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Decision-Making Level Fusion Based on DSmT for Multi-Sensor Life Detection Platform

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Abstract: Life detection based on a single type of information sources detection technology cannot completely meet the needs of the earthquake relief. First, we analyze the present situation of typical life detection technology, then the advantages of multi-sensor synergy detection technique are given. Second, we explained the platform structure and information fusion model. Finally, the fusion rule based on Dezert-Smarandache theory (DSmT) is used to achieve the decision level fusion. We present the results reached by the fusion with the conjunctive rule, the Dempster, the Yager and the DSmT. The experiments show that DSmT can get more comprehensive and more accurate information about the scene of rescue and survivors. The multi-sensor synergy life detection platform based on DSmT is more suitable for complex quake rescue environment. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Life detection, Decision level fusion, Dezert-Smarandache theory, Infrared sensor, Acoustic wave sensor.

1. Introduction

Searching for survivors after a disaster is always a race against time. The correct use of rescue methods and equipment to be trapped rescue personnel positioning, can be twice the result with half the effort. Existing life detection techniques are based on a single type of sensor, there exist their defects. Based on multi-sensor synergy research will become the focus of detecting technology. At present, the application of multi-sensor synergy mainly concentrated in military, aerospace and industrial production areas, while to detect the rescue of life is very little [1, 2].

Data and information fusion clearly is a key enabler in the provision of decision quality information to the decision maker. The essence of decision-making in civilian, military and public security operations is people making timely decisions in the face of uncertainty, and acting on them. This process has been immeasurably complicated by the overwhelming and increasing volume of raw data and information available in the current age.

Multi sensor synergy life detection is to make survivors recognition based on multi-source information fusion. It is more effective than single source detection (such as audio life detection, video life detection, radar Life Detection, and so on). D-S theory is suitable for without any prior information, but also in the representation of uncertainty, measurement and has the advantage of combination, and it accords with the decision the process of human reasoning. Evidence theory but in evidence for the occurrence of high conflict situations will be effective fusion have counter intuitive conclusion port J. to realize multi-source information in highly conflict evidence is an urgent problem to be solved. A lot of literature that this is caused by the combination of rules and improved, but the effect is not very ideal. In this case, Dezert and Smarandache et al proposed DSmT in 2002. DSmT is the extension of the classical D-S theory, but DSmT is different with the D-S theory [3-5]. This paper describes DSmT and its application in survivor identification, and verified with an example.

2. Life Detection Technology Analysis

Life detection is to use the sensor technology to collect the survivors' physiological, physics and chemical information, to effectively identify the position of the living organisms [6]. According to the sensor type can be divided into audio life detection technology (including sound waves, vibration wave), video life detection technology (including optics, optical fiber, infrared) and radar life detection technology (including imaging, the imaging). The life detection technologies based on single type of sensor have their own defects.

2.1. Audio Life Detection Technology

Audio life detection technology is the application of the principle of vibration wave sound spread, through the detection of underground weak such as the men groan, shout, creeping, beating from audio sound waves and vibration wave to judge whether life exist [7]. But it is a kind of passive detectors receiving audio signal and the vibration signal; therefore, it is vulnerable to the surroundings noise interference. People need to find space stretch into probe in the ruins, detection at a slower speed.

2.2. Video Life Detection Technology

Video life detection technology is turning rescue environment and object into visual images, so as to provide the rescuers with environmental information, the survival position information, etc. Among them, the infrared detection equipment life in rescue in the process of using more widely, it will be a different temperature objects invisible infrared ray into a visual images, using the human body black and white image to determine the survivors and victims of the instrument can be dark, smoke to search the environment, and has the function of night vision, this makes life work from the light detection effect, can help rescue team quickly, accurately determine buried in the ruins in or hidden in the back of the victims of the haze position [8]. But the infrared life detector could not penetrate obstacles, still need to looking for the big or small hole, crack, etc, to reach into the probe to observe internal situation, so the application subject to certain restrictions.

2.3. Radar Life Detection Technology

Radar detection technology is to fuse radar technology and biomedical engineering technology to one life detection equipment, with strong penetration, precise range and strong anti-interference ability, strong ability to target recognition etc, which can accurately identify the living organisms [9]. Commonly used radar life detection technology can be classified into two kinds, namely Continuous Wave (CW) radar detection life and the Ultra Wide Band (UWB) radar life detection. Continuous wave radar detection means life continuous wave radar launch mw beam of the body, the reflection of the echo was living life activities (such as breathing, heartbeat, etc) cause budge the modulation, make some of the echo signal parameters change, use of appropriate signal processing technology of the parameters of the living organisms extract signals (such as breathing, heart rate, etc). Ultra-wide band radar detection means life pulse declined beam irradiation living organisms, organism the reflection of the echo pulse repeated sequences of cycle sport because organism and change information, using a digital signal processing technology of the parameters of the living organisms extract signals (such as breathing, heart rate, etc) .

The disadvantages of radar life detector are high cost and electromagnetic wave radiation effect to human body, so radar life detector does not apply to close detection.

2.4. The Advantage of Heterogeneous Sensors Synergy

Visible, the life detection technologies based on a single type of information source have their own defects, cannot completely meet the needs of the earthquake relief, the life detection technology based on heterogeneous sensors become a new hotspot.

The target compound recognition based on information fusion using heterogeneous sensors to collaborative detection has the following advantages:

1) Broaden the surveillance space and detection coverage;

2) Play to the advantages of each sensor and complement each other in order to improve the target recognition rate;

3) The anti-interference performance of the multi-sensor much better than single sensor;

4) Improve the reliability and fault tolerance.

For more collaborative detection sensor at home and abroad research mainly focus on three aspects:

- The construction of the multi-sensor integration model;
- Multi-sensor selection strategy and
- Control structure research [10] and the multi-sensor information fusion method research [11].

3. Multi-sensor Life Detection Platform Design

Infrared and acoustic sensors can be in the dark, smeary wait for the bad environment under the working conditions of, and has simple structure, low cost, adaptable, does not damage easily, etc. Through the infrared sensors can get living organisms of the environment which image, using the principal, passive sound waves to living organisms can sensor for a weak distress signal detection of living organisms and more accurate positioning, and both can work together to make the rescue plan to provide more accurate basis for decision-making, reduce relief time, reduce loss disasters.

3.1. The Platform Structure

This synergy detection platform function model is shown as Fig. 1.

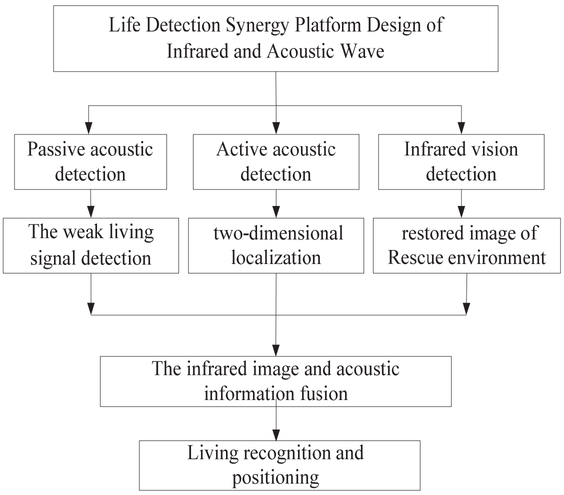

Fig. 1. Function model of life detection synergy platform.

First, the passive acoustic detection technology, in the ruins in the ruins or empty detection, acquisition and extracting the organism of a sound wave signal (the men groan, shout, creeping, beating from audio sound waves), to judge the living organisms exist suspected area. In this area for the ruins and empty, using infrared vision detecting, living environment image collection. At the same time to target launch ultrasonic active organism, in order to accurately position are living organisms. Through information fusion processing of the above can realize the target recognition and living location, and provide decision support for formulate effective rescue plan.

3.2. Hardware Structure

The hardware of the platform mainly includes:
1) Multi-channel sound waves information collector;
2) Video acquisition module;
3) Signal fusion processor (FPGA + DSP);
4) Embedded processor: communication, control, display, etc.

The hardware configuration of infrared and acoustic life synergy detection platform is shown as Table 1.

Table 1. The hardware configuration.

No.	Description	Technical specifications
1.	Multi-sensor fusion signal processing platform	1) Backplane; 2) 8 channel Sound/vibration signal synchronous sampling rate: 204.8 kS/s; 3) Embedded processor: 2.53 GHz Intel Core 2 Duo T9400; 4) System throughput ≤1 GB/s, single slot throughput: 250 MB/s; 5) 1 channel Camera Link interface
2.	Vibration sensor	Impact resistance value >1000 g Frequency response: 1~3000 Hz
3.	Audio sensor	Frequency response: 200 Hz to 3000 Hz

Multi-channel data collection realizes low frequency sound and signal and ultrasonic sound wave signal synchronous collection. Video collection module implements video collection of the infrared transmission and pretreatment. Signal fusion processor can complete the master of passive acoustic signal processing. Embedded processor is responsible for the communication of the whole system, control, display, etc.

3.3. The Platform Building

The synergy detection platform is composed of hardware platform and software platform. The hardware platform includes infrared sensor, vibration sensor, ultrasonic sensor, multi-channel acoustic/vibration data acquisition card, ultrasonic data collection card, embedded processors and I/O devices, as shown in Fig. 2. The software platform use the LabView as a development tool, to complete the video and sound information collection, information display and processing.

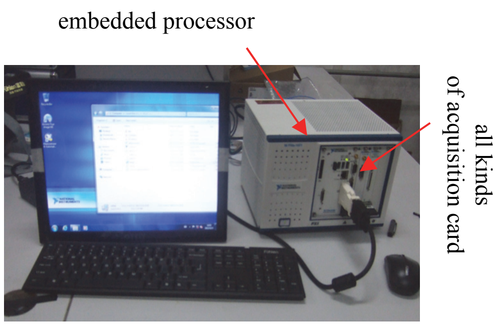

Fig. 2. Hardware platform structure.

4. Decision-making Level Fusion Based on DSmT

The infrared image and acoustic information is completely different qualitative information, that is, different information. Usually, different information has the very strong complementary to each other, so the fusion of information produced by the more practical value. However, alien sensor information fusion are faced with many difficulties, the main difficulty is currently there is no general mathematical tools and methods, description and analysis of the different information features and many sources of information fusion corresponding.

The multiple source information fusion general can carry out in different levels, such as data level, characteristic level and decision level. Because different inherent characteristics of information and is currently in the data layer of fusion extremely hard, general only limited characteristic layer or decision-making for research. And decision-making level fusion is in the top of the said information on the fusion processing.

4.1. Backgrounds on Combination Rules

The hybrid DSm rule can deal with the potential dynamicity of the frame and its model as well [5]. The DSmT deals properly with the granularity of information and intrinsic vague/fuzzy nature of elements of the frame Θ to manipulate. The basic idea of DSmT is to define belief assignments on hyper-power set D^Θ (i.e. free Dedekind's lattice) and to integrate all integrity constraints (exclusivity and/or non-existential constraints) of the model, say $M(\Theta)$, fitting with the problem into the rule of combination. Mathematically, the hybrid DSm rule of combination of $s\geq 2$ independent sources of evidence is defined as Eq. 1 for all $X\in D^\Theta$.

$$m_{M(\Theta)}(X)\overset{\Delta}{=}\phi(X)[S_1(X)+S_2(X)+S_3(X)], \quad (1)$$

where $\Phi(X)$ is the characteristic non-emptiness function of a set X, i.e. $\Phi(X)=1$ if $X\in\emptyset$; and $\Phi(X)$ = 0 otherwise, where $\emptyset \triangleq \{\emptyset_M, \emptyset\}$. $\emptyset_M$ is the set of all elements of D^Θ which have been forced to be empty through the constraints of the model M and Ø is the classical/universal empty set. $S_1(X)$, $S_2(X)$ and $S_3(X)$ are defined by Eq. 2, Eq. 3 and Eq. 4.

$$S_1(X)\overset{\Delta}{=}\sum_{\substack{X_1,X_2,\ldots,X_s\in D^\Theta\\ X_1\cap X_2\cap\ldots\cap X_s=X}}\prod_{i=1}^{s}m_i(X_i), \quad (2)$$

$$S_2(X)\overset{\Delta}{=}\sum_{\substack{X_1,X_2,\ldots,X_s\in\phi\\ [u=X]\vee[(u\in\phi)\wedge(X=I_t)]}}\prod_{i=1}^{s}m_i(X_i), \quad (3)$$

$$S_3(X)\overset{\Delta}{=}\sum_{\substack{X_1,X_2,\ldots,X_s\in D^\Theta\\ X_1\cup X_2\cup\ldots\cup X_s=A\\ X_1\cap X_2\cap\ldots\cap X_s\in\phi}}\prod_{i=1}^{s}m_i(X_i), \quad (4)$$

with $u \triangleq u(X1)\cup u(X2)\cup\ldots\cup u(Xs)$ where u(X) is the union of all θi that compose X and $It \triangleq \theta1\cup\theta2\cup\ldots\cup\theta n$ is the total ignorance. S1(A) corresponds to the classic DSm rule for k independent sources based on the free DSm model Mf (Θ); S2(A) represents the mass of all relatively and absolutely empty sets which is transferred to the total or relative ignorance associated with non existential constraints (if any, like in some dynamic problems); S3(A) transfers the sum of relatively empty sets directly onto the (canonical) disjunctive form of non-empty sets5.

4.2. Fusion Example of Infrared Image and Acoustic Information

In this case, the space of discernment Θ represents the survivor identification on infrared images and acoustic information. The experts give their perception and belief according to their certainty. Consequently we have to take into account all these aspects of the applications. In order to simplify, we consider only three classes in the following: survivor as A, no-survivors, referred as B, and indetermination, referred as C. Hence, on certain tiles, A, B, and C can be present for one or more experts. The belief functions have to take into account the certainty given by the experts (numbers in [0, 1]) as well as the proportion of the kind of survivor identification.

We give the obtained results on a multi-sensor life detection system for the fusion of two experts in infrared images and acoustic information. Table 2 shows the generalized confidence given by two experts, which m_1: confidence given by expert1 based on infrared image; m_2: confidence given by expert1 based on acoustic information; m_3: confidence given by expert2 based on infrared image; m_4: confidence given by expert2 based on acoustic information.

Table 2. Generalized confidence functions.

Target type	m_1	m_2	m_3	m_4
A	0.5	0	0.55	0.55
B	0.2	0.9	0.1	0.1
C	0.3	0.1	0.35	0.35

We present here the results reached by the fusion with the conjunctive rule, the Dempster, the Yager and the DSmT, shown as Table 3.

The results in Table 3 show that Dernpster's result is contrary to intuition, which determine the target identity as "B". Because evidence 2 has "veto", no amount of evidence to support "A", it is a serious error. In the same way, Yager rule assign all conflicts to "C", which is no good to make a decision. However, DSmT determine the target identity as "A", which is satisfied the verdict. It means that DSmT is suit to solve the problems brought by high conflict evidence.

Table 3. Results with different conjunctive rule.

Results	Dempster	Yager	DSmT
$m(A)$	0	0	0.392
$m(B)$	0.671	0.002	0.058
$m(C)$	0.329	0.004	0.187
$m(A\cup B)$	—	—	0.078
$m(A\cup C)$	—	—	0.045
$m(B\cup C)$	—	—	0.167
$m(A\cup B\cup C)$	—	—	0.073
$m(\Theta)$	—	0.995	—

5. Conclusions

At present life detectors are still based on a single type sensor. While in the actual earthquake relief work, life detectors and rescues often need to combine various information. Infrared and acoustic synergy life detection based on DSmT can make up the defects of single sensor life detection. Decision-making level fusion based on DSmT is more suitable for complex environment of earthquake relief, and can get more comprehensive, more accurate information of survivors. We have shown on real data that there is a difference of decision following the choice of the combination rule. The results show that DSmT is suit to solve the problems brought by high conflict evidence.

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