A Fast Algorithm of Cartographic Sounding Selection

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ABSTRACT An effective strategy and framework that adequately integrate the automated and manual processes for fast cartographic sounding selection is presented. The important submarine topographic features are extracted for important soundings selection, and an improved "influence circle" algorithm is introduced for sounding selection. For automatic configuration of soundings distribution pattern, a special algorithm considering multi-factors is employed. A semi-automatic method for solving the ambiguous conflicts is described. On the basis of the algorithms and strategies a system named HGIS for fast cartographic sounding selection is developed and applied in Chinese Marine Safety Administration Bureau (CMSAB). The application experiments show that the system is effective and reliable. At last some conclusions and the future work are given.

KEY WORDS cartographic sounding selection; DEM; TIN; influence circle; topology consistency

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Introduction

Even if many of the steps involved in chart production have been automated, the compilation of nautical charts remains predominantly a manual task. One of the cartographic compilation tasks is the selection of soundings for displaying on a chart, which provides information about the morphology of the seabed between chart depth contours. Soundings presented on a chart are only a small subset of the soundings used to support compilation of the chart depth contours, but there still may be thousands of soundings on a single chart. So it is necessary to select a small number of suitable soundings, which represent a large group of soundings adequately. To perform the selection properly, it is necessary to analyze the selection criteria. The following is a set of criteria proposed by researchers for such a purpose.

1) To select shallower soundings and throw away deeper soundings. That is, in any small area of the chart, the shallowest soundings must be chosen so as to keep navigation safety.

2) To select those soundings that represent important topography features. In the dangerous and other important areas, the density of soundings must be high enough so as to attract the attention from navigators. Closed depth contours and import feature points in depth contours must be controlled by sounding selection.

3) To make the distribution and density of soundings vary with the importance of submarine topography features. Generally speaking, in the areas with complex topography like sea-route, watercourse and dangerous areas, the density of soundings is higher than that in flat areas.

4) To make the pattern of soundings distribution diamond-shaped. And the shorter diagonal of the rhombus should be perpendicular to the vertical direction of the seacoast and sea-route. The ratio between the long and short diagonals...
of the rhombus should vary with the gradient of the submarine topography.

5) To keep consistency between soundings and other features such as seacoast, depth contours, beaches, islands, reefs and so on, when selecting soundings.

So far, some sophisticated selection techniques have been proposed, e.g., the matching method\(^1\), the neural network\(^2\),\(^3\),\(^4\), the expert system\(^4\),\(^5\), the TIN method\(^6\),\(^7\), the feature recognition method\(^8\). However, because of the complexity and difficulties of sounding selection, almost all these algorithms are not very satisfactory\(^9\). This is not suitable for the rapid development of marine science and techniques. On the other hand, in chart compilation and production it is very urgent to build a reasonable framework or workflow so as to reduce sounding selection workload and improve work efficiency.

Although fully automation for cartographic sounding selection is very difficult, it is still desirable to develop some practical semi-automated algorithms and strategies for fast sounding selection in chart production projects. In the light of this standpoint, the authors analyze the algorithms presented in the literatures and present a framework for semi-automated solution. In other words, all the algorithms and strategies are designed for fast sounding selection not for pure theoretical perfection. On the basis of these algorithms and strategies, a system named HGIS that is a subsystem of the hydrographic production and management information system (HY-PAMIS) for sounding selection was developed for Chinese Marine Safety Administration Bureau (CMSAB).

1 Basic principle and framework for sounding selection

As described above, the main purpose of this study is to develop an new algorithm for fast and accurate selection of different types of soundings for the compilation and production of charts instead of pure algorithm perfection. Therefore, an effective method adopted in this study is semi-automated. That means, on one hand, automated processes are employed as much as possible and, on the other hand, semi-automated or manual procedures are paid more attention for those operations that are difficult to computer. This is one of basic strategies for fast sounding selection system.

In fact, three problems should be resolved in sounding selection. The first is how to select important soundings; the second is how to configure the pattern and density of selected soundings; and the third is how to resolve the conflicts between selected soundings and other features and subsequently to adjust the incorrect relationship. The first and the second problems are all related to terrain features. So digital elevation model (DEM) is used to represent these features. A number of topographic parameters are computed and/or extracted from DEM, including slope/aspect, surface area, average height, valleys, ridges and so on. These parameters can be used to help the selection of important soundings. For those features related to safe navigation such as sea-route, seacoast, watercourse, dangerous areas, all information including spatial extent, main profile direction, profile position and the like are obtained by computer-aided methods. Such parameters are recorded in four layers, i.e., sounding parameters layer, topographic area layer, special area layer and profile layer. Different layers make the system very flexible when some soundings have undergone changes because of update, modification or other reasons. For sounding selection, an improved algorithm based on influence circle is employed. A special algorithm considering many factors is designed for automatic configuration of selected soundings. For the third problem the system can automatically provides users with the ambiguous conflicts and the operator can quickly solve it according to context information. The framework and flow chart of the system are illustrated in Fig. 1, dotted lines represent semi-automated and/or manual operations.
2 Key procedures for sounding selection

2.1 Recognition and extraction of important topography features

DEM is one of the most important representation methods for submarine topography. A lot of algorithms for creating DEM from irregular points and feature lines are available. The Delaunary triangulation is the most popular method and is employed here to build TIN(triangulated irregular networks). An interpolation process is applied to the TIN to create grid DEM and the depth contours are traced in grid DEM. In order to represent accurate submarine topography the value of depth contour interval is defined as the minimum space interval among soundings.

The key soundings always lie in those areas with important submarine topographic features and so it is necessary to extract these important features. Generally speaking, many important submarine topographic features appear in those area that is composed of “flat triangles” (i.e. triangles whose three vertices have same heights) and therefore extraction of flat triangles from TIN become a key to success. An example of flat triangles is shown in Fig. 2. Other missing important topography feature should also be extracted from DEM. The existed algorithms can be employed for such a purpose. For these important submarine topographic features, the VIP (very important point) areas are built and corresponding parameters are recorded.

Considering the difficulty of automatic extraction of important areas such as sea-route, water-course, dangerous areas and so on, manual opera-
tion using some editing tools is the best choice. In order to help the operator find and outline these important areas quickly, the ortho-shading map created from DEM is employed for representing distinct information (shown in Fig. 3). Of course, other information is also helpful.

![Fig. 2 Extraction of submarine topographic features from flat triangles based on TIN](image1)

2.2 An improved sounding selection algorithm

In general, an algorithm based on "influence circle"[^1] for selecting soundings (especially background soundings) is very effective when ignoring other complex factors. The basic principle of this algorithm is that only the shallowest sounding will be chosen among all the soundings inside the circle and the others will be eliminated. The radius of the influence circle can be defined as

\[
R = a \times S^2 + b \times S + c \quad (1)
\]

where \( S \) is the sounding value; \( a, b, c \) are coefficients defined by the user. Obviously, the sounding is deeper, the influence circle is larger. An example of influence circle is shown in Fig. 4. In Fig. 4(b), the other lines are sea-route, and other dangerous features that are important to safe navigation.

![Fig. 3 Overlapping the ortho-shading map created by DEM and vector data to help the extraction of important topographic features](image2)

This algorithm is effective when only soundings are used, however, if considering submarine topography features and other features, the algorithm needs to be modified. Here we call this algorithm as conditional influence circle algorithm. The principle and steps of the modified algorithm are described as follows.

1) Prepare two lists and one list array. The first list is the raw list and the second is the selected list. The list array is for the VIP area.
2) Sort the whole data set by depth with the shallowest sounding first and put the sorted results into the raw list.
3) Check the sorted results for each important feature area and put the soundings that fall in this feature area into the corresponding VIP area.

![Fig. 4 Principle of influence circle sounding selection algorithm](image3)
These soundings are then removed from raw list.

4) Select the first sounding in this list (the shallowest one) and place it in the selected sounding list. Other soundings whose centres are in the influence circle are removed except this one from the raw list.

5) Examine the next sounding in the updated raw list and repeat Step 2 until all the soundings in the raw sounding list are removed.

In order to speed the search procedure, a grid index is employed. This means that the whole data set can be divided into \( n \times m \) cells and each cell records one unique ID number for the sounding falling into this cell. The number of row and column can be calculated by use of the extent of the whole data sets and the radius of influence circle. Suppose the width and the height of the data envelope is \( W \) and extent \( H \) respectively, the radius of the influence circle is \( R \), then we have

\[
\begin{align*}
    n &= \frac{W}{R} \\
    m &= \frac{H}{R}
\end{align*}
\]

Generally speaking, to primary soundings and limiting soundings, the distribution pattern is not as important as the density. Especially for complex and dangerous area, the soundings would be so dense that the radius value of influence circle would be very small. The soundings selected based on the "influence circle" algorithm are not yet the final results, because soundings distribution pattern and import areas are all not considered although the shallowest soundings are selected.

### 2.3 Automatic configuration of soundings distribution pattern

The distribution pattern and density of soundings are important for safe navigation and pretty configuration of nautical charts. The density, direction, shape and size of soundings should be different for different types of submarine topographic features. Generally speaking, the distribution pattern of soundings should be diamond-shaped. The ratio between long and short diagonals of sounding rhombus always varies with the change in topographic slope, as shown in Fig. 5. The direction of short diagonal is perpendicular to the slope direction of the topography in current sounding. To those special areas including seacoast, sea-route, watercourse, dangers, the short diagonal direction is perpendicular to their vertical profile direction that can be designed by users in pre-processing procedure. It can be seen from Fig. 5 that the larger the slope angle, the larger the ratio of long and short diagonals. Obviously the calculation of topographic slope is a key to the arrangement of distribution pattern, although calculation of slope value from DEM is not a difficult problem\(^{(8)}\). In order to raise the efficiency, the slope of each sounding is calculated and saved in advance.

![Fig. 5 Different ratio between long and short diagonal of soundings distribution rhombus with different slope\(^{(2)}\)](image)

The steps of automatic configuration of soundings distribution pattern can be briefly described as follows.

1) Prepare four lists; one list for saving result soundings (result list), another for temporary processing results (temporary list), the third for saving all soundings (raw list) and the fourth for saving soundings in VIP areas (VIP list).
2) Sort the whole soundings data sets by depth and put the sorted results into the raw list.

3) Select the first sounding $S$ in the selected list (described in Section 3.2) and put it into the result list. Suppose the slope angle of this sounding is $P$ and the tolerance is $X$. Create a sector whose centre is the position of $S$, whose radius is the 1.5 times of influence circle radius, whose start angle is $P - X$ and whose end angle is $P + X$. Subsequently search all soundings except $S$ fall in this sector from the selected list and VIP area list array, and then put the researched results into the temporary list. About $S$, according to given distance we can find one sounding in its slope direction and two soundings in the perpendicular direction with slope direction. Put these three soundings into the result list and remove them from selected list and VIP area list array. The soundings in the VIP area list are marked as Selected flag. If the temporary list is empty or the three soundings cannot be found, then search all the soundings from the raw list until satisfied soundings are found. The corresponding soundings are removed from the raw list.

4) Examine the next sounding in the updated selected list and repeat Step 3 until all the soundings in the selected sounding list are removed.

5) Search all VIP area lists and find those lists whose flag is not marked as Selected flag. For those VIP areas, use influence circle algorithm for selecting soundings and put them into result soundings. The pattern is configured like the Step 3 but the slope angle should be replaced by the angle perpendicular to profile direction of VIP areas.

2.4 Topology consistency control

The consistency between soundings and other features including depth contour, seacoast, beach, island, reef and so on is very important to representation of submarine topography. In general, the following requirements should be met.

1) Closed depth contours and important features points in opening contours should be controlled by selecting soundings.

2) The conflicts between soundings and other features like over-plotting, incorrect relationship and so on should be solved.

For each closed depth contour, at least one sounding falls into it. So we search all the closed depth contours and use the point-in-polygon algorithm to select suitable soundings according to the relationship between the soundings and the closed contour. If no sounding is found in a closed contour, then add a sounding whose value can be defined by depth contour value plus 0.5 or information provided by users. It is necessary to create topological surface to validate the above algorithm considering many depth contours are composed of a few single arcs. The important points in open depth contours are selected by calculating the curvature of each point. For those conflicts caused by overlapping between different features, break the feature lines automatically or provide the conflict position to users is the better choice, and for those conflicts caused by incorrect relationship, providing the conflict position for users is still the best choice.

3 Implementation of the system

The algorithms and strategies have been implemented into the HGIS, which is a specialized GIS for hydrographic survey and is built upon an object-oriented database management system. In this system, all the chart features are treated as an object and their attributes are assigned according to the paper charts and S57 standard. A sample for the sounding selection result is shown in Fig. 6. In Fig. 6, the break parts between depth contours are other features which are not displayed in order to highlight selection results. According to experiences with manual operation, it takes an average of 1.5 days to complete the sounding selection for one chart, excluding other compilation procedures relative to sounding selection. However with the new system, it takes only half a day to do the same task. This means a time saving by 2/3.
4 Conclusions

After near two years of application of the HGIS system, it shows that fast cartographic sounding selection can be performed successfully and reliably. The sounding selections in the new system are similar even superior to those manually made by cartographers working from the same data sets. In the future, on one hand, it is useful to develop automatic sounding selection algorithms without any manual operation; on the other hand, providing more advanced ideas and tools to hydrographers so as to enhance the information level of Chinese Marine Safety Administration Bureau.

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