Node Design of Wild Unmanned Alert System Based on Dempster Shafer Evidence Theory

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Abstract. Unmanned alert system is widely used in unattended surveillance, indoor security, battlefield situational awareness and wild fortress defense. However, due to the complex geographical conditions, poor information environment and various sources of interference in the wild, the design of wild unmanned alert system is more demanding. This paper took the design of the unmanned alert system nodes as the background, designed the pyroelectric infrared sensor, the microwave induction displacement module and the flame sensor. The algorithm used the Dempster Shafer evidence theory to fuse multi-sensor information, which realized energy-saving and stability of the wild unmanned alert system. Experiment shows that the node of wild unmanned alert system has strong anti-interference ability, and it can effectively realize the alert function.

1. Introduction

Unmanned Alert System (UAS) is a wireless multi-sensor network composed of sensor nodes with sensing, computing and communication capabilities, which cooperate in real-time information transmission through wireless networking. Its sensors generally include cameras, infrared sensors, microwave induction displacement sensors, and flame sensors, which are capable of detecting physical characteristics such as image features, infrared radiation, displacement motion, and flame source generated by an invading target in the surroundings; thereby the system can identify the state and characteristics of the invading target. Therefore, UAS is widely used in unattended surveillance, indoor security, fortress defense and wild training [1]. Due to the complex and harsh environment in the wild, how to ensure the energy-saving ability and stability of the unmanned alert system in the wild needs further study.

In order to realize the stable work and accurate identification of Wild Unmanned Alert System (WUAS) nodes, multi-sensor information, such as the information of pyroelectric infrared sensor, microwave induction displacement sensor and flame sensor is fused by Dempster Shafer evidence theory to determine whether there is an invading target or not. Similarly, in order to ensure that the nodes of WUAS can work continuously and efficiently, we design a method to ensure that the node is energy-saving when no target intrusion occurs. Through the target intrusion test, the node can play an unmanned surveillance function in the wild efficiently and stably.

The organization of the paper is as follows. Section II presents the whole structure of WUAS node, including the design of the typical hardware module, the algorithm fusing the multi-sensor information
and the model of the node detecting invading targets. In Section III, the target intrusion test of the WUAS node is carried out in the wild, and the experimental results are presented. Conclusion is presented in Section IV.

2. The Structure of System Node

Fig. 1 shows the structure block diagram of WUAS node. The node of WUAS is mainly composed of a camera, a pyroelectric infrared sensor, a microwave induction displacement module, a flame sensor module, a wireless module, a power module and a STM32 MCU. The camera adopts PTC08 serial port camera, and other modules are designed by ourselves.

The workflow of the node is: when the information fused by the sensors is that there exists an invading target, the node activates the camera to take pictures of suspicious targets in the surroundings and upload the picture to the control center via a wireless module. When the fused information is no target intrusion, the camera sleeps and the node is dormant.

2.1. Design of Pyroelectric Infrared Sensor

Pyroelectric infrared sensor detects infrared energy radiated by the invading target and converts it into electrical signal [2]. Fig. 2 shows its components. It consists of an infrared detector, a Fresnel lens and an infrared signal processing circuit. Its function in WUAS is to detect the invading target, such as human or large animal, etc.

Two LHi968 detectors are selected as the signal acquisition part of the sensors. The signals collected by the detectors are superimposed and input into the processing circuit. LHi968 is a dual pyroelectric infrared detector. It possesses infrared filtering function, high sensitivity, low noise, and can avoid strong white light interference.

Figure 1. The structure block diagram of wild unmanned alert system node

Figure 2. Components of pyroelectric infrared sensor
Fresnel lens can focus infrared signal, divide the detection area into several alternate bright and dark areas, so that moving objects entering the detection area can produce infrared signal on PIR detectors in the form of temperature change [3]. 8204-1 narrow-angle long-distance Fresnel lens is selected. Its focal length is 25 mm, focusing angle is 10 degrees and focusing distance is 40 m.

Infrared signal processing circuit adopts the newest human pyroelectric infrared detection scheme. We select AS085 as the sensor’s processor, which has low power consumption and can automatically adjust to the current environment, filter out environmental noise, effectively extract human signal.

Fig.3 shows the circuit schematic of pyroelectric infrared sensor. Part I is designed for signal processing, part II is used for signal amplification, and part III is the part of signal acquisition. The experimental results show that the detection distance of the designed sensor can reach up to 40m, which meets the requirements of the system.

2.2. Design of Microwave Induction Displacement Module

The microwave induction displacement module is a sensor based on Doppler shift principle, which can detect moving objects in a certain range. Its function in WUAS is to detect the information of moving objects in the surroundings. Table 1 shows the main performance parameters of GH-719C microwave induction module.

| Parameters                  | Table Column Head                  |
|-----------------------------|------------------------------------|
| Center frequency            | 10.525GHz                          |
| Working voltage             | 3.5V-20V                           |
| Quiescent current           | 1.7mA                              |
| Induction distance          | 1-30m, 16-level adjustable         |
| Operating temperature       | -30℃-70℃                           |

Due to the high power consumption of the microwave induction displacement module, a pulse power supply circuit is designed to save the power consumption of the module to ensure the energy-saving work of the WUAS node. Fig.4 shows the circuit schematic of the module.

A low power, universal timer chip ICM7555 is selected to design a pulse generator with continuously adjustable frequency and duty cycle. Experiments show that when the frequency and duty of the pulse power supply is relatively 2 KHz and 2%, the module works normally, and the power consumption can be greatly reduced. In addition, the detection distance of the module can reach up to 40m, which also meets the requirements of the system.
2.3. Design of Flame Sensor Module
Flame sensor is used to detect the heat radiation released by fire source. It is composed of a focusing lens, a detector and a signal processing circuit. The focusing lens can focus the flame radiation in a certain range, thereby improving the detection range of the flame sensor. Fig.5 shows the circuit schematic of the sensor. Flame sensor’s function is to detect the fire carried by the invading target or in the surroundings, and to play an alert role in the WUAS.

2.4. Design of Intrusion Target Detection Model
Let $\Theta$ be an identification framework, namely a hypothesis space. Basic Probability Assignment (BPA) is a function defined as $m$ [4], which satisfies the following conditions within the recognition framework $\Theta$:

$$m: 2^\Theta \rightarrow [0,1], m(\emptyset) = 0, \sum_{A \subseteq \Theta} m(A) = 1$$

Among them, A is a hypothesis in the identification framework, the function $m$ is called mass function, so that $A$ with $m(A) > 0$ is called Focal Elements (FE), and $m(A)$ describes the support degree of the evidence for hypothesis $A$.

Belief Function (BF) is defined as:

$$Bel(A) = \sum_{B \subseteq A} m(B), \forall A \subseteq \Theta$$

The Plausibility Function (PF) is defined as [5]:

$$Pl(A) = \sum_{B \cap A \neq \emptyset} m(B), \forall A \subseteq \Theta$$

Figure 4. Circuit schematic of microwave induction displacement module

Figure 5. Circuit schematic of flame sensor module
When the evidence rejects A, \( P_l(A) = 0 \); when there is no evidence to reject A, \( P_l(A) = 1 \). Confidence interval \([\text{Bel}(A), P_l(A)]\) refers to the interval composed of belief function and plausibility function, which is used to express the degree of confirmation of a hypothesis A [6].

DS evidence theory is a common method to fuse multiple independent sensor information. The fusion rules are as follows:

For the two mass functions \( m_1 \) and \( m_2 \) within the framework \( \Theta \), the fusion rule is [7]:

\[
m_{1 \oplus 2}(A) = \frac{1}{K} \sum_{B \cup C = A} m_1(B) \cdot m_2(C)
\]

Among them, \( K \) is a normalized constant, which satisfies:

\[
K = \sum_{B \cup C = \emptyset} m_1(B) \cdot m_2(C) = 1 - \sum_{B \cup C = \emptyset} m_1(B) \cdot m_2(C)
\]

(5)

For finite mass functions \( m_1, m_2, \ldots, m_n \) within the identification framework \( \Theta \), the fusion rule is as follows:

\[
(m_1 \oplus m_2 \oplus \cdots \oplus m_n)(A) = \frac{1}{K} \sum_{A_1 \cap A_2 \cap \cdots \cap A_n = \emptyset} m_1(A_1) \cdot m_2(A_2) \cdots m_n(A_n)
\]

(6)

Among them, \( K \) is a normalized constant, which satisfies:

\[
K = 1 - \sum_{A_1 \cap A_2 \cap \cdots \cap A_n = \emptyset} m_1(A_1) \cdot m_2(A_2) \cdots m_n(A_n)
\]

(7)

After getting the fusion results of multiple sensors, how to judge the reliability of the fusion results in practical application is a problem that needs to be considered when making decision.

According to the basic probability assignment function, belief function and plausibility function, there are corresponding maximum basic probability criterion, maximum belief function criterion and maximum plausibility function criterion [8].

In the design of the WUAS node, the set of the invading target attributes is \{invading targets, no invading targets\}, recorded as the identification framework \( \Theta = \{\text{YTT, NTT}\} \). The set of evidence sources is \{pyroelectric infrared sensor, microwave induction displacement module, flame sensor module\}, recorded as \{PIR, MID, FSM\}. Fig.6 shows the invading targets detection process of the system.
According to the sensitivity and accuracy of each sensor, Table 2 shows the basic probability allocation of each sensor evidence source. In the table, the former number represents the probability allocated when the sensor detection signal is high-level (Target being detected), and the latter number represents the probability allocated when the sensor detection signal is low-level (Target not being detected).

Based on the basic probability assignment function and the detection signals obtained from the evidence sources of each sensor, the belief function and plausibility function of the intrusion target attributes in the identification framework \( \Theta \) are calculated.

\[
Bel(YTT) = (m_{PIR} \otimes m_{MID} \otimes m_{FSM})(YTT)
\]

\[
Bel(NTT) = (m_{PIR} \otimes m_{MID} \otimes m_{FSM})(NTT)
\]

\[
Bel(\Theta) = (m_{PIR} \otimes m_{MID} \otimes m_{FSM})(\Theta)
\]

\[
Pl(YTT) = Bel(YTT) + Bel(\Theta)
\]

\[
Pl(NTT) = Bel(NTT) + Bel(\Theta)
\]

\[
Pl(\Theta) = Bel(\Theta)
\]

Finally, the confidence interval is obtained:

\[
\begin{bmatrix}
Bel(YTT) & Pl(YTT) \\
Bel(NTT) & Pl(NTT) \\
Bel(\Theta) & Pl(\Theta)
\end{bmatrix}
= \begin{bmatrix}
Bel(YTT) & Bel(YTT) + Bel(\Theta) \\
Bel(NTT) & Bel(NTT) + Bel(\Theta) \\
Bel(\Theta) & Bel(\Theta)
\end{bmatrix}
\]

Table 2. Basic Probability Allocation of Evidence Sources

| Target Evidence Attribute | Evidence Sources of Sensors |
|---------------------------|-----------------------------|
|                           | \( PIR \) | \( MID \) | \( FSM \) |
| YTT                       | 0.8/0.15 | 0.8/0.05 | 0.9/0.4 |
| NTT                       | 0.1/0.7  | 0.1/0.9  | 0.05/0.5 |
| \( \Theta \)              | 0.1/0.15 | 0.1/0.05 | 0.05/0.1 |

Table 3. Test Data of Target Intrusion

| Target Attribute | Sensor Signal | \( Bel(Y), Bel(N), Bel(\Theta) \) | Fusion Result          |
|------------------|---------------|----------------------------------|------------------------|
| Invading Targets | “111”         | 0.9948, 0.0045, 0.00065          | Invading Targets Exist |
| Invading Targets | “110”         | 0.9439, 0.0537, 0.0023           | Invading Targets Exist |
| Invading Targets | “101”         | 0.8177, 0.1799, 0.0024           | Invading Targets Exist |
| Invading Targets | “011”         | 0.9377, 0.0596, 0.0027           | Invading Targets Exist |
| Invading Targets | “010”         | 0.5669, 0.4268, 0.0064           | Invading Targets Exist |
| No Invading Targets| “001”        | 0.2583, 0.7382, 0.0034           | Invading Targets don’t Exist |
| No Invading Targets| “000”        | 0.0286, 0.9699, 0.0015           | Invading Targets don’t Exist |
| No Invading Targets| “100”        | 0.2808, 0.7161, 0.0032           | Invading Targets don’t Exist |

3. Experimental Tests and Analysis

Target intrusion test is carried out on the WUAS node. Taking human target intrusion as experimental variable, pyroelectric infrared sensor, microwave induction displacement module and flame sensor...
return the corresponding intrusion target recognition signal ("1" represents that the intrusion target is detected by the sensor, and "0" represents that no intrusion target is detected by the sensor). Sensor information is fused by DS evidence theory. The data obtained from the experiment is shown in Table 3. According to the calculation of experimental data, the results obtained by the fusion of DS evidence theory almost conform to the actual target intrusion situation, and the system can play its alert function normally.

4. Conclusion
This paper mainly focuses on the research of the wild unmanned alert system node, including designing the sensors, building the system node, establishing an intrusion detection model and carrying out the experimental test. Specifically, our main work is designing a pyroelectric infrared sensor, a microwave induction displacement module and a flame sensor module. In addition, we use DS evidence theory to fuse multi-sensor information. The results show that the WUAS node can play an automatic alert role, and can work stably and economically in the wild.

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