Multi-Infrared Sensors Data Fusion Algorithm on Four Unit Photoelectric Sensors Detection System

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Abstract
In order to improve the identification rate of deceptive target of multi infrared photoelectric sensor positioning system, this paper proposes the fusion method based on Fuzzy Data Association. Using correlation recognition method of multiple sensors, a reasonable judgment criterion and decision-making concept was obtained. With the research of D-S joint rule algorithm, the diagnostic model of multi infrared photoelectric sensor is established and then the method to obtain the reliability function was given in this paper according to the spatial geometry relationship of four photoelectric sensors; presented the reasonable judgment criterion and decision-making concept of target authenticity identification on D-S data fusion algorithm. The experimental results demonstrate that the D-S joint rule algorithm can effectively identify the deceptive targets. Especially, the identification rate reached to 98% in the condition of high contrast.

Key words: Date Fusion; Photoelectric Sensors Detection; Fuzzy Association

1. INTRODUCTION
In outdoor conditions, the natural light source is complex and the environment temperature is different with the local and seasonal differences. Obviously, it usually leads to disturbance to the sensitivity of photoelectric sensor(Hu and Shan, 2001). In order to detect the position parameters of the target in the air at anytime sometimes the weak radiation signal of 10-14W needs to be captured(Li, 2016), the infrared photoelectric detection is one of the best choice. With the rapid development of infrared technology(Bogler, 1987), in industrial and military fields infrared photoelectric detection has been widely used, such as robotic systems, machine tool parameters detection, infrared guidance, anti-aircraft detection system. Besides, infrared sensor has many advantages which other photoelectric sensors do not have, such as good concealment, strong electronic jamming resistance, variety of information, unlimited frequency allocation and anti stealth.

Because of the limited of collection scope, single sensor can not obtain the complete information for the air targets identification. When there are two or more similar goals, it can not accurately distinguish them with the limited data(Li, 2015). On the process of multi-sensor target identification, due to the geometric location of the target object a large number of false intersection points are emerged during collecting the azimuth angle, elevation angle and other angles data. The number of false intersection points increases exponentially when the sensor layout is not reasonable. In this paper, the design of four sensor placement is reasonable, it can detect the target in a larger range, and the accuracy of information capture is high(Li and Lei, 2010).

There are many ways to deal with the data fusion of multi infrared sensor data(Li and Lu, 2014). The classical algorithm is multidimensional assignment model theory(Krishna and Yarkov, 1993), but this theory exist some defects. The cost function is constructed with the data calculated by maximum pseudo-likelihood method instead of the real data of object precise location(Glossas and Aspragathos, 2001), Ignoring the deviation of maximum pseudo-likelihood method, the authenticity of recognition similar objects is decreased. On the other hand, decision method based on D-S data fusion can obtain the accurate position of the target. By fusion distributing the reliability function of each sensor, this method can be simple and effective identify the true target and the deceptive target.
2. MULTIINFRAREDSENSOR DATAFUSION ALGORITHM

When the D-S evidence theory is applied to multi-sensor data fusion, the relative values obtained from the sensors are the evidence in the theory(Ouyang and Ji, 2011). It may constitute a distribution of reliability function for target identifying, showing a confidence level of each target model assumption. Each sensor forms an evidence set. Based on the D-S joint rules, the so-called multi-sensor data fusion is a combination of several evidence to form a new comprehensive evidence group (Deb, Yeddanapudi and Pattipati, 1997). It is means that combining distribution of reliability function with D-S joint rule algorithm of each sensor is to form the fusion distribution of reliability function (Zhang, Wei and Lu, 2008). So we can provide comprehensive and accurate information for the decision of the target mode. Figure 1 is the true or false target identification system of multi infrared sensor data fusion technology. Where $n_0$, $n_1$, …, $n_i$ is uncertain true and false target mode to be identified, $m_1(n_0)$, $m_1(n_1)$, …, $m_1(n_i)$ are the reliability function value of the distribution to the deceptive target model from sensor 1, $m_2(n_0)$, $m_2(n_1)$, …, $m_2(n_i)$ are the reliability function value of the distribution to the deceptive target model from sensor 2, sensor 3, sensor 4 and so on are also the same. $m(n_0)$, $m(n_1)$, …, $m(n_i)$ are the reliability function value of the distribution to the deceptive target model with multi sensor data fusion. (Huang and Tao, 1999).

![Figure 1. Block diagram of data fusion for multi infrared photoelectric sensor](image-url)

2.1. Belief Function Distribute and Belief Function

A frame of Discernment is the domain of the argument theory, marked as $\Psi$, it including limited basic proposition, marked as $\{n_0, n_1, \ldots, n_i\}$, correspondence basic event in probability theory, called primitive. In the identification of the deceptive targets corresponding basic deceptive target model, the events in $\Psi$ are mutually exclusive (Zhu and Yu, 2002).

If the set function $m$ is $2^\Psi - \{0, 1\}$, ($2^\Psi$ is $\Psi$ power set ) satisfied

$$\sum_n m(n) = 1, \quad n \in \Psi$$

Where $\Psi$ is recognize framework, $m$ is framework of the $\Psi$ belief function assignment, * is null, if $n \in \Psi, m(\ n)\ is\ known\ as\ the\ value\ of\ the\ reliability\ function\ of\ n,\ when\ m(n) \neq 0, n$ is called a focal element of the belief function assignment. The reliability function value of $n$ reflects the reliability of the $n$ itself, that is, the exact value of the reliability function assigned to the $n$.

2.2. Reliability function acquisition

Distribution of reliability function means an inference for target identification model assumption of people. It is a person’s judgment, so this kind of judgment is influenced by various factors. Different judgments form different distributions of reliability function. We consider the impact of the number of target patterns, at the same time, combined with the literature (Huang and Tao, 1999) to determine the distribution of reliability function. $\alpha_i = \max \{C_j(n_i)\}, \quad i=1,2,\ldots,N.(3)$

$$\beta_i = \left(\frac{N_c W_i/ \sum_{i=1}^{N_c} C_j (n_i) - 1}{N_c - 1}\right), \quad N_c \geq 2(4)$$

$$R_i = \frac{W_i \alpha_i \beta_i}{\sum_{k=1}^{N} W_k \alpha_k \beta_k}, \quad k=1,2,\ldots,N.(5)$$
Where $\mathcal{C}_j(n_i)$ is the target of $n_i$, correlation coefficient, the sensor $j$. $N_i$ is the number of target modes. $N$ is the total number of sensors. $W_j$ is the environmental weighting factor of sensor $j$, its range is $[0,1], \alpha_j$ is the maximum correlation coefficient of the sensor $j$. $\beta_j$ is the relative distribution of the sensor $j$. $R_j$ is the reliability coefficient of the sensor $j$. The sensor $j$ on the target mode, reliability function $m_j(n_i)$ as

$$m_j(n_i) = \frac{\mathcal{C}_j(n_i)}{\sum_{i=1}^{N} \mathcal{C}_j(n_i) + N(1-R_j)(1-W_j\alpha_j\beta_j)}$$

(6)

The reliability function of uncertainty $\tilde{\Theta}$ for sensor $j$ can be described

$$m_j(\tilde{\Theta}) = N(1-R_j)(1-W_j\alpha_j\beta_j)/\sum_{i=1}^{N} \mathcal{C}_j(n_i) + N(1-R_j)(1-W_j\alpha_j\beta_j)$$

(7)

Formula 6) and 7) show that $W_j$ is an uncertain value that is determined by the characteristics of the sensor and the experience of the field personnel. $N$, $N_C$ is a fixed value in the specific system. How to determine the correlation coefficient $\mathcal{C}_j(n_i)$ of sensor $j$ to the target mode $n_i$ is the key. Here, instead of $\mathcal{C}_j(n_i)$ we used the membership function $\mu_{ij}$ in fuzzy theory to solve it. Because in the physical sense; these two quantities are expressed by the correlation between the two. This kind of correlation is based on a sensor measurement value. To evaluate the target mode according to the measured value is belonging to a certain degree of the target type.

2.3. D-S fusion and the principle of distinguishing the deception target

According to the D-S joint rule algorithm

$$m(A) = \sum_{A=A_i \cap B_j} \{m_1(A_1)m_2(B_j)/(1-C), A \neq \emptyset (8)$$

$$C = \sum_{A=A_i \cap B_j} \{m_1(A_1)m_2(B_j)\}$$

(9)

Where $m_1$, $m_2$ is corresponding to the confidence function distribution in the same recognition framework $\Psi$, focal element respectively is $A_1$, $A_2$, ..., $A_i$ and $B_1$, $B_2$, ..., $B_i$. If $\sum_{A=A_i \cap B_j} \{m_1(A_1)m_2(B_j)\} \leq 1$, the function is defined by the following type $m : 2^\Psi \rightarrow [0,1]$ is connected the reliability function distribution. Eq 9) show that $C$ is the sum of all the belief functions, which contains the full conflict assumptions $A_i$ and $B_j$. The so-called conflict assumptions $A_i$ and $B_j$ refers to the assumption that target patterns of $A_i$ and $B_j$ may not exist at the same time in $\Psi$ (empty set), namely mutual exclusion. Formula 9) indicates that $A$ is an integrated proposition, which is a Boolean combination of the assumption target model $A_i$ and $B_j$. $m(A)$ which means reliability function value of $A$ is the sum of the product of all belief functions, without conflict assumptions $A_i$ and $B_j$.

Focal element in the identification of the deception targets $A_1$, $A_2$, ..., $A_i$ and $B_1$, $B_2$, ..., $B_i$ that is the true and false model of the previously identified $n_i$, $n_j$, ..., $n_k$ for specific target authenticity identification, it refers to the set of objects to be searched for, and $m(A)$ is the after data fusion is assigned the value of the reliability function of each wait to identify the target (Grimberg and Savin, 2000).

2.4. Target pattern discrimination rule

Classification and decision making of target model, based on rules approach, its basic principles are

(1) Determine the target type should have the maximum value of the reliability function.

(2) Determine the difference between the target type and other types of reliability function is greater than a certain threshold, such as 0.35.

(3) Uncertain belief function value must be less than a certain threshold value. Such as 0.05.

(4) Determine the target type of the value of the reliability function is greater than the uncertainty function value, such as not less than 0.35.

3. EXPERIMENT AND ANALYSIS

Based on the principle of multi infrared sensor measurement, in this experiment, we use high sensitivity and low noise infrared photoelectric sensor, a test platform is constructed as shown in Figure 2. Infrared sensor wavelength is 1000nm, the responsibility of infrared sensor is $10^6$, optical lens uses fixed focal lens, its focal length is 200mm, its relative aperture is 1:5.6, four sensor arrangement spacing, the unit is millimetres, A(-5000, 0), B(0, -5000), C(5000, 0), D(0, 5000), system acquisition card adaption rate of 20 MHz. Four sensors can be constructed to detect a range of regions of 12m*12m a detection region, the waveforms collected by the acquisition card are shown in Figure 3 and 4, figure 3 the action distance is about 3.8m, figure 4 the action distance is about 6.1m, figure 3 is about 2.43V and figure 4 is about 1.12V, the waveform can be seen in the state of figure 2 and 3, the farther away from the target, the target of the infrared radiation of the target’s own
contribution to the energy of the sensor surface is weakened, lead to output amplitude decreased significantly, also shows that inside the same target and field of view, because of the difference of the pose of the target, under the same detection distance, the infrared sensor to the target’s radiation is also a slight difference.

Figure 2. Multi infrared photoelectric sensor target acquisition and testing platform

Figure 3. Oscillogram of 3.8m effect distance.
Figure 4. Oscillogram of 6.1m effect distance.

According to the principle of the figure 2 and select the equipment parameters, a number of tests. Table 1 shows the four sensors in the same environment, the expected value of the peak value of the measured target and its standard deviation are collected from two kinds of measured targets. These two objectives, the existence of false targets. In order to strictly identify the real target, we need to combine the second chapter of the data fusion algorithm, and further discussion and analysis. From Table 1, in the detection range, it belongs to a random location. Although each sensor collects several sets of data, the expected value of each sensor is significantly different from its standard deviation. This is reflected in the same position, the four sensors to obtain the goal of their own radiation can vary. We apply the data fusion algorithm and the judgment criterion to judge and decision.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Target 2</th>
<th>Target 1</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \mu )</td>
<td>( \sigma )</td>
<td>( \mu )</td>
</tr>
<tr>
<td>S1</td>
<td>2.43</td>
<td>0.82</td>
<td>1.12</td>
</tr>
<tr>
<td>S2</td>
<td>2.25</td>
<td>0.73</td>
<td>1.22</td>
</tr>
<tr>
<td>S3</td>
<td>2.91</td>
<td>1.14</td>
<td>1.43</td>
</tr>
<tr>
<td>S4</td>
<td>2.41</td>
<td>0.83</td>
<td>0.93</td>
</tr>
</tbody>
</table>

\[
n(z) = \begin{cases} 
1 - \frac{z - \mu}{2\sigma}, & z - \mu < 2\sigma \\
0, & z - \mu \geq 2\sigma 
\end{cases} \quad (10)
\]

In (10), \( z \) is measured value; \( \mu \) is mean value of voltage; \( \sigma \) is deviation.

According to D-S joint rule algorithm and the judgment criterion of chapter 2.3, based on the test data of Table 1, the reliability function values of each sensor are obtained, as shown in Table 2. The reliability function values from Table 2 show that the reliability function value difference between two kinds of target signals is large in test system. We found that the target A, in the confidence interval of the confidence reached 75%, B only 25%. In accordance with the 2.3 chapter of the judgment criteria, we can determine the decision of the B as a false target, in the process should be removed.
Table 2. Reliability function value

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Reliability function value</th>
<th>m(μA)</th>
<th>m(σA)</th>
<th>m(μB)</th>
<th>m(σB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td>0.15</td>
<td>0.67</td>
<td>0.42</td>
<td>0.71</td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td>0.44</td>
<td>0.13</td>
<td>0.19</td>
<td>0.21</td>
</tr>
<tr>
<td>S3</td>
<td></td>
<td>0.51</td>
<td>0.18</td>
<td>0.11</td>
<td>0.28</td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td>0.37</td>
<td>0.24</td>
<td>0.27</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table 3 for the test system of four infrared photoelectric sensors in low background conditions, the expected value of the peak value of the collected two kinds of target and its standard deviation. Because of the low background environment, the contrast of the target and the environment is more obvious, so the infrared radiation of the sensor can be increased. According to the data of Table 3, and combined with the D-S joint rule algorithm and decision theory, the reliability function value is obtained in Table 4. According to the results of Table 4, target 1 in the range of the value of the reliability function is 100%, target 2 in the range of the value of the reliability function is 50%. Through the experimental data of Table 1 to Table 4, it is indicated that the D-S joint rule data fusion algorithm is scientific and correct.

Table 4. Reliability function value

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Reliability function value</th>
<th>m(μA)</th>
<th>m(σA)</th>
<th>m(μB)</th>
<th>m(σB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td>0.62</td>
<td>0.06</td>
<td>0.06</td>
<td>0.11</td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td>0.51</td>
<td>0.07</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>S3</td>
<td></td>
<td>0.57</td>
<td>0.11</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td>0.49</td>
<td>0.17</td>
<td>0.17</td>
<td>0.21</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

In this paper, the target detection area of 12m*12m is formed according to the principle of the orthogonal arrangement of four infrared photoelectric sensors. And then we proposed the D-S joint rule algorithm with a reasonable judgment criterion and decision-making concept. The photoelectric positioning platform is set up, and the output signal of the four sensors is collected with this algorithm. Combining assignment of target signal we caught, the detailed analysis procedure was given using D-S joint rule algorithm. The result indicates that the D-S joint rule algorithm is feasible and reliable. Further more, this algorithm is not only applied to the target recognition of the four photoelectric infrared sensor, but also can be extended to the data fusion recognition system of more sensors. It greatly improves the reliability of multi photoelectric infrared sensors for identifying deceptive targets, and provides a good technical support for the engineering practice.
REFERENCES


