# A Model of Sounding Generalization Based on Recognition of Terrain Features

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## Abstract

As a main part of nautical chart generalization, sounding generalization is also one of the bottlenecks in the way of automatic chart generalization. Because submarine topography is mostly represented by sounding on chart, to some extent, generalization of chart mainly means sounding selection. Even in manual generalization, it is one of the most difficult and time-consuming links in the production chain, not to mention in the automated charting procedures.

In this paper, author proposed a new theoretical model, which based on recognition of topographic features. With the aid of Delaunay triangulation, the information, which contains the topology, distribution character, distribution density, can all be gained. All the methods mentioned in the paper have been proved to be feasible and sound.

## 1. Rules of Sounding Selection

The major rules for sounding selection include:

- Soundings which are at the top of a raised under-water area (shoals, rocks, etc.) have the highest priority to be selected.
- Select the soundings, which show the waterways.
- Select the soundings, which represent the outline of sea, bottom the best.
- The density of selected soundings must increase in shoal areas and decrease in less dangerous areas.
- In areas of homogeneous depth, soundings fulfilling the chart should form- as far as possible- a rhomboidal pattern.

Obviously, we can conclude from above, sounding selection deals with synchronously both spatial and attributive characteristics of chart features. There are different rules for different areas as well as different kinds of terrain features. That only have we understood them fully, the proper and efficient automatic generalization could be realized. So this paper proposes an important idea, that recognition of terrain is the basis of automatic sounding selection.

## 2. Recognition of Topographic Features

In order to extract the terrain information from those discrete soundings, this paper proposes a model based on sounding clustering and sounding tree, with the aid of Delaunay triangulation.

### 2.1 Sounding Clustering

The aim of space clustering is to divide the whole object into several groups, according to different standards, and use it as the basis of corresponding analysis. It is just the united clustering, including attribute data (depth) and geometry data, that sounding clustering is.

Definition 1: Sounding set can be expressed by set function $P=(p_1,p_2,\cdots p_n)$, if $p_i=(x_i,y_i,z_i)\in P$, and $p_i \cap p_j=\varnothing$, $i\neq j$, then $P$ may be called as the *sounding cluster*, its coordinate and depth are expressed by $(x_i,y_i)$, and $z_i$.

Definition 2 : Subgroup $S$ is given by $S=(P_1,P_2,\cdots,P_m)$ $(1\le m\le n)$, $S_i\in P$ $(1\le i\le n)$, if $z_i\in[a,b]$, $dis\in[l_1,l_2]$, then $S$ is called as the *subgroup* of sounding cluster $P$. Where $dis=\max(dis_{ij}\mid i,j\in[1,m])$, $dis_{ij}{}^2=(x_i-y_i)^2+(x_j-y_j)^2$, $(x_i,y_i,z_i)=P_i\in P$, a ,b are the threshold for attribute clustering, and $l_1$, $l_2$ are the threshold for geometric clustering.

With the aid of Delaunay triangulation, sounding set can be divided into different groups according to its depth and coordinate. The model is expressed as follows:

1) Constitute the Delaunay triangulation of P, meanwhile establish the relationship of Node, Tri and every edge as figure 1 shows.

2) $ClusteringP(Node,Tri[m])\{$

If $z_i\in[a,b]$ $(z_i\in Node)\{$

Then $NodeList.Add(Node)$

$Node=Node'$ $Node'\in Tri[m]$

$ClusteringP(Node,Tri[n])$

$\}$

$Otherwise\{$

$Node=Node'$ $Node'\in Tri[m]$

$ClusteringP(Node,Tri[n])$

$\}$

$\}$

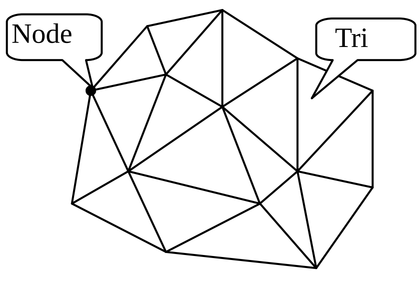



Fig.1 Example of Delaunay triangulation

3) $S_i = NodeList$
4) Change the threshold a and b, then repeat step 2,3, until all the discrete points have been dealt with.
5) Thus we get the aggregate S（$S_i \in P, \quad i = 0, 1, \cdots, n$）.

## 2.2 Recognition Of Topography

After the process mentioned above, several different subareas according to certain constrained conditions, will be come into being. The character of each subarea, such as its size, its shape and its depth, becomes the precondition of recognition. However, such subareas can not be used as the data structure of recognition fully since they are discrete independent. In order to get the relationship, especially topology relationship, of those subareas; we import the *sounding tree*, which becomes the base of topography recognition.

Structure of Sounding Tree

See figure 2, the root of tree denotes the shallowest subarea, which includes all of others. Each edge links two subareas, not adjacent but having parent-child relationship. Moreover, one parent node may have many sub-nodes, corresponding to the nek of topography. On the contrary, each sub-node can only have one parent node, denoting the ordinal relation of different depth areas, so it can ensure every subarea is exclusive. Meanwhile, one or more brother nodes may lie in the same level, they describes the adjacent areas. It is obvious that such a sounding tree can fully describe the topology relationship of all the subareas and we can get the relevant information of topography from it.

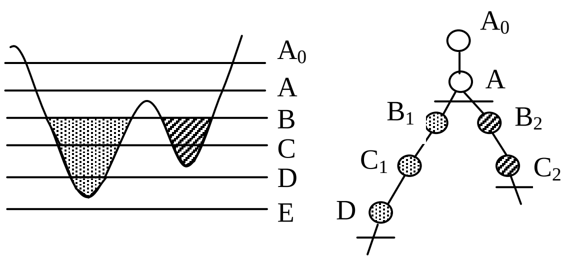


Fig.2 Sounding tree

Recognition of Ridge and Vale

When one branch has only one link between parent and child, it means that the area, this branch denotes, has no transformation from ridge to valley, or from valley to ridge. It must be single ridge or single valley. Furthermore, if the area is so small that can only be expressed by closed depth contour (on condition of certain scale), then it must be isolated ridge, or valley. Its (isolated ridge) significance is equal to the submerged reef, for it is the important content of chart generalization. The model is as follows:

```
extract_connected_closed_contour(origin_node, current_node){
        if(m>1)          (m is the amount current_node){
            origin_node <= current_node
        }
        else if (m=0){
```

```
        add the contour which is specified from origin_node to current_node
    }
    for (j=1    To    m){
        current_node <= subnode of current_node
        extract_connected_closed_contour(origin_node, current_node)
    }
}
```

Recognition of Sea-route

On chart, the cartographer must ensure that he retains sufficient numbers of the deeper soundings to show the full range of sea-route. If he does not, he is likely to mislead the navigator who uses his echo sounder to help verify his position or the mariner choosing an anchorage of suitable depth. And, cartographer must select the sounding that can show the width, shape, orientation and etc of sea-route. In order to satisfy this criterion, we must recognize where is the sea-route at first.

Definition 3:

The node of sounding tree is specified by $Node(x)$, where $x$ is depth value. If it has more than one subnode, represented by $NodeR(x_R), NodeL(x_L)$, and $x > x_R$, $x > x_L$, the range represented by $Node(x)$ displays just like a strip, then the sea area between the area represented by $NodeR(x_R)$, $NodeL(x_L)$ is called sea valley, yet sea-route in chart.

Furthermore, the width and axis can be derived from the measurement of $NodeR(x_R), NodeL(x_L)$.

Recognition of Complicated Topography

Definition 4:

Node of sounding tree is specified by $Node(x)$, while its subnodes are $Node_1(x_1), Node_2(x_2), \cdots, Node_m(x_m)$. If m>2 and the area involved in $Node_i(x_i)$ is less than a certain value, the topography, which represented by $Node_1(x_1), Node_2(x_2), \cdots, Node_m(x_m)$, is called complex topography. Meanwhile, many parameters of complex topography, such as the outline, area and distance between two adjacent ones, can all be derived from the subnodes.

### 2.3 Distribution and Density of Background Sounding

Sounding posted on a chart can be separated into three basic types: prime soundings, background soundings, and limiting depth soundings [Steven ZORASTER]. Among them, background soundings are usually the most numerous soundings on a chart. As far as possible, they should form a rhombus pattern. As water depth gradually decreases, rhombus size becomes smaller in a smooth continuous manner. The distance separation of soundings in relation to the water depth has been empirically determined as follows:

* 1.0~1.5 cm where depth <20.

* 1.2 ~2.0 cm where depth between 20 and 50.
* 1.8 ~3.0 cm where depth > 50.

In addition, the shape of rhombus (ShapeScale = length of long diagonal: length of short diagonal) changes along with the slope, just as the figure 3 describe. The steeper the gradient is, the larger ShapeScale is. At the narrow sea-route, or water area, the ShapeScale may come to 2 or 3 times, as figure 3(d) describes. So we can see, sounding distribution on chart depends on topography features.

There are many methods to calculate the gradient in mathematical field, but they are all very complex and time-consuming. As we needn't the accurate gradient value in this generalization process, so in this paper author proposes a model based on calculating the coefficient of gradient with the help of contour line. Figure 4 describes it.

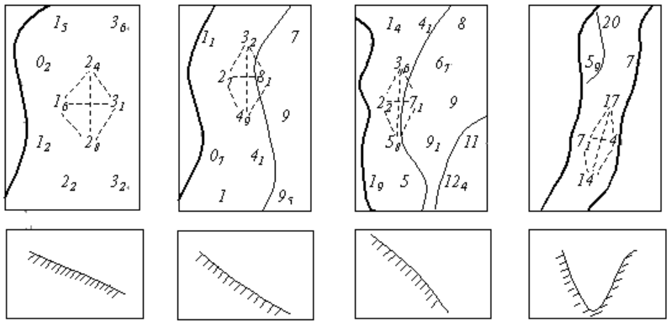


Fig 3 Shape of hombus alters to the topography

Definition 5: Contour line is defined by $C = (f(z_1), f(z_2) \cdots f(z_n))$, if $z_i \neq z_j$ , $(0 \le i, j \le n)$, so $C$ is called one group. Where $z_i$ is the depth value of $C_i$, and *f(z)* is its corresponding function.

The model is as follows:

- Evaluate the normal $\vec{N}$ to the C.
- Give one line, whose start point locates at the fringe of the area, orientation is consistent with $\vec{N}$, and length is set as a certain fixed value.
- Evaluate the intersection number(*num*) between C and L.
- Establish the association of *num* and gradient, and decide the shape of rhombus with it.

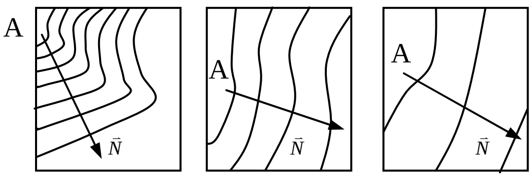


Fig.4 Calculate the coefficient of gradient

## 2.4 Check for Topological Correction

On chart, in order to describe the topography fully and exactly, contour and sounding must be harmonious and consistent. On the one hand, local bottom irregularities and small "closed" depth contours should be emphasized by the depiction of a sounding. This criterion is applied to shoal depth contours and extensions of shoal depth contours into deeper water areas. And, at the place of contour's notable inflection, where at least one sounding should be selected to control it. In this way, it can improve the reliability of chart itself. On the other hand, sounding and contour must have the correct topology relationships. Figure 5 shows the example of incorrect topology relationship after contour generalization. Obviously, on origin chart, the sounding 11 locates at the left of contour S, but after generalization, sounding 11 lies right. The key of the problem mentioned above is to recognize the area of features firstly.

Extract the Information of Topography Features

Areas with depth contour irregularities or small closed depth contours must be emphasized with the depiction of depths (figure 6). In this paper, the system identifies those areas utilizing the generated depth contour to create a Tin, whose vertices are taken from the depth contour. Obviously, those triangulation (HTri) which have the same depth nodes composes the irregularities areas or closed contours. Furthermore, the incorrect topology relationship often occurs in these areas, because the irregular part of contour always becomes the generalization object.

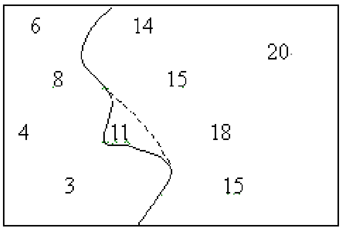



Fig.5 Incorrect topology relationship with contour and sounding

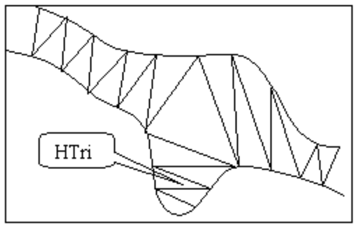



Fig.6 Construct Constrained Delaunay triangulation between contours

Examine Method

- ✧ After Extract the information of topography features, the contour irregularities have been identified, we can conclude whether the topology relationship of generalization result is correct, by judging soundings in them.
- ✧ If this area have no sounding, one sounding around should be filled at least.
- ✧ If the topology relationship is incorrect, one way is removing this sounding, the other is modifying the contour. Which way is chosen lies on the level of sounding. If it is essential, or no sounding is around it among origin data, we should select the latter, otherwise, select the former.

# 3. Generalization of Submarine Topography

## 3.1 Generalization Model

According to the generalization principle, and methods mentioned above, the proposes model is as follows:

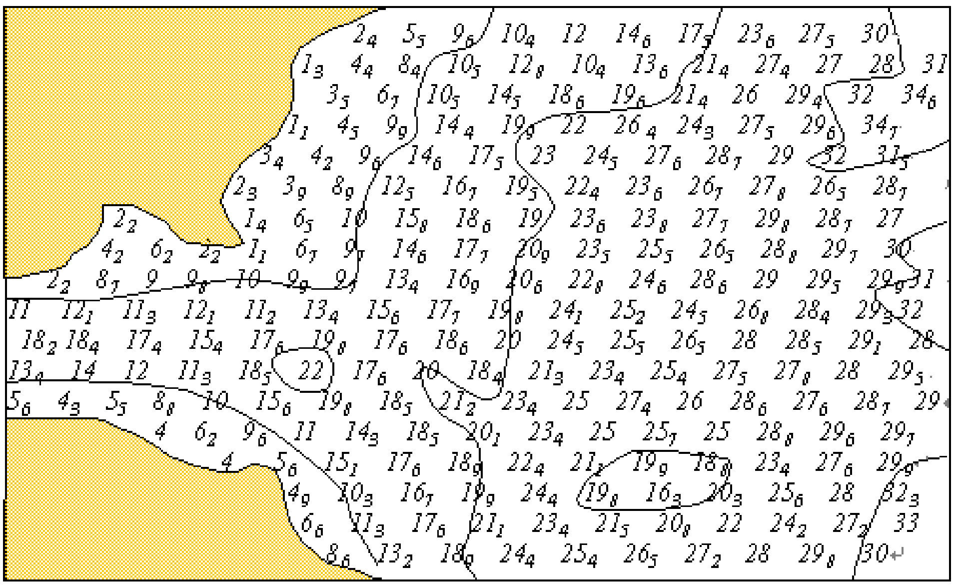
1) Sounding area A as the object, utilize the sounding cluster model described in 2.1 to generate the sounding tree that was composed by subareas.
2) According to the sounding tree, and depend on the recognition function (mentioned

in 2.2) to identify the sea-route, isolate shallow area.
3) Using the coastal line L, generate the convex of L, and decide the orientation of rhombus. Meanwhile, decide its shape and size according to 2.3.
4) Select the deepest and shallowest sounding whenever and wherever within every subarea.
5) Order the subareas to the depth and location.
6) Select the background sounding along with the rhombus in each area in turn.
7) Select the control sounding along with the contour, judge the topology relationship, and modify them when necessary.

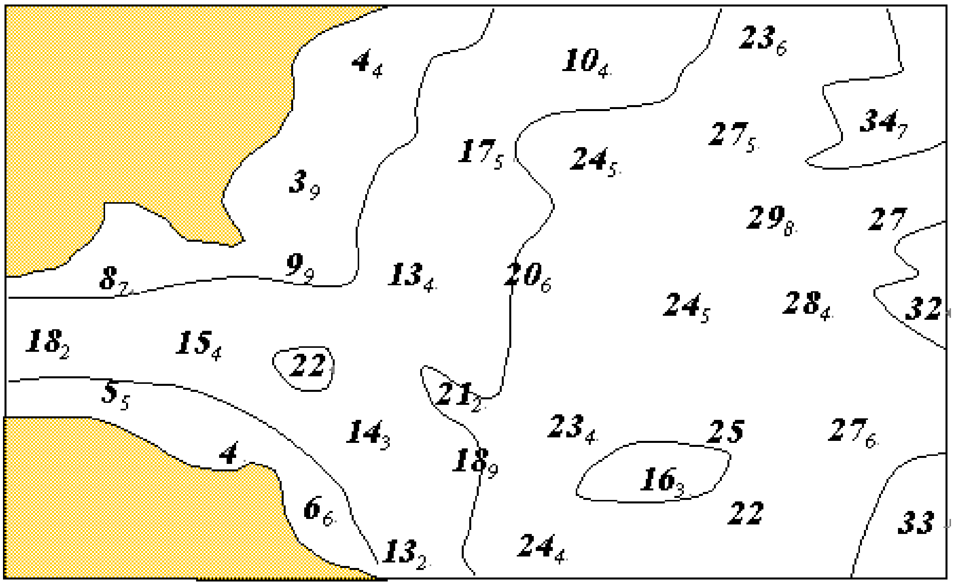
### 3.2 Generalization Test

The generalization model is proposed based on recognition of terrain features. Different methods used to different terrain. Meanwhile, relation of soundings and depth contours generalization results are examined. Figure 7(a) shows the original data set and (b) the selected soundings with the use of the model.
All the methods mentioned in the paper have been proved to be feasible and sound, the results are summarized as follows:

- Select the shallow and isolated soundings, which are hazardous regions.
- Select the deepest and shallowest sounding among different kinds of benthal terrain.
- Select the threshold soundings at the sea-route, and besides, retain sufficient numbers of the deeper soundings to show the full range of depths.
- Rhombi, which background sounding form, change its shape, size and orientation along with the terrain feature.
- The density of selected soundings increase in shoal and irregularities areas.
- Relation of sounding and depth contour preserve correct.



(a)




(b)

Fig.7 Example of sounding generalization

## 4. Concludes

As a main part of nautical chart generalization, sounding generalization is also one of the bottlenecks in the way of automatic nautical chart generalization. With the aid of deep analysis on the rules of sounding generalization, this paper proposed a new theoretical model, which based on recognition of topographic features. It was tested with a number of data sets and the quality of the results reported is satisfactory. In future, automatic sounding generalization not only used for chart design and production process, but for database update mostly.

## 5. Reference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