Multi-image Source Target Fusion Detection Based on D-S Evidence Theory

Hao Lei 1, Zengxue Yang 1, Zhizheng Zhang 1 and Weiqiang Wang 1

1 Weapon testing center, Shaanxi Huayin, China
Hao Lei: 825631748@qq.com

Abstract. Aiming at the difficulty of detecting and tracking infrared targets under complex background interference, a new multi-image source target fusion detection method based on D-S evidence theory[1] is introduced, combining the infrared and visible sensor of the photoelectric theodolite structure advantages. Through the second detection of the suspected target area and evidence theory fusion of the test results, it achieves effective fusion detection of multiple image source targets, which improves the reliability and stability of multi-source sensor image target tracking.

1. Introduction

In the optical test of the conventional range, the effective detection of infrared targets is the basis of stable tracking. However, many difficulties are brought to infrared target detection because of the complex environment and background interference of the field area. The traditional detection methods[2] such as template matching, correlation detection and optimal projection are based on single sensor detection. The detection effect is limited and cannot meet the test requirements in the complex background with too much interference.

According to the analysis above, a new multi-image source target fusion detection method combining the infrared and visible sensor of the photoelectric theodolite structure advantages[3] is introduced. By formulating a reasonable decision model based on the D-S evidence theory, it achieves effective fusion and satisfactory detection results of multiple image source targets.

2. Multi-image source target fusion detection

The photoelectric theodolite can measure both infrared and visible images in the range test. Aiming at effective fusion of target detection results from infrared and visible light sensors and correlation tracking of the target, the multi-image source target fusion detection process can be divided into the second detection of the suspected target area and evidence theory fusion of the test results.

2.1 Second detection of the suspected target area

The suspected target detection locations of each image may be inconsistent in the fusion process of multi-image source. At this time, the second detection is needed, that is, detecting the mapping area again after the inconsistent detection locations are mapped to each other.

The visible light sensor and infrared sensor on the theodolite are basically coaxial design. The distance from the sensor to the target is close to infinity relative to the target size. In this case, the distance between the target and the two sensors can be considered equal and the shafting difference between the sensors can be assumed to be zero. The position difference between images obtained by
different cameras mainly includes the translation, rotation and scaling, considering the focus difference of the lens. Therefore, the spatial model of image transformation can be determined.

Common coordinate system[4] includes the world coordinate system, the camera coordinate system and the image coordinate system. The world coordinate system \((X_w, Y_w, Z_w)\) is a user-defined three-dimensional spatial reference coordinate system for describing the position of cameras and objects. The camera coordinate system \((X_c, Y_c, Z_c)\) is used to describe the relative position of the object in the optical path with the lens optical center as the origin. The image coordinate system is divided into image pixel coordinate system \((u, v)\) and image physical coordinate system \((x, y)\). The relationship between them is showed in Figure 1.

The matrix relationship between the point \(M\) in space and its projection \(m\) on the imaging surface is as follows:

\[
\begin{bmatrix}
\frac{f}{d_x} & \delta & \frac{u_0}{d_x} & \frac{0}{d_x} & \frac{0}{d_x} & X_w \\
\frac{f}{d_y} & \frac{0}{d_y} & \frac{v_0}{d_y} & \frac{0}{d_y} & \frac{0}{d_y} & Y_w \\
0 & 0 & 0 & 1 & 0 & 1
\end{bmatrix} \begin{bmatrix}
x \\
y \\
z
\end{bmatrix} =
\begin{bmatrix}
\frac{f}{d_x} & \frac{0}{d_x} & \frac{u_0}{d_x} & \frac{0}{d_x} & \frac{0}{d_x} & X_c \\
\frac{f}{d_y} & \frac{0}{d_y} & \frac{v_0}{d_y} & \frac{0}{d_y} & \frac{0}{d_y} & Y_c \\
0 & 0 & 0 & 1 & 0 & 1
\end{bmatrix} \begin{bmatrix}
x \\
y \\
z
\end{bmatrix}
\]

\(f\) —— The focus
\(d_x, d_y\) —— Pixel physical size;
\(u_0, v_0\) —— Coordinates of the origin of the physical coordinate system in the pixel coordinate system;
\(\delta\) —— Shaft alignment difference between device sensors.

The pixel coordinates relationship between \((u_1, v_1)\) and \((u_2, v_2)\) on the image plane of the two corresponding sensors are as follows:

\[
\begin{bmatrix}
u_1 \\
v_1
\end{bmatrix} = R_1 R_2^{-1} \begin{bmatrix}
u_2 \\
v_2
\end{bmatrix}
\]

The coordinate conversion model output result error is less than 3 pixels verified by algorithm simulation, and the corresponding position matching points in the corresponding image can be quickly found within the tolerance of the error. The location map is shown in Figure 2. Each image completes its own capture or tracking algorithm, to get the location, confidence and other target information. According to the mapping location interaction with prior conditions, the reference target information values are obtained from each other, to complete target correlation tracking. This method not only ensures the algorithm complexity, but also meets the real-time requirement, which improves greatly the reliability and stability of multi-source sensor image target tracking.
2.2 Evidence theory fusion of the test results
The mathematical principle of the D-S evidence synthesis law is as follows:

Assume that \( P_1, P_2, \ldots, P_n \) are multiple independent but non-conflicting evidences under the identification framework \( \theta \), \( m_1, m_2, \ldots, m_n \) are the corresponding basic probability distribution functions respectively, and \( A_1, A_2, \ldots, A_n \) are the corresponding propositions. The mathematical principle can be defined as follows:

\[
 m(A) = K \sum_{A_1 \cap \cdots \cap A_n \neq \emptyset} m(A_1) \cdots m(A_n) \quad (\forall A \subseteq \theta, A \neq \emptyset)
\]

(3)

\( m(A) \) ——Joint probability assignment value of proposition \( A \);

\[
 K = [1 - \sum_{A_1 \cap \cdots \cap A_n = \emptyset} m(A_1) \cdots m(A_n)]^{-1}
\]

The target detection methods and feature information described by the test results of each image source are different. We complete the information fusion of multi-channel image source detection results with the D-S evidence theory, as shown in Figure 3.

![Figure 3. Fusion process of D-S evidence theory](image)

For each suspected target, firstly, the basic probability distribution value \( m_1(A) \) and \( m_2(A) \) of the proposition \( A \) is obtained according to its visible light characteristic and infrared characteristic respectively. Then, given the basic probability distribution function of different evidence, a total trust function can be calculated with the D-S evidence theory synthesis rule if the evidence is not completely conflicting, which can be used to make judgments and draw decision conclusions.

The recognition framework \( \theta \) of the design object is composed of the target (marked as \( s \)) and background (marked as \( c \)). There will be four propositions. \( \Phi \) means the recognition object can be both target and background. \( A_1 = \{s\} \) means the recognition object is target. \( A_2 = \{c\} \) means the recognition object is background. \( A_3 = \{s,c\} \) means the recognition object is neither. The joint probability distribution value of each proposition is as follows:

\[
 \begin{align*}
 m(A_1) &= K [m_1(A_1)m_2(A_1) + m_1(A_2)m_2(A_2) + m_1(A_3)m_2(A_3)] \\
 m(A_2) &= K [m_1(A_1)m_2(A_2) + m_1(A_2)m_2(A_1) + m_1(A_3)m_2(A_2)] \\
 m(A_3) &= K [m_1(A_1)m_2(A_3) + m_1(A_3)m_2(A_1) + m_1(A_2)m_2(A_3)] \\
 m(\Phi) &= 0
\end{align*}
\]

(4)

In it, \( K = [1 - m_1(A_1)m_2(A_2) - m_1(A_2)m_2(A_1)]^{-1} \)

In order to guarantee the accuracy of target recognition results, the decision formula used is as follows:

\[
\begin{align*}
 m(A_i) - m(A_j) &> \varepsilon_1 \\
 m(A_i) &> m(A_j) \\
 m(A_i) &< \varepsilon_2
\end{align*}
\]

(5)

\( \varepsilon_1, \varepsilon_2 \) ——Pre-set threshold

If the above formula is established, \( A_i \) is considered as the judgment result, otherwise \( A_2 \) is considered as the judgment result.

3. Test verification
In order to verify the validity and reliability of the proposed algorithm, three related tests were carried out, namely, shooting position indicator light, a certain type of light tracer and a self-seeking missile test. The results are as follows:

3.1 Shooting position indicator light
The results are shown in Figure 4. The original infrared image is shown on the left, with a large background fog and low visibility. The image on the right is the detection image after image fusion, and the target is relatively clear, reducing the influence of thick fog.

![Figure 4. Effect of shooting position indicator light](image)

3.2 A certain type of light tracer test
The results are shown in Figure 5. On the left is the image taken by the infrared camera. Due to the long flight distance of the target, the discrimination between the target and the background becomes worse. Therefore, the theodolite cannot capture and track automatically.

![Figure 5. Effect of light tracer test](image)

3.3 A self-seeking missile test
The results are shown in Figure 6. The original infrared image is shown on the left, in which the missile has tail flame ejection during flight to cause certain interference to target tracking. The figure on the right shows the target image processed according to the mapping relation and image fusion, removing the interference of tail flame and realizing the stable tracking of the target.

![Figure 6. Effect of self-seeking missile test](image)

4. Conclusion
In this paper, a method of multi-image source target fusion detection based on D-S evidence theory is proposed to solve the problem of infrared target detection under complex background interference in optical theodolite test. Taking the photoelectric theodolite structure advantages of combining the infrared and visible sensor, by making rational decision model based on the D-S evidence theory, the second detection of the suspected target area and evidence theory fusion of the test results, the fusion detection of infrared target is realized effectively, which provides reliable guarantee for the effective detection and stable tracking of infrared target.

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