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Study on Maritime Search and Rescue Decision-Support System

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Abstract

The uppermost task of maritime search and rescue (SAR) is to find the targets rapidly and accurately, such as the ships and persons in distress, the lifeboats and life rafts and so on. Because the main equipments used in maritime target detection including conventional telescope, infrared telescope and radar all have their own strengths, weaknesses and the application ranges, it is necessary to integrate them to improve the target detection efficiency. After analyzing the efficiency of the visible light sensor, infrared sensor and radar sensor respectively under different environments, the sensor with the best efficiency in the SAR spot was selected to be the main way for target detection. A maritime SAR decision-support system was built by means of computer programming technology, which can provide a fast and efficient decision support for maritime SAR.

Keywords: maritime search and rescue; decision-support system; remote sensor; visible light; infrared; radar.

1. Introduction

The ships' navigation environment is complicated and changeable. The navigation safety is influenced by the natural conditions, traffic conditions and many other factors as well as the ship's own conditions. Therefore, ship accident is still difficult to avoid. Maritime accidents often result in huge economic losses, casualties, sea pollutions and other serious consequences. The SAR decision should be made as soon as possible after the accidents to minimize the loss caused [1]. In a word, an accurate and efficient decision is vital to the whole maritime SAR.

Maritime accidents mostly take place under bad weather or heavy traffic conditions, making the SAR much more difficult [2]. Because visible light, infrared and radar and other target detection systems all have their own characteristics and advantages, if the data gained from multiple detectors were integrated, we can get much more information than using separated one only, which can improve the detection and tracking performance. Besides, the false alarm rate and miss rate can be cut down after comprehensive analysis and comparison of all detection results. The search performance of these three kinds of detection sensors respectively, and determined the influencing factors for each sensor was analyzed firstly. And after comparing and pre-judging their performance under different conditions using entropy method, the target information from each sensor was organically integrated to provide decision-making support for the maritime SAR. Also a decision-making support system based on computer programming is built for future application.

2. Search Performance of Each Sensor

2.1 Visible Light Sensor

The data of visible light image is intuitive and rich in information. Besides, it is widely used because of its multiple acquisition methods and

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low requirements on the equipments. However, the complicated marine environment has brought some difficulties and challenges to the detection of the weak and small targets based on the visible light sensor. It is tested on board that it has a good detection performance within the distance of 500 meters under good visibility, or it will be affected by the wave. The minimum detection distance, generally about 30 meters, is determined by its height above the water surface and the blind area. The influence of the blind area can be made up by the detector's observation within the range of 30 meters. But, the search performance will be greatly influenced when the target is some objects easily affected by the bad sea conditions, such as persons in the water.

2.2 Infrared Sensor

Infrared sensor is more suitable to the detection of the weak and small target above water, especially at night or some other conditions with inadequate light, because the target's brightness in infrared image is generally larger than the average gray value of the background [3]. But, the noise interference of itself is stronger than that of the visible light sensor. Also, infrared equipments for civil use have detection distance restrictions, only suitable in a small range. The detection distance is mainly influenced by the temperature difference between the detected object and the surrounding environment, and also the absolute temperature of the object itself. That is, the higher the absolute temperature and the temperature difference, and the lighter the wave, the better the search performance of the infrared sensor is. However, it is inclined to produce false target or target missing and other bad results when using to maritime SAR, because the infrared sensor is easily affected by the wave and the temperature of the sea-water [4].

2.3 Radar Sensor

The radar sensor is superior to the two above-mentioned on the aspects of gaining the direction and distance information of the target. Besides, its detection performance is independent from the visibility and the object's temperature. But when the height of the radar antenna is close to the masthead, out of its blind area, the target detection performance is easily influenced by the wave echo, island echo, radio frequency interference and the target reflection, etc[5]. Within its detection range, the radar sensor can find the objects easily such as ships and other large objects or some objects having good reflection properties to the radar wave. In a word, the radar sensor does well in the detection of larger objects such as ships, but worse in the weak and small objects such as persons in water.

3. Pre-judging the performance of each sensor

In order to find the target timely and accurately to minimize the loss caused, before making SAR decision, it is necessary to pre-judge the relative parameters of the possible targets, and then, integrate the detection results from every sensor sub-system to provide the basis for decision-making [6]. Fig. 1 shows the pre-judgment flow.

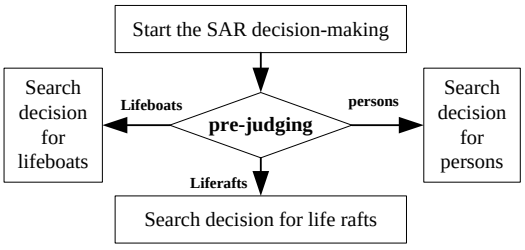

Fig.1 Pre-judgment flow of the SAR

Fig. 2 shows the hierarchical structure of the influencing factors of each sensor. It is seen that the influencing factors of the visible light sensor

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are the light condition, sea-condition, visibility and the target's size, while the infrared sensor are the temperature difference between the target and the surrounding environment and the target's absolute temperature. And, the search performance of the radar sensor is influenced by the target's size and reflection properties and also the wave condition of the sea.

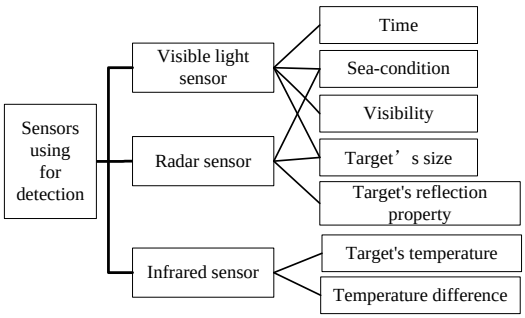

Fig.2 Hierarchical structure diagram of the influencing factors of each sensor

Then, the efficiency value R of each sensor:

$$R = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \end{bmatrix} = \begin{bmatrix} Visible-light \\ Infrared \\ Radar \end{bmatrix}$$

$$= \{Coefficient\ set\}\{Factor\ set\}$$

$$= \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ w_{71} & w_{72} & w_{73} \end{bmatrix}^T \begin{bmatrix} time \\ sea-condition \\ visibility \\ target's\ size \\ reflection\ properties \\ target's\ temperature \\ temperature\ difference \end{bmatrix}$$

Where, the coefficient set means the influence degree of each factor on the search performance of three different sensors. There are plenty of methods to determine the weight of each factor, such as AHP, expert consultation method, Delphi and so on. But, regarding to the complexities on the maritime SAR spot, it is very difficult to determine the influencing degree of each factor just relying on the experts' subjective judgments. That is, we should seek for one scientific and objective method for this problem. Accordingly, the concept of information entropy is introduced to determine the weight of each factor. The larger the information entropy of a factor, the less useful information it provides, that is, it plays a smaller role in the comprehensive evaluation, so it is given a smaller weight. Conversely, this factor will be given a relatively large weight. Using entropy method, an objective weighting method, can overcome the subjective influences in some conventional methods, which will enhance the objectivity, practicality and scientificity of the evaluation. So, it is helpful to the efficient operation of the maritime SAR decision-making.

Table 1: The values of the factors corresponding to three different kinds of sensors

Factors \ Sensors	visible light	Infrared sensor	Radar sensor
Time	y_{11}	y_{21}	y_{31}
Sea-condition	y_{12}	y_{22}	y_{32}
Visibility	…	…	…
Target's size	…	…	…
Reflection properties	…	…	…
Target's temperature	…	…	…
Temperature difference	y_{17}	y_{27}	y_{37}

The steps of using entropy method to determine the weight of each factor are as follows:

Step 1: calculating p_{ij}, that is the weight of the y_{ij} in all the values of the j th factor:

$$p_{ij} = y_{ij} \Big/ \sum_{i=1}^{m} y_{ij} \qquad (1)$$

Where, m is the number of the object to be evaluated, here $m = 3$.

Step 2: calculating the information entropy

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E_j of the j th factor:

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (2)$$

$j = 1,2,\cdots,n$, and here n=7.

Step 3: calculating the Difference Coefficient g_j of the j th factor:

$$g_j = 1 - E_j \quad (3)$$

Step 4: calculating the weight of the j th factor:

$$w_j = g_j \Big/ \sum_{j=1}^{n} g_j \quad , 0 \le w_j \le 1, \qquad \sum_{j=1}^{n} w_j = 1 \quad (4)$$

According to the steps above, the weights of each factor can be gained automatically after determining all the factors' values of each sensor under that SAR environment. So, it is available to pre-judge the search performance of each sensor real-timely on the spot.

4. Maritime SAR Decision-Support System

4.1 The Target Search Flow

First, the SAR staff determined the basic search point through the signals from the ship in distress combining with the data from the remote sensing satellites. When the SAR ships arrived to the approximate cross position or nearby area, it is mainly based on the target's characteristics, sea-condition, visibility and the others factors to select the usable sensor. And then, comparing the search performance of each sensor under that condition, integrating the detection information of three sensors, then, the sensor with the best performance is preferential , or, multiple useful sensors are combined together to target detection. The decision-making flow of the SAR method in the maritime accident spot is shown in Fig. 3.

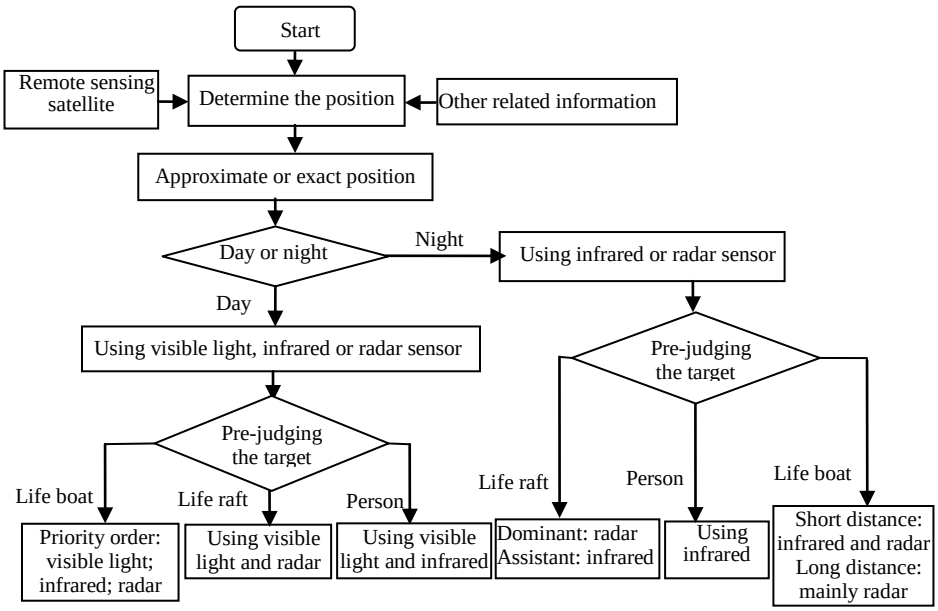

Fig.3 The decision-making flow of the SAR method in the maritime accident spot

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4.2 Information Fusion of the Detection Results from Each Sensor

The detection accuracy of the sensor depends on the time, weather, sea-condition, visibility, the target's features (including the size, the reflection properties to the radar, temperature and the temperature difference, and so on) and the detection performance of the sensor under that condition, etc. So, the accuracy value of the information from each sensor P can be demonstrated as:

$$P = p_1 * Time + p_2 * Wind + p_3 * Sea\_condition + p_4 * Target\_feature + p_5 * Sensor\_feature$$

Here, $p_i (i = 1,2,\cdots,5)$ means the influencing degree of the factors on the performance of each sensor, which is generally determined by the way of experience method or expert consultation method. The larger the value of P, the better the detection performance of the sensor is. So, we can select the optimum sensor according to the value of P.

4.3 Analysis of the Decision Results

In daytime, the brightness is good enough. The detection distance of radar is relatively far, while that of the visible light and infrared is easily affected by the visibility and backlight and other factors. If the target is so far that beyond the detection range of the infrared and visible light, the radar can be used to guide the search. While the target is within the search ranges of the three sensors, it is asked to decide which one is optimum according to the value of P.

At night or in restricted visibility, the visible light sensor is generally out of action. At this time, the detection mainly relies on the infrared and radar sensor. When the target is quite far, the radar becomes the dominant method while the infrared sensor working as an assistant. While the target is relatively nearer, outside of the blind area of radar, the infrared and radar can be combined together to work. Besides, the persons wearing a life jacket with reflective tape and other similar targets in water are helpful to the search and recognition of radar.

4.4 Building the Maritime SAR decision-support system

We built a maritime search and rescue decision-support system based on Visual C++. This system can computer the accuracy of the search information of each sensor according to the weather, sea-condition, target's feature and other factors, and then, give some corresponding decision-making suggestions on the detection method.

Step 1, determination of the search position and time. The approximate position of the ship in distress is determined by the alarm information from the ship and the remote sensing information (if possible), besides, the time then is cleared to decide whether the visible light is usable (Fig. 4).

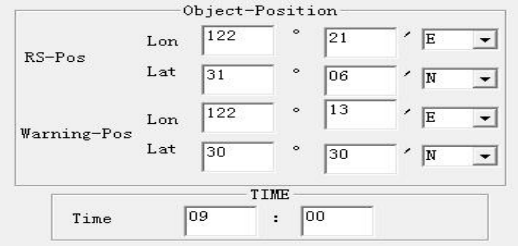

Fig.4 Determination of the position and time

Step 2, pre-judgment of the search performance of each sensor. The influencing factors and the coefficient values are determined (Fig. 5).

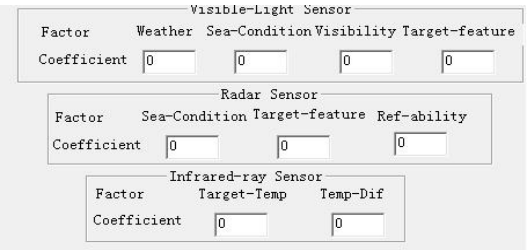

Fig.5 Influencing factors and weights of each sensor

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Step 3, giving decision-making support. The sensor with the best search performance is selected to target detection in spot, and some corresponding suggestions are shown in this system (Fig. 6).

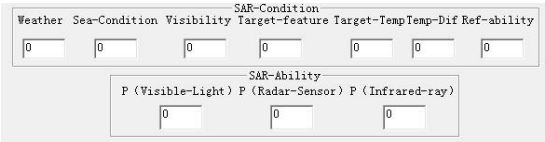

Fig.6 The accuracy value of the search information

5. Conclusions

This paper analyzed the search performances of visible light, infrared, radar in maritime SAR, and determined the influencing factors of each sensor. And then, the sensor with the best performance was selected to the target detection according to the actual condition of the target and the spot. Besides, some corresponding suggestions on the SAR were given. Meanwhile, an automatic decision-support system was built based on the computer programming technology, which can provide a timely and effective decision-support to the maritime SAR. However, it still needs some further study and analysis to find a scientific and appropriate method to determine the coefficient set of the influencing factors of each sensor.

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