SARGIS: a GIS-based Decision-making Support System for Maritime Search and Rescue

LIAO Guoxiang
School of Navigation,
Wuhan University of Technology
Wuhan 430063, China
liaogx@whut.edu.cn

LI Maofeng
Division of Dangerous Cargo Management and Pollution Prevention
Guangdong Maritime Safety Administration
Guangzhou 510230, China

Abstract—A geographic information system (GIS) based software tool, namely SARGIS, is developed to provide supporting information for the maritime search and rescue (SAR) service. SARGIS is mainly consisting of supporting databases, application modules and graphical user interface (GUI). The geographic information, SAR resources, vessel movements and ocean environment databases are established to provide necessary data for SAR incident response operations. The drift prediction module can estimate the temporal-spatial distribution and trajectory of the targets using a Monte-Carlo particle model, in which the tidal current, wind-driven current and leeway are taken into account. The SAR planning module can assist the response commander to determine the searching area, and search patterns, allocate the SAR units. From the data management to the visualization of SAR prediction and decision making results, all the system operations can be directed shown in the well-designed interactive GUI/GIS platform.

Keywords- maritime search and rescue (SAR); drift prediction model; decision support; geographic information system (GIS)

I. INTRODUCTION

Harsh weather condition, such as storms and typhoons, may cause serve incidents which requires the maritime search and rescue services. To minimize the loss of the lives and properties due to such events, the government needs to respond quickly and determines feasible searching area and rescue plans in short time. Traditionally, such a decision-making procedure for the emergency response is handled manually. It is inefficient in practice. By far, the computer-based decision support software tools are widely used in different fields and have shown their powerful effects in practice. Therefore, it’s meaningful and important to develop a computer-based decision making software tool for the maritime search and rescue services.

The International Aeronautical Organization (ICAO) and the International Maritime Organization (IMO) have published the international aeronautical and maritime search and rescue (IAMSAR) manual, which focuses on the organization and management, mission co-ordination, and mobile facilities, and provides a lot of technical supports for the search and rescue operations [1]. The developed countries such as the United States, the United Kingdom, and Canada have established their systematic organizations and applied the advanced information software systems (i.e. SARIS of UK, SAROPS of USA, and CANSARP of Canada [2]) to improve the operation efficiency in search and rescue services. China has also established a rather complete organization system and achieved lots of success in maritime search and rescue over the past decades. Recently, more and more Chinese scholars paid attention to the applications of information technology to the maritime search and rescue. Zhai (2006) comprehensively discussed the information mixture theory used in search and rescue decision [3], Chen et al. (2008) presented a flow field model and its application in search and rescue operations in adjoining sea area of Zhanjiang [4], Ma et al. (2009) developed a maritime search and rescue decision-making system using the Microsoft VC# programming technique [5]. However, compared with the software tools applied by the developed countries, those developed and used in China is still need to be improved, especially, in the visualization platform. Applications of the Geographic Information System (GIS) have shown its great advantages in the geospatial data management and visualization [6]. It has also shown a great potential in decision-making support for the public emergency incident treatment [7]. Therefore, we developed a GIS-based computer tool, namely SARGIS, aiming to provide more efficient, easy-to-use and visual display supports for the emergency response in maritime search and rescue services. In this paper, an overview of SARGIS will be presented in Section 2, the main methods of system development and implementation will be introduced in Section 3, and the conclusion will be given in Section 4.

II. AN OVERVIEW OF SARGIS SYSTEM

A. System Structure

According to the national response plan for maritime SAR emergency, the basic procedure of maritime SAR is listed as follow:

(a) receiving an alarm call;
(b) handling and collecting the necessary information and data (e.g. time and location of the incident, types of distress targets, ocean environment condition);
(c) analyzing and determining the possible areas that contain the search targets;
(d) making a feasible search and rescue plan, or starting the oil spill response plan if applicable;

At the end the whole actions, results will be evaluated until it meets the requirements of ending the tasks.
The SARGIS system is designed to meet the actual requirements of the maritime SAR. It consists of supporting databases, application modules, GIS platform, and graphical user interface (GUI), as illustrated in Fig. 1.

![Schematic overview of the SARGIS system](image)

**B. Application modules**

1) **GIS Application Platform**

The GIS platform has two main sub-application functions. They are the basic GIS functions and the Interaction functions for numerical modeling. The former includes the electronic map operations, e.g. zooming in/out of the electronic map, measuring distance/area, printing of the map, controlling GIS layers and map projection. In SARGIS, the GIS platform is designed to help users to implement the generation and visualization of the input data (wind and current fields, computational grids, etc.) and output results (the drifting pathways of search targets, search patterns, etc.).

2) **SAR Resources Management Module**

This module is designed to manage the diverse SAR resources and provide quick inquires of these data. In SARGIS, most of the data are stored in the related databases. It is easy to use the current database technologies to implement the data managements such as adding/editing/deleting data records. Moreover, the system also provides the functions of both accurate and fuzzy inquires of the data, which help the user to find the required information for maritime SAR in short time.

3) **Search Targets Drift Trajectory Prediction Module**

One of the most important tasks in maritime SAR practices is to determine the possible temporal-spatial locations of the search target. For this purpose, a model for predicting the drift of the search target is designed and employed in SARGIS. The output of this model including the possible area where the target might be, and helps the response commander to make feasible search and rescue plans.

4) **SAR Planning Module**

The SAR planning module includes the determination of datum and the search area, developing an attainable plan for search and rescue units (SRU) allocation, selecting search patterns and tracking spacing to achieve a suitable area coverage, planning on-scene co-ordination, transmitting the search plan to the on-scene commander/SRUs and periodically reviewing/updating the search plan. The most suitable search and rescue plan can be recommended automatically by this module after collecting corresponding data for analysis.

5) **Oil Spill Response Module**

The oil spill pollution may occur in the cases where the distress ship is grounded or collided. In such cases, an oil spill response planning is also necessary. We have developed an oil spill simulation program in the previous study [8], which can predict the trajectory and fates of the spilled oil, analyze the risk of sensitive resource and coastline that may be impacted, and provide the necessary response information (e.g. oil spill response plan, the oil clean techniques). This program is integrated with SARGIS.

III. **SYSTEM IMPLEMENTATION**

In this paper, we summarize some key technologies of system development including the establishment of the supporting databases, development of the search targets drift prediction model, selection of different search patterns, and methods for system integration.

A. **Establishment of Supporting Databases**

1) **Geographic Information Database**

The digital maps required by the system are generated using a digital scanner. The corresponding geographic information database is updated manually by the internal add/edit/delete function. In SARGIS, the geographic information database is mainly made up of two categories of geographical data, i.e. marine geographic information and land geographic information. The former includes shorelines, islands, soundings, isobaths and sea-routes. The latter covers the administrative districts, place names for cities, counties and towns, the government offices, roads and so on.

2) **Search and Rescue Resources Database**

The resources available for responding to a search and rescue practices are saved in this database. Those include several categories of data as below:

(a) Support organizations, e.g. the maritime safety administration (MSA), state oceanic administration (SOA), public security bureau, traffic bureau, bureau of fishery etc.

(b) Response teams, e.g. the professional marine rescue teams, the experts that can provide professional solution to relative technical problems, and the medical team to save lives that may be in distress.

(c) Search devices including the salvage ships, aircrafts, real-time communication devices, search radars and other equipments that may assist the search actions.

3) **Vessel Movement Database**

The vessel movement data always are of great importance in maritime SAR practices. In SARGIS, the dynamic vessel movement data are extracted from several important maritime operation systems, including the vessel management system (VTS), the automatic identification system (AIS) and the vessel movement reporting system. Once
the vessel data are linked with the GIS platform, they can be searched and displayed on the electronic navigation map.

4) Ocean Environment Database

In practice, the ocean environment data forms the basis of predicting the drift behavior of the search targets. In this database, the historical winds, currents, waves, temperatures, and other important ocean environmental elements are stored. In SARGIS, most of the above data are provided by the meteorological bureau. For the surface sea current data, it also can be predicted using a two-dimensional current prediction model integrated with the system. In this way, when the SAR incidents happened, the users can obtain the latest observed and predicted oceanic environment data quickly.

B. Search Objects Drift Prediction Modeling

In maritime SAR practices, the allocations of SAR units depend on the estimated locations of the search targets (e.g., vessels or persons in water). In this subsection, the related model for predicting the trajectory of the search object is presented.

1) Tidal Current Prediction

In this study, a two-dimensional tidal current model is developed to generate the surface current filed for the search targets drift prediction. Assuming constant density, the tides and tidal currents are controlled by the following equations, in which the x-axis is eastward, y-axis northward:

$$\frac{\partial \eta}{\partial t} + \frac{\partial (Hu)}{\partial x} + \frac{\partial (Hv)}{\partial y} = 0 \quad (1)$$

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} - fv + g \frac{\partial \eta}{\partial x} + g \frac{u}{HC^2} \sqrt{u^2 + v^2} = 0 \quad (2)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + fu + g \frac{\partial \eta}{\partial y} + \frac{v}{HC^2} \sqrt{u^2 + v^2} = 0 \quad (3)$$

in which the x-axis is eastward, y-axis northward; \(g\) is gravitational acceleration; \(f=2\Omega\sin\varphi\) is the Coriolis force coefficient, \(\Omega\) is the rotational angular velocity of the Earth, \(\varphi\) is latitude; \(u, v\) are eastward and northward velocities, respectively; \(H = h + \eta\), where \(h\) is the water depth and \(\eta\) is the surface elevation; \(C\) is the Cherry coefficient and is given by \(C = 1/n \times (H)^{1/6}\), where \(n\) is the Manning coefficient, and \(H\) is the average depth around the calculation point.

Eqs. (1) to (3) are solved numerically using the finite difference method adopting an alternating direction implicit (ADI) technique. The equations are discretized by using a regularly spaced grid, and the second-order central difference scheme is used.

Both the closed and open boundaries need to be set for calculation. On the closed boundaries, the velocities are set to be zero and the gradient of the surface elevation across the boundaries is zero. On the open boundaries, the surface elevation is given harmonically and the gradient of velocities across the boundaries is zero.

After being generated, the current field can be displayed in the GIS platform of the system. An example is shown in Fig.2 for the current field at the Pearl River estuary of Guangdong Province in China.

2) Leeway Simulation

The occurrence of the winds causes a leeway effect moving the search targets (e.g., vessels or persons in water) from one place to another. This makes it more difficult to determine the exact positions of the search targets. Hence, the leeway effect generated by wind must be taken into account in the drift prediction model. The leeway effect \(VL\) can be calculated using the following formula:

$$V_L = k \times W \quad (4)$$

where \(W\) is the wind speed at 10 meters above the sea surface; \(k\) is a coefficient whose value varies for different search targets, tonnages and the ratio of the depth against the draft. Under the condition that the sea wind speed is 3–20 m/s, the empirical relationships between the leeway and the drift speed for different search targets can be estimated based on the statistics data, see table 1.

Table 1 Empirical formulas of wind pressure drifting speed for different types of search targets [4]

<table>
<thead>
<tr>
<th>Search targets</th>
<th>Empirical formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light load passenger ships (low tonnage), skiffs, and life-crafts, etc.</td>
<td>0.07W + 0.04</td>
</tr>
<tr>
<td>Full load passenger ships (load tonnage), skiffs, and life-crafts, etc.</td>
<td>0.05W – 0.12</td>
</tr>
<tr>
<td>Large passenger ships, and large ships with idle load</td>
<td>0.05W</td>
</tr>
<tr>
<td>Half load cargo ships (mid tonnage) and fishing boats</td>
<td>0.04W</td>
</tr>
<tr>
<td>Ships (large tonnage) with full load</td>
<td>0.03W</td>
</tr>
<tr>
<td>Sailboard</td>
<td>0.02W</td>
</tr>
</tbody>
</table>

3) Drift Trajectory Prediction

To predict the drift trajectory of the search target, a model based on Monte-Carlo particle method is developed. In this model, the possible position of the search target is represented by a large number of particles with their initial location being set as the last known position. It is assumed that the target is passively floating without any source of motivity. At every time step forward, the new position of each particle is estimated using:

$$X_i = X_{i-1} + U\Delta t + L \quad (5)$$
where $X=(x,y)$ and the subscribe $i$ and $(i-1)$ represent those at the $i^{th}$ and $(i-1)^{th}$ time step, respectively; $U=(u,v)$ in which $u$ and $v$ are the mean horizontal velocity vector of the summation of the ocean surface current and the leeway effect; $\Delta t$ is the time step; $L=(l_x,l_y)$ with $l_x$, $l_y$ being the eastward and northward random walk distances, respectively. At every time step, the search area that contains the target may be estimated using the spatial distribution of all particles.

C. Search Patterns

Once we have obtained necessary information listed above, the system is able to assist selecting a proper search pattern which is very important procedure in the maritime search and rescue practices. A reasonable pattern will help to find the lost target in shorter time. In practice, different search patterns will be applied based on the results generated by the drift prediction model. There are several built-in search patterns available in SARGIS, including expanding square search, sector search, parallel search, and creeping line search, as shown in Figure 4.

D. System Integration

1) Integrating the Modules with GIS

The search target drift prediction module is written using the FORTRAN programming language and built as an executable program under Microsoft Windows operation system. The communication between the model and the GUI of the system is through file. For example, the GUI generates a file containing all required input parameters for the search target drift prediction module and the latter read the file to collect the data. The output files will be interpreted and then visually displayed in the GIS platform. From the point of system integration, this module is integrated with GIS in a loose coupled way.

The other modules and GUI are designed and implemented using Visual C++ programming language. Thus, these modules are tightly integrated with the GIS platform.

2) Graphical User Interface

Figure 5 shows the GUI of SARGIS. Mark A is the system menus and toolbars, many shortcut buttons are embedded in the toolbars, which allow the users to quickly execute the operations such as map operation, environment data management, and so on. Mark B is the GIS layer control. The users can easily enable or disable the visibility of any GIS layer. Mark C is the map display area, in which all geographically referenced data (e.g. the current filed, trajectory, search patterns) can be display visually in static or dynamic way. Mark D is the dialog for the search target drift prediction. Mark E is the message board, in which messages will be shown to notify the uses the ongoing operations.

Fig.5 Graphical user interface of the SARGIS system

IV. CONCLUSION

A GIS-based maritime search and rescue software system (SARGIS) is designed and presented in this paper. The use of GIS enables the system easy to manage the data and visualize the input/output. Many necessary application functions, i.e. SAR resources management, search target drift prediction module, SAR planning generation, have been developed and integrated in the system. All these aims to provide a powerful decision support tool for the SAR emergency services.

REFERENCES