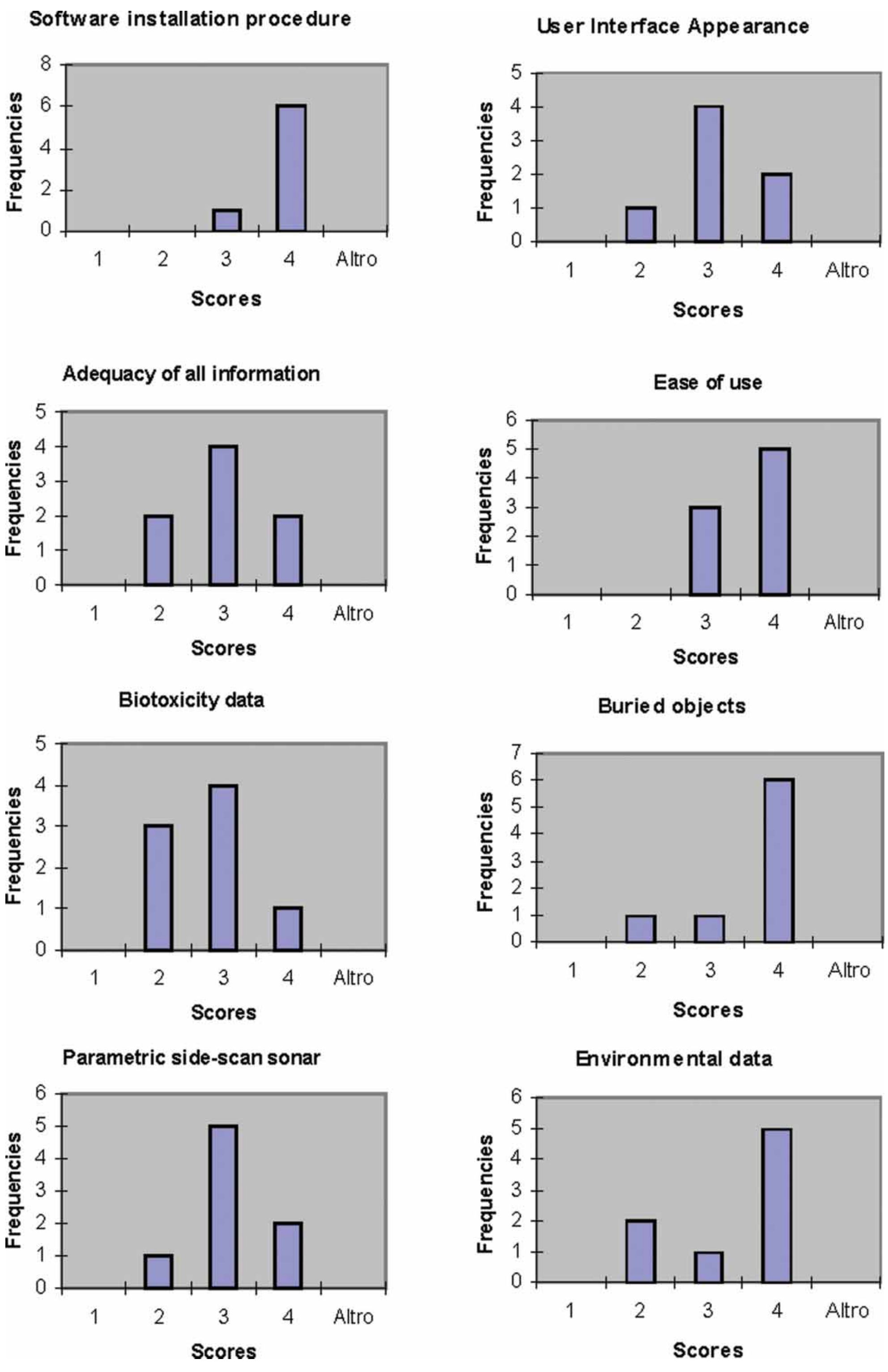


Figure 14. Results of the subjective evaluation by a panel of potential end-users.

Table 1. Summary of the mode (most frequent score) on the eight selected topics for GIS system qualitative evaluation.

Topic	Mode of the scores
Software-installation procedure	4
User-interface appearance	3
Ease of use	4
Adequacy of information	3
Biotoxicity data presentation	3
Buried-object presentation	4
Parametric side-scan sonar presentation	3
Environmental-data representation	4

topic is reported in table 1. A clear indication of user satisfaction emerges from the subjective evaluation exercise.

6. Conclusion

The general framework and objectives of the SITAR project have been described. Among the several enabling technologies for enhancing environmental risk assessment at sea-bed dump sites, investigated by the project, this paper has focused on the development of an integrated, GIS-based, data-presentation system. The developed system allows the display and interrogation of all the relevant data, from standard oceanographic and environmental information to specific, SITAR generated, data. Among these, particular attention has been paid to the representation of buried objects, either natural or man-made, that are made available through a volumetric acoustic-scattering image. The processing from the ‘raw’ acoustic image to a virtual rendering of the object and estimation of its geometrical features has been described, based on data from a tank experiment. The procedure for evaluating users’ subjective satisfaction on the final results have also been described. A general satisfaction on all aspects of the GIS system evaluated by the users emerges from the evaluation exercise. As mentioned throughout the paper, the aim of the project, as well as that of the present paper, is not to make a specific case study with the available field data, but that of showing current research results in marine technology developments guided by the requirements of the environmental community.

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