Target recognition algorithm for compound scanning imaging based on fuzzy theory

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Abstract. In order to solve the problem of low recognition rate and poor anti-interference ability of single-mode lidar, a multi-element linear array laser/infrared composite detection device is used to realize scanning images. A target recognition model based on associated information is proposed. The proposed method performs feature extraction and fusion on the top three-dimensional contour of the target and the top infrared radiation information, and comparing with the standard model parameter library. A target recognition algorithm based on fuzzy comprehensive evaluation method is proposed, and three sets of recognition probabilities are obtained. The three types of sub-recognition results use fuzzy theory for decision fusion to obtain the final recognition results. The simulation results show that the recognition probability of the composite detection target is greatly improved compared with the single mode recognition method.

1. Introduction

Lidar detection has various advantages, such as rich information, good directivity, and strong resistance against electromagnetic environment interference in the environment[1-5]. However, its penetration ability in smoke and cloud environments is not strong[6-8]. The use of composite detection technology can effectively improve the anti-interference ability of the system. The linear laser/infrared composite detection device can scan and obtains the top contour information and the top infrared radiation information of the target. By analyzing these two types of features information, the association feature of the target is extracted to complete the target discrimination. There are different target recognition algorithms proposed in the literature that use different detection mechanisms. For instance, single point laser/infrared composite target recognition algorithm based on combinational logic discriminant method, Area target laser/infrared composite target recognition algorithm based on feature reduction, and Linear laser/infrared composite target recognition algorithm based on support vector machine (SVM)[7][9-11]. A single point laser/infrared composite target recognition algorithm is relatively simple to implement, but the recognition results are not good. Area target laser/infrared composite target recognition algorithm quickly extracts high-resolution image information, however, when processing image information, there are problems with large calculations and inadequate real-time performance. In addition, the computational cost of detection is also high. Linear laser/infrared composite target recognition algorithm based on SVM has better capability to classify and discriminate against the target. However, it is difficult to train on large-scale samples.
Thus, the three aforementioned algorithms have performance problems making them less efficient. Since the association feature information of the target often has a more reliable feature basis than the single-mode target information, the application of the related information has a better discriminating effect on target recognition. Considering the aforementioned issues, we propose a linear laser/infrared composite correlation feature target recognition algorithm based on a fuzzy comprehensive evaluation method. The proposed algorithm solves the problems of insufficient application of target association feature information, algorithm’s computational complexity, and difficult training process.

2. The design of the linear sweeping model

The linear array laser/infrared composite detection device is equipped on a drone or a quadcopter. The drone sweeps over the target area at a certain speed and in a particular direction to obtain complete information from the top view of target and infrared radiation information. Figure 1 shows that the composite detection device uses active laser scanning detection and passive infrared scanning detection. The detection device sends the information detected by the sensor to the information processing module to extract target features and make identification judgments.

![Figure 1. Schematic diagram of laser infrared scanning vehicle target](image)

The linear scanning detection system realizes the simultaneous scanning of the height information and infrared radiation intensity information of the target. The N-element linear array laser detector and the line-infrared detector are arranged in parallel. Due to their detector structures, a column of N-element sequences are obtained by one scan sampling. Assume that the entire target is scanned M times, then the resultant matrix is:

\[
\mathbf{f}(i,j) = \begin{bmatrix}
x_{1(1)} & x_{1(2)} & \cdots & x_{1(m)} \\
x_{2(1)} & x_{2(2)} & \cdots & x_{2(m)} \\
\vdots & \vdots & \ddots & \vdots \\
x_{n(1)} & x_{n(2)} & \cdots & x_{n(m)}
\end{bmatrix}
\]

\[
\mathbf{f}(i,j) = \begin{bmatrix}
x_{1(1)} & x_{1(2)} & \cdots & x_{1(m)} \\
x_{2(1)} & x_{2(2)} & \cdots & x_{2(m)} \\
\vdots & \vdots & \ddots & \vdots \\
x_{n(1)} & x_{n(2)} & \cdots & x_{n(m)}
\end{bmatrix}
\]

(1)

The two matrices obtained by the detection matrix include the target contour information and the target infrared radiation information. The target's associated information is extracted by using the spatial distribution of these two types of information. Three types of feature sequences of laser features, infrared features and association features are obtained by extracting the characteristics of the three types of information. Compared with the standard target parameter library, fuzzy comprehensive evaluation method is used to obtain the recognition probability P1, P2 and P3 of the three types of information for the target. We use fuzzy theory to find the compute recognition probability P of the target to achieve the decision-level discrimination of the target. The block diagram of the target recognition process is shown in Figure 2.
3. Target recognition algorithm based on fuzzy theory

3.1. Determine factor set and judgment set

The purpose of this work is to provide a reliable decision basis for the identification of vehicle targets. This is done by extracting the target information obtained by the laser and infrared detectors and the association feature information between the two, then we extract the corresponding features to form the factor set $U$. If we extract the $j$-type features from the $i$-th type of information, a feature set $U_i^j = \{u_i^j, u_i^{j-1}, \ldots, u_i^1\}$ is formed, which serves as a factor set for the evaluation target of this type of information. We assume to constitute \{true target, much like target, suspect target, unlike target, false target\} five target recognition levels of recognition. That is, evaluation sets, which are represented as $V = \{v_1, v_2, \ldots, v_5\}$.

3.2. Determining the single factor judgment set

When discriminating against the target, the influence factors of a certain type of information on the feature parameters of the target recognition on the judgment of the target's authenticity are different, and the relationship between the two is represented by the fuzzy matrix $R_i^j$. The mapping of the relationship between the two is accomplished based on the membership function.

$$R_i^j = \begin{pmatrix}
r_{i1}^j & r_{i2}^j & \cdots & r_{in}^j \\
r_{i1}^{j-1} & r_{i2}^{j-1} & \cdots & r_{in}^{j-1} \\
\vdots & \vdots & \ddots & \vdots \\
r_{i1}^1 & r_{i2}^1 & \cdots & r_{in}^1
\end{pmatrix} \quad (2)$$

We make use of the standard target model library for estimating the error between the characteristic parameters and the standard parameters, and give the membership function $C_j^k(x)$, which is expressed as a function constructed by the extracted $j$-th feature of the $i$-th information, which belongs to Class $k$ recognition level. Use the triangle membership curve to establish the corresponding membership function:

$$C_j^k(x) = \begin{cases}
1-\frac{a-x}{b} & a-b<x<a \\
1-\frac{x-a}{c} & a\leq x<a+c \\
0 & \text{other}
\end{cases} \quad (3)$$
3. Determine fuzzy weights

When using the \(i\)-th type of information is used for recognition, each characteristic parameter contained in it has a corresponding weight distribution, that is represented by a fuzzy weight vector \(A = (a_i, a_2, \ldots, a_n)\).

4. Comprehensive evaluation

We use fuzzy relations for obtaining the fuzzy comprehensive evaluation vector \(B' = (b'_1, b'_2, \ldots, b'_m) = A \circ R'\). According to the principle of maximum membership, the recognition probability, i.e., \(P_i = \max_{j=1,2,\ldots,m} \{b'_i\}\) at the \(i\)-th information of the target is obtained, and the recognition level of the target is determined as \(v_i\).

4. Vehicle target feature extraction and recognition

In this experiment, the linear laser/infrared composite detection device scans the target vehicle in the form of push sweep as shown in Fig. 3. The device then obtains the detection information using laser and infrared and recognizes the target to be tested based on the extracted respective features of the two and their association features and applying the fuzzy comprehensive evaluation method.

4.1. Laser information processing and feature extraction

Linear array lidar scans to obtain the elevation information of all targets in the scanning field of view, the height information of the target includes the contour characteristics of the top of the target and the position characteristics of the vulnerable parts. Figure 4 presents the three-dimensional contour image of the top of the target acquired by lidar. For the convenience of processing, the three-dimensional contour image is normalized into a two-dimensional grayscale image for image processing.

4.1.1 Target contour information preprocessing and image segmentation. After the elevation data obtained by laser detection, it is normalized to a gray value image, The image’s information is then denoised. Because there are gray values that change drastically at the boundary of each contour area on the top, the image area is segmented using a Canny edge detector. The image processing process continues as:

1. Use an average filter to smooth the image, as shown in Figure 4 and Figure 5 before and after image filtering.

\[
 f_c(i, j) = G(i, j) \ast f_o(i, j)
\]  

Where \(G(i, j)\) represents a Gaussian function, \(f_o(i, j)\) is the input normalized grayscale image, and \(f_c(i, j)\) is the filtered image.

2. Calculate the gradient amplitude image \(A(i, j)\) and angle image \(\theta(i, j)\) of the filtered image.

\[
\begin{align*}
   A(i, j) &= \sqrt{g_i^2 + g_j^2} \\
   \theta(i, j) &= \arctan(g_j / g_i)
\end{align*}
\]  

The boundary of each area in the obtained gradient amplitude image is rough, therefore, non-maximum suppression is applied to refine the boundaries of the gradient image. Afterward, we use a double threshold algorithm to detect and connect the edges. The image \(f_c^*(i, j)\) is obtained after performing area segmentation, where 0 represents edge pixels, and 1 represents non-edge pixels. Figure 6 presents the pre-segmented image of the target area. Since the edges of the image segmented
by the canny operator are unconnected, morphological processing is used to obtain the segmented image that efficiently refines the target edge is presented in Figure 7.

![Figure 4. Top profile](image1)

![Figure 5. Filtered contour image](image2)

![Figure 6. Pre-segmented image](image3)

![Figure 7. Edge refinement segmentation](image4)

4.1.2 Target contour feature selection. Based on the segmented image $f^*(i, j)$ located at the top of the target, the area and centroid features of each region are extracted. Suppose there are $g$ regions in the top contour of the target, and the edge of each region is composed of $x$ pixels, then the edge pixels of the region are recorded as $E_g(i, j), x = 0, 1, \cdots, n$.

The horizontal and vertical coordinates of the centroid are:

$$
\begin{align*}
\bar{i}_g &= \frac{\sum_{i=0}^{n} j_i}{n} \\
\bar{j}_g &= \frac{\sum_{j=0}^{m} i_i}{n}
\end{align*}
$$

(6)

Area of an area (number of area pixels):

$$
A_g = \sum_{j=0}^{n} f^*(i, j), \quad (g = 1, 2, \cdots, m; \quad f^*(i, j) = 1)
$$

(7)

In equation (6), $A_g$ is the set of all pixels in a connected domain (region). The area of this region is compared with the area $A_w = (a_{max}, a_{max})$ of the reference region of the standard model. When the relation: $a_{min} \leq A_g \leq a_{max}$ is satisfied, the reference area of the target measured in this area is considered. We extract the centroid $G_g(l_{i}, l_{j})$ as the reference point $G_g(l_{i}, l_{j})$ for the entire target.

4.1.3 Laser information feature extraction and target recognition. The point on the surface of the three-dimensional image $f^*$ that maps the planar point is called the spatial point $f^*(i_{x0}, j_{x0})$ of the planar point. We calculate the distance $l_g, (g = 1, 2, \cdots, n)$ between this point and the spatial centroid point $f^*(i_{x0}, j_{x0})$ that corresponds to the centroid of the $g$-th area, and the angle $\theta_g, (g = 1, 2, \cdots, n)$, between the straight line formed by the two points and the ground. At the same time, the distance between the reference point $G_0$ and the regional centroid point $G_g$ is $l'_g$.

$$
\begin{align*}
&l_g = \sqrt{(i_{x0} - i_{x})^2 + (j_{x0} - j_{x})^2 + \left[ f^*(i_{x0}, j_{x0}) - f^*(i_{x}, j_{x}) \right]^2} \\
&l'_g = \sqrt{(i_{x0} - i_{x})^2 + (j_{x0} - j_{x})^2} \\
&\theta_g = \arccos \left( \frac{l'_g}{l_g} \right), \quad g = 1, 2, \cdots, n
\end{align*}
$$

(8)
The top contour of the target is described by the feature vector \( T_i = [l_i, \theta_i] \). We obtain the corresponding feature error vector \( T_{se} = [l_{se}, \theta_{se}] \) and classify each feature parameter \( VT_i = [\forall l_i, \forall \theta_i] \). Now, the fuzzy weight of each parameter is assigned as \( A^i = (0.5, 0.5) \). Finally, the fuzzy comprehensive evaluation method is used to obtain the target recognition rate P1 during single laser detection.

4.2. Infrared data processing and feature extraction

The linear array infrared detector scans the object to obtain the target radiation, image and completes the identification of the target by extracting the radiation characteristics of the key area of the target. The extraction process of infrared information is accomplished by given steps.

(1) Infrared information preprocessing

The infrared image is first smoothed and filtered to obtain the image \( f'(i, j) \). The sharpened image \( f''(i, j) \) is then obtained based on the high and low cap transformation process, as shown in Figure 8 and Figure 9 before and after filtering.

(2) Infrared image automatic threshold segmentation

To extract the key feature area of the target from the infrared image, the image is processed by automatic threshold segmentation. The final threshold obtained by the processing is 117. At this time, the separable metric of the image is 0.902, and the image \( g_i \) is obtained after the application of threshold segmentation.

(3) Infrared image feature selection

According to the analysis of the image pre-segmentation results presented in Figure 10, it is evident that there is some interference due to bright objects in the image \( g_a \). The radiation characteristics are further refined, and the image \( g^2 \) is obtained by excluding the infrared radiation area with a smaller area in the image, as presented in Figure 11.

\[
\begin{align*}
\text{Figure 8. Infrared radiation image} & & \text{Figure 9. High-low hat translation} \\
\text{Figure 10. Image and segmentation} & & \text{Figure 11. Finally split the image}
\end{align*}
\]

Based on the segmented radiation image, we select the strongest radiation peak point \( g^u_{\text{max}}(i, j) \) in the feature area to determine the key point of the target. To eliminate the influence of interference, an appropriate constant \( \varepsilon \) is set, and an image \( T \) with a gray value greater than \( g^u_{\text{max}}(i, j) - \varepsilon \) containing a maximum peak point is obtained. Figure 12 and Figure 13 show images with peak points and maximum peak points, respectively.

\[
T(i, j) = \begin{cases} 
  g^u(i, j) > g^w(i, j) \geq g^w_{\text{max}}(i, j) - \varepsilon \\
  0, & \text{other}
\end{cases}
\]  \( (9) \)

\[
\begin{align*}
\text{Figure 12. the strongest peak point of infrared radiation} & & \text{Figure 13. the maximum peak point of infrared radiation}
\end{align*}
\]
The greater the radiation intensity is in the key feature area of the target, the greater is the proportion of the radiation peak point and the total number of pixels in the total image, and the greater the radiation contrast between the average intensity of the radiation peak point and the average grayscale of the image. Based on this characteristic, the target radiation peak point occupation ratio characteristic $q_{r}$ and radiation contrast characteristic $q_{c}$ are extracted. The distribution of radiation peak points extracted from infrared images are obtained as the number of radiation peak points $a$ in the target and the average intensity $\bar{q}$ of the radiation peak points, respectively.

We first convert the image into a binary image $BW_{i}$:

$$BW_{i}(i,j) = \begin{cases} 1, & T(i,j) > 0 \\ 0, & \text{other} \end{cases}$$ (10)

Then, we estimate the number of non-zero points in the binary image is the number of radiation peak points.

$$a = \text{sum}(BW_{i}(i,j) == 1)$$

$$\bar{q} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \text{sum}(T(i,j))}{m \times n}$$ (11)

The average gray value $\bar{q}$ of the entire image is obtained from the acquired infrared radiation gray image $f_{i}$ on the top of the target, which represents the typical average gray characteristic of the target in the detection field of view:

$$\bar{q} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \text{sum}(f(i,j))}{m \times n}$$ (12)

The proportion of the radiation peak point is $\eta_{r} = a/(m \times n)$, and the radiation contrast is $\eta_{c} = \bar{q}_{r}/\bar{q}$. Thus, the feature vector $T_{s} = [\eta_{r}, \eta_{c}, \bar{q}]^{T}$ in the infrared radiation information at the top of the target is obtained. We compare the characteristic parameters of the target to be measured with the corresponding parameter vector $T_{s} = [\eta_{r}, \eta_{c}, \bar{q}]^{T}$ in the standard target to obtain the corresponding infrared characteristic error vector $\nabla T_{s} = [\nabla \eta_{r}, \nabla \eta_{c}, \nabla \bar{q}]$. We then classify each characteristic parameter. The fuzzy weight value of each parameter is assigned to $A' = (1/3, 1/3, 1/3)$, and the applied fuzzy comprehensive evaluation method is used to obtain the target recognition rate $P2$ in single infrared detection.

4.3. Laser/infrared information association and target recognition

Based on the feature correlation between laser information and infrared information, the center of mass (reference point) $G_{i}(i_{0}, j_{0})$ of the reference plane on the top contour of the target is selected to be associated with the peak point $T_{i}(i_{0}, j_{0})$ of infrared radiation. The two types of points are mapped into the three-dimensional image of the target to form the space. The relationship between distance and spatial angle.

The distance from the spatial reference point $f_{i}(i_{0}, j_{0})$ of the center of mass of the reference surface in the target laser contour image to the $k$-th infrared point in the infrared image is $f_{i}(i_{k}, j_{k})$. The angle between the line and the ground is $\theta_{k}$.

$$S_{k} = \sqrt{(i_{g} - i_{k})^{2} + (j_{g} - j_{k})^{2} + [f_{s}(i_{g}, j_{g}) - f_{s}(i_{k}, j_{k})]^{2}}$$

$$S_{k} = \sqrt{(i_{g} - i_{k})^{2} + (j_{g} - j_{k})^{2}}, \quad \eta_{k} = \arccos(S_{k} / S_{k})$$ (13)

$$\theta_{k} = 0, 1, 2, \ldots, L$$
The association features are obtained, which include spatial distance, horizontal distance, and spatial angle feature. We represent it by the associated feature vector $\mathbf{T}_s = [S, S', \theta]$ . We then compare the characteristic parameters of the target to be measured with the corresponding parameter vector $\mathbf{T}_s' = [S', S', \theta']$ in the standard target to obtain the corresponding infrared characteristic error vector $\nabla T_s = [\nabla S, \nabla S', \nabla \theta]$. And then the characteristic parameters are graded. The fuzzy weight of each parameter is assigned as $A' = (1/3, 1/3, 1/3)$. Finally, fuzzy comprehensive evaluation method is used to obtain the target recognition rate P3 based on the associated features.

### 4.4. Compound target recognition

The target recognition results in P1, P2, and P3 are based on laser information, infrared information, and association information are the fusion of feature levels. To further improve the recognition probability of recognizing the target, the decision results of the single and dual mode are made at the decision level fusion. This is done by, using the fuzzy inference theory to establish three input and output membership functions for identification probabilities. In addition, according to the single-mode and dual-mode working modes of the detection system, fuzzy rules are established to fuse the sub-recognition results of the target to obtain the final target recognition probability P to achieve the target discrimination.

### 5. Simulation and experiment

In the data acquisition process, the linear array laser radar emits pulse frequency $f = 3.5 \text{kHz}$ . The infrared detection system is passive detection. The linear array laser/infrared detection device is equipped with a stable flying UAV platform, and it flies horizontally at the speed of $v = 20 \text{m/s}$ . The total field of view is 40° , and the detection platform is 10m above the ground. The specific dimensions of the target vehicle under test in the actual measurement environment are 4.5m×2m×2m.

The complete vehicle target of the 32-element linear laser/infrared scanning detection system scans and intercept a 32×128 laser information matrix and infrared radiation information matrix.

The two types of information matrix obtained are simulated using MATLAB. We separate the top contour image and the top infrared radiation image of the target, respectively. We extract the top contour characteristics and infrared radiation characteristics of the target. We use the fuzzy comprehensive evaluation algorithm to obtain the recognition probability P1 when the single laser is working, recognition when the single infrared is working Probability P2, and recognition probability P3 based on laser/infrared correlation features. According to the working mode of the system, with three points of recognition probability P1, P2, P3 as fuzzy input, the target recognition result P based on fuzzy inference is obtained, as shown in Table 1. Table 1 presents the 10 sets of fuzzy input and the corresponding output results.

**Table 1. Identification results of decision fusion**

| Laser recognition results P1 | Infrared recognition results P2 | Association recognition results P3 | Fusion Recognition Results P |
|-----------------------------|-------------------------------|-------------------------------|-----------------------------|
| 0.610                       | 0.512                         | 0.611                         | 0.650                       |
| 0.713                       | 0.580                         | 0.564                         | 0.809                       |
| 0.744                       | 0.651                         | 0.768                         | 0.930                       |
| 0.736                       | 0.269                         | 0.157                         | 0.736                       |
| 0.638                       | 0.580                         | 0.701                         | 0.860                       |
| 0.656                       | 0.602                         | 0.763                         | 0.879                       |
| 0.718                       | 0.722                         | 0.856                         | 0.932                       |
| 0.122                       | 0.8691                        | 0.131                         | 0.869                       |
| 0.651                       | 0.611                         | 0.754                         | 0.874                       |
| 0.798                       | 0.558                         | 0.710                         | 0.872                       |
Table 1 presents the recognition probability of the decision fusion of the target acquired by the laser/infrared detection system based on the single and dual mode cooperative work. The results presented in Table 1 reveal that the recognition probability of the output decision fusion is higher than the input three-point recognition probability to a certain extent. When one of the two detection modules cannot accurately identify the target, the detection system still relies on the single-mode detection system to effectively discriminate against the target.

The simulation results show that the fuzzy fusion algorithm based on association information has higher recognition probability and a stronger ability to adapt to the environment. In addition, the detection and recognition performance of the proposed system is better than that based on single-mode detection.

Figure 14 presents the three-dimensional surface map obtained using three sets of recognition results as input. Figure 5(a) presents P1 (single laser recognition) and P2 (single infrared recognition) are used as the fuzzy input. Figure 8(b) presents P1 (single laser recognition) and P3 (feature association recognition) are used as fuzzy input. Figure 8(c) presents P2 (single infrared recognition) and P3 (feature association recognition) as fuzzy input. The three combinations are through fuzzy inference Corresponding output.

![Figure 14](image)

**Figure 14.** The output junction when the input is a pairwise combination of recognition results

On the basis of comparative analysis of results of the three pairwise combinations, it is noticeable that the combination of Figure 8(a), the identification result of the output is to a large extent lower than the output of Figure 8(b) and Figure 8(c) result. The reason for analyzing the results is that the latter two combination methods have the recognition probability P3 of laser/infrared feature association. This is the recognition probability obtained based on the linear laser/infrared information association feature, which shows the recognition of association feature information. The results of the proposed method are better as compared to the recognition results of single-mode information.

6. Conclusion

In this paper, a linear laser/infrared composite scanning model is proposed on the basis of associated information. Based on the target contour information and infrared radiation information, we extract the top contour features of the target and infrared radiation image features, according to the spatial distribution relationship of the feature points corresponding to the two types of information, extract the target association features, which are distance and angle between the feature points. We compare the corresponding standard model feature parameter library and then complete the discrimination of the target single mode and feature association based on fuzzy comprehensive evaluation algorithm. Based on sub-recognition, fuzzy inference is used to complete decision fusion discrimination. The proposed method is suitable for performing detection in an environment with high interference. The simulation results and experiments show that the fuzzy recognition algorithm based on associated information has accurate recognition, strong practicability, and is easy to implement. By adjusting the corresponding model parameters of the standard model, target discrimination in multiple detection environments is achieved.
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