Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 62 (2013) 985 – 993

Procedia Engineering

www.elsevier.com/locate/procedia

The 9th Asia-Oceania Symposium on Fire Science and Technology

Investigation of the performance and improvement of optical smoke detectors

Hingman To, Naikong Fong*

Department of Building Services Engineering, The Hong Kong Polytechnic Unibversity, Hung Hom, Kowloon, Hong Kong, China

Abstract

To reduce the false alarm from the smoke detectors, a series of experiments were conducted to collect and analyse the time series of signal pattern generated by the detectors under three fire categories – flaming fire (propanol), smoldering fire (cloth-cotton) and non-fire sources(joss stick and steam). The time series of each fire category was studied. Dissimilarity measure such as Euclidean Distance was used to discriminate the data collected. It is used to classify the fire category into fire class or non-fire class and enhance the effectiveness of the fire alarm judgment system. 30 sets of learning samples of each fire category (total: 120 experiments) are collected. It showed that the accuracy of smoke detector was over 80%. If multi-sensor (smoke and heat) detector was used, the accuracy was over 90%.

Selection and peer-review under responsibility of the Asian-Oceania Association of Fire Science and Technology

Keywords: Fire; Smoke detector; False alarm; Euclidean distance

1. Introduction

The purpose of an automatic fire detection system is to detect fire at the earliest practical moment and to give an alarm so that appropriate action can be taken such as evacuation of occupants, summoning the fire fighting organization, automatic triggering of extinguishing processes [1]. An effective automatic fire detection system therefore needs reliable automatic fire detectors to detect the fire at an early stage and provide an effective warning/alarm signal to indicate the location of fire before unacceptable damage in order to protect human life, property, against business interruption and the environment [2].

Various types of detectors are designed to detect fire including heat detectors and smoke detectors. However, many researchers and codes [3, 9, 10, 11] indicated that the performance of automatic fire detection system is not good enough due to the unreliable fire detectors. The existing smoke detectors have a poor performance especially regarding false alarms [9]. Since smoke detectors are designed to detect smoke particles, they are not able to differentiate between smoke from actual fire and particles from other non-fire events such as cigarette smoke. According to the data collected during 2006 to 2010 by the Hong Kong Fire Services Department (HKFSD) [4-8], it showed that the percentage of false alarms continued to increase. In 2010, 76% of total alarm calls were false alarms as shown in Fig. 1. Moreover, from statistics obtained by National Fire Protection Association (NFPA) [3], it reported that 2,177,000 false alarms were estimated in 2009. These false alarms significantly damaged the credibility of the automatic fire detection systems. In above issues, the causes of false alarms are not yet well understood. In terms of these, the present study aims to look for a method to reduce the false alarms from smoke detectors and improve the reliability of smoke detectors.

* Corresponding author. Tel.: +852 2766 5854.
E-mail address: benkfong@polyu.edu.hk.

Selection and peer-review under responsibility of the Asian-Oceania Association of Fire Science and Technology
doi:10.1016/j.proeng.2013.08.152

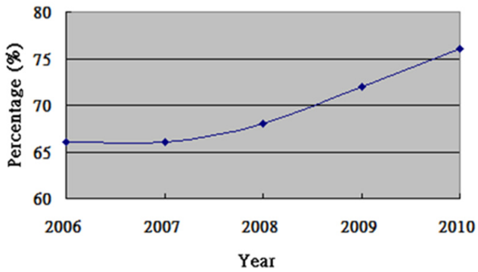

Fig.1. Percentage of false alarms in Hong Kong (2006-2010) from FSD.

2. Objectives

The main objectives of this study are:

- Collect the time series of signal pattern under three fire categories (flaming fire, smoldering fire and non-fire sources).
- Quantize the time series of signal pattern into a gradient histogram of 36 dimensional vectors for feature extraction.
- Use the dissimilarity measure (Euclidean Distance) to classify the time series into two classes, which are fire class and non-fire class, in order to reduce false alarm problem.

Table 1. Recommendations of design factors to reduce false alarm in standards and codes

	NFPA 72	BS Standards (BS 5839 Part1, BS 5445 Part 1,7,9)	Underwriters Laboratories Inc. (UL 268, UL 260)
Type of Detector	Heat-Sensing Fire Detector, Smoke-Sensing Fire Detector, Radiant Energy-Sensing Fire Detector, Multi-Sensor Detector	Heat Detector, Smoke Detector, Combustion Gas Detector, Infra-red or Ultraviolet Radiation Detector	Smoke Detector
Different Type of Test and Test Method	(1) Calibrated test method (2) Manufacturer's calibrated sensitivity test instrument (3) Other calibrated sensitivity test methods approved by the authority having jurisdiction	(1) High ambient temperature test (2) Sensitivity to ambient light test (3) Humidity test (4) Corrosion test	(1) Velocity-sensitivity test (2) Humidity test (3) Dust test (4) Fire Tests (5) Smoldering smoke test
Test Fire	Standard fire sources: (1) Wood (2) Flaming liquid fire (3) Gas	Standard fire sources: (1) Open cellulosic fire (2) Smouldering pyrolysis fire (3) Glowing smouldering fire (4) Open plastics fire (5) Liquid fire	Standard fire sources: (1) Paper fire (2) Wood fire (3) Flammable liquid fire (4) Polymeric materials
Parameter leading False Alarm	Smoking, dust, humidity, high air velocity, lack of maintenance, insects, steam, cooking	Cooking, tobacco smoke, dust, insects, high air velocity, high humidity	High air velocity, high humidity, dust, corrosion, transient
Design Consideration / Factor to Reduce False Alarm	(1) Ceiling shape and surface (2) Ceiling height (3) Compartment ventilation (4) Ambient temperature, pressure, altitude, humidity, and atmosphere	(1) The speed of fire detection required (2) Probable rate of fire growth and spread (3) The nature of the environment (e.g. humidity and temperature) (4) The height of the protected area (5) The speed of response to fire	(1) Ambient temperature (2) Air velocity (3) Relative humidity (4) Sensitivity level (5) Combustion characteristics of test fire (6) Ceiling shape and surface

3. Code review

There are several codes and standards [1, 2, 12-16] to regulate the automatic fire detection system currently, but the false alarm problems still occur from time to time. A summary of design factors are listed in Table 1. Thus, the present study is to conduct a series experiments to investigate the performance of smoke detectors and heat detectors under different types of fire sources in order to identify the common sources leading to false alarm in Hong Kong and to figure out an effective or a "tailor-made" measure to reduce the false alarm problems for Hong Kong situation.

4. Literature review

In past years, many researchers had conducted experiment to investigate the performance of various types of fire detectors. Their results showed that improvement to existing detection system is needed.

An experiment was conducted by Derbel [9] to investigate the response time and reliability between commercial fire detectors (*e.g.* Optical and Ionization detector). The results showed that false alarms occurred in testing non-standardized fires and the commercial detectors provided late response when testing standard fires. Since fires would produce gaseous products and temperature rise, a multi-sensor detector which consisted of a commercial optical detector, a set of gas sensors, and a temperature sensor were suggested for the early fire detection in order to reduce false alarm problems.

On the other hand, the fire alarm algorithms used (1) CO and smoke and (2) CO_2 and smoke to reduce the false alarms and response times were studied by Chena et al. [10] as the rates of rise of CO and CO_2 could be measured to identify flaming and non-flaming fires. The first advantage was to allow the alarm threshold to be set at a more sensitive region without causing false alarm. The second advantage was that the alarm point is insensitive to constant offsets in the gas concentration measurements.

The actuation time of the smoke detectors with different combustibles in different fire ignition locations at the initial stage was investigated by Lai et al. [11]. Their results showed that door opening areas, smoke emission rates and fire source locations affected the actuation of smoke detectors. For example, the larger opening area increased the outdoor air supply and generated more smoke. Also, when the fire source was located near a corner, the plume corner effect greatly increased. All of these scenarios would activate the smoke detectors quickly. A brief summary of literature review on false alarm study is shown in Table 2.

Table 2. Literature review on different fire detector study for reduce false alarm.

Author	Derbel [9]	Chena et al. [10]	Lai et al. [11]
Objective	Investigate the response time and reliability of detector	Analyze the fire alarm algorithms	Investigate the actuation time of detector in different location
Types of detector	(1) Optical Detector (2) Ionization Detector	(1) Muilt-sensor Detector (CO and CO_2)	(1) Smoke Detector
Types of test fire	(1) Standard test fires (2) Non-Standard test fires	(1) Combustible materials (2) Liquid fuels	(1) Moveable test fires (2) Fixed test fires
Aim	Reduce the False Alarms	Increase the reliability of detector	Increase the reliability of detector
Result	(1) False alarms occurs in testing Non-standard fire (2) Late response when testing Standard fire (3) Using Muilt-sensor can reduce false alarm	(1) CO and CO_2 can used to identify flaming and non-flaming fire (2) Alarm threshold can set at a more sensitive valve	(1) Fire source location, smoke emission rates and door opening affect actuation time of smoke detector (2) Fire source located near a corner, smoke detector activate quickly.

5. Methodology

For the present study, in order to achieve the objectives, a series of experiments were conducted to collect the time series of signal pattern of different fire category. In the experiment, two main equipment (Honeywell FS90 fire panel and thermocouple tree) with photoelectric smoke detector (SD) and heat detector (HD) were selected to test three fire categories– flaming fire (propanol), smoldering fire (cloth-cotton) and non-fire sources (joss stick and steam). All those were defined in

EN54 part 9 [17]. Also, the thermocouple tree was used to monitor the room temperature. Honeywell FS 90 fire panel was commonly adopted in buildings for fire protection. It can be used to collect the signal data from the detectors for data analysis.

According to the NFPA 72 Standards test conditions, a room with a smooth ceiling, the distance between the combustible and ceiling should be 2.1 m. The test should be conducted in an ambient temperature between 20 °C and 27 °C at 50%±10% relative humidity [12]. Therefore, the experiments were carried out in a full scale room (4 m Length x 3 m Width x 2.8 m Height) in The Hong Kong Polytechnic University (The HK PolyU) as shown in Fig. 2. Five detectors were placed at the ceiling at 5 different positions directly above the test fire. For detector 1, it was placed 2700 mm away from the sidewall and indicated as position 1. The other 4 detectors were also placed above the test fire (2750 mm away from sidewall at position 2, 2850 mm away from sidewall at position 3, 2900 m at position 4 and 3000 mm at position 5). The test fire was located on the floor level at the centre of the room under the detectors. At last, all the signals were captured by the Honeywell FS 90 panel and data were collected by computer.

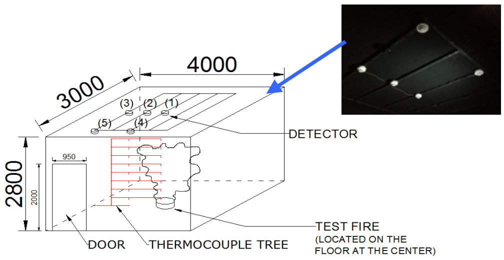

Fig. 2. Experimental set-up for fire detector response measurement.

There were three main stages in the research. The first stage was to collect all the time series of signal pattern under three fire categories (Table 3). Test 1 was to test the flaming fire by using 180 g propanol at a 300 mm diameter pan. Test 2 was to test smoldering fire with 30 g cotton clothes, which was cut to 100 mm x 20 mm paper chip size. Test 3 and 4 were conducted with 8 pieces of joss stick and steam for non-fire source testing. The steam was generated by an electric kettle with 500 g water. All tests mentioned above tests were repeated 15 times at the same location. The second stage was to quantize the time series into a gradient histogram for feature extraction. Finally, the dissimilarity measure (Euclidean Distance) was utilized to classify the time series into fire class and non-fire class, which was useful for us to build a database to improve the sensitivity of existing fire detection system by reducing the false alarm problems.

Table 3. Different fire category for data collection.

Test No.	1	2	3	4
Test Category	Flaming Fire	Smoldering Fire	Non- Fire	Non- Fire
Fuel Source	Propanol	Cloth(Cotton)	Joss Stick	Steam
Quantity	180 g	30 g	×8	500 g
Test Condition	Pan size: 300 mm	Cut to paper chip (100 mm×20 mm)	Whole joss stick	Electric kettle
Test Detector		SD+HD		
Test Location		Same		
Remarks		Repeat 15 times		

6. Data analysis

6.1. FS90 Fire Panel Signal

The Honeywell FS90 Fire Panel Signal Level captured the electrical signal from SD and HD at the position 1 and converted the signal into numerical values. The signals from SD and HD were then displayed as time series. SD measured the obscuration level of smoke and HD measured the static temperature. According to the manufacturer's information, numerical value 110 from SD represented about 2% of obscuration level and the numerical value 100 of HD represented about 60 degrees in temperature. These were the threshold values commonly used to trigger the fire alarm.

After obtaining the data, data analysis was conducted. A region of interest (ROI) from the time series of the FS90 Fire Panel Signal was segmented into 150 seconds. ROI was defined to capture the detector signal before and after the signal reached the fire alarm threshold value. For SD, the ROI was defined as the period between 90 seconds prior to the alarm level (110) and 60 seconds after the actuation time (Fig. 3). For HD, the ROI was defined as the period between 90 seconds prior to the alarm level (100) and 60 seconds after the actuation time (Fig. 4).

In the flaming fire, the time series of SD and HD had generally a small fluctuation and increased slowly (Fig. 6). In the smoldering fire, the time series of SD showed a large fluctuation and increased suddenly whereas the time series of HD had a little fluctuation and increased slightly (Fig. 7). For these two categories of the fire class, the time series of SD ended at a high level and maintained above the threshold value. Also, the difference between flaming and smoldering fire was large.

In the non-fire class, the time series of SD ended at a low level and did not stay above the threshold value. It decreased quickly after reaching the threshold value. For the joss stick, the time series of SD had large fluctuations and peaks while the time series of HD was similar to the normal condition (Fig. 8). For the steam, the time series of SD had large fluctuations and peaks but did not reach to the threshold value, and the time series of HD did not change as well (Fig. 9).

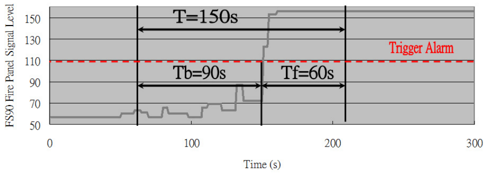

Fig. 3. 150s region of the signal for SD.

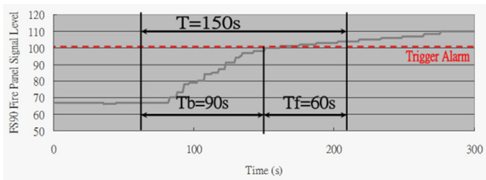

Fig. 4. 150s region of the signal for HD.

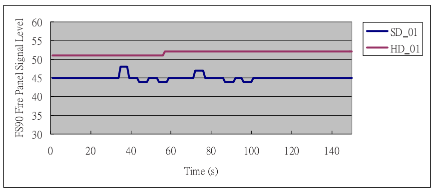

Fig. 5. Normal condition (no fire source).

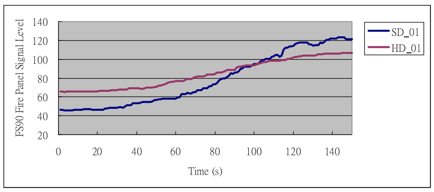

Fig. 6. Average value of flaming fire (180g propanol).

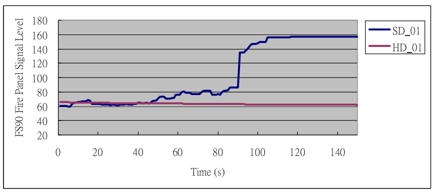

Fig. 7. Average value of smoldering fire (30g cloth-cotton).

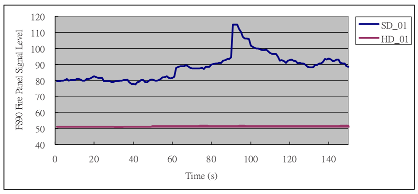

Fig. 8. Average value of non-fire source (x8 joss stick).

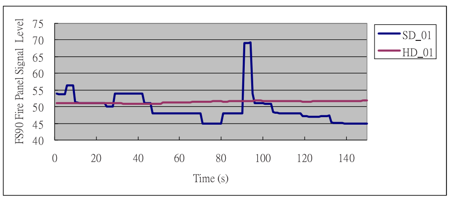

Fig. 9. Average value of non-fire source (500g steam).

6.2. Feature extraction

Different features from the three fire categories were extracted from the time series. The time series were first converted into a gradient histogram for feature extraction using the method proposed by Tsuruoka et al. [19]. Two amplitudes of p_i and p_{i+2} and one gradient (a_1) at the three sequential sampling points (p_i, p_{i+1}, p_{i+2}) were used for the feature extraction (Fig. 10). a1 was the angle determined by the line joining p_i, p_{i+1} and horizontal axis. By using the p_i, p_{i+2} and a_1, a feature vector (p_i, a_1, p_{i+1}) would be formed The amplitude of p_i at time t_i was quantified into 4 indexes which are 0 ($p_i \leqslant 80$), 1 ($81 \leqslant p_i \leqslant 90$), 2 ($91 \leqslant p_i \leqslant 100$) and 3 ($p_i > 101$). The gradient a_1 between the line p_i,p_{i+1} and the horizontal line t_i,t_{i+1} was labelled as the 3 indexes which were 0 (<0 deg), 1 (=0 deg) and 2 (>0 deg). The amplitude of p_{i+2} at time t_{i+2} were quantified into 3 indexes 0 (Down), 1 (Level) and 2 (Up) by comparing to the amplitude p_i.

Therefore, the dimensional vectors of feature extraction were 4 (amplitude: p_i) x 3 (gradient: a_1) x 3 (amplitude: p_{i+2}) = 36 vectors. Each sampling point in the ROI was assigned into one index of 36 dimensional vectors. The gradient histogram consisted of the frequencies of the index.

The gradient histogram of the three fire categories were shown in Figs. 11-14. For SD, there were many points with low amplitude in flaming fire. These caused high frequency of (011) vector (Fig. 11). In the smoldering fire, many point of high amplitude are found, so that the frequency of (311) vector was large (Fig. 12).

In the non-fire class of joss stick, many points were distributed in all low, middle and high amplitude in the gradient histogram (Fig. 13). It reflected that time series of joss stick had many fluctuations. In the non-fire class of steam, the frequency of (011) was very large as many number of amplitude were zero (Fig. 14).

For HD, the points were mainly distributed in (011) and (311) in flaming fire since many fluctuations are found in its time series (Fig. 11). Besides, the time series of the rest of fire categories contain relatively low fluctuations, so there are many points allocated in (011) (Figs. 12-14).

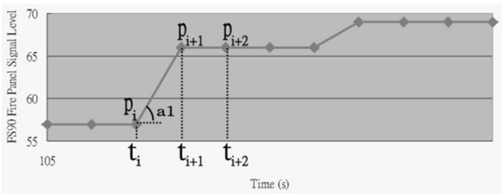

Fig. 10. Feature extraction of signal level.

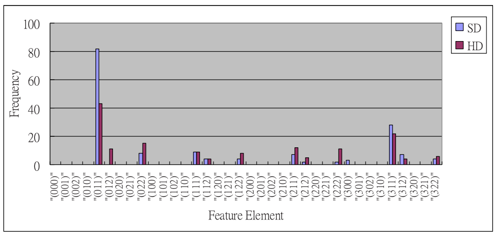

Fig. 11. Average value of flaming fire (180g propanol).

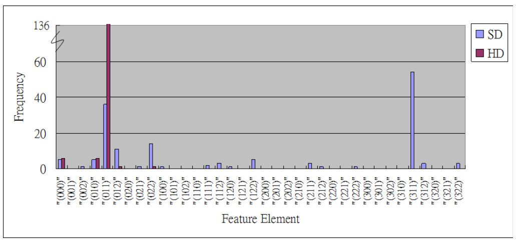

Fig. 12. Average value of smoldering fire (30g cloth-cotton).

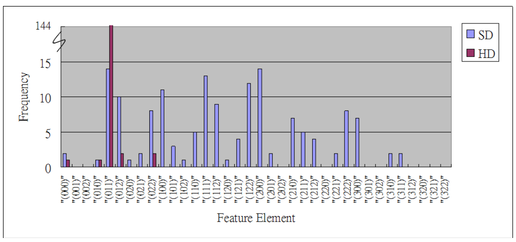

Fig. 13. Average value of non-fire source (x8 joss stick).

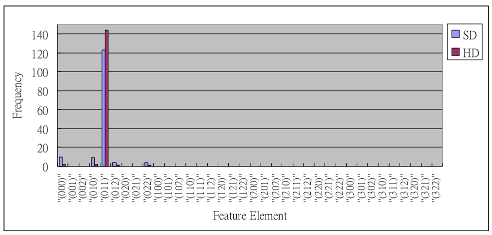

Fig. 14. Average value of non-fire source (500g steam).

6.3. Dissimilarity measure

The dissimilarity measure such as the Euclidean Distance was adopted in the paper for data discrimination [19]. It was calculated from the feature vector to classify the time series of the three fire categories into two classes which were fire class and non-fire class [19].

The purpose of the Euclidean Distance Method was to compare the distance between two objects in Euclideanspace [20]. For the object of this dissimilarity measure, it was the time series of each fire test under the three fire categories. The Euclidean Distance formula was shown in Eq. 1. In the formula, x and y represented the frequency of dimensional vector in different test of fire categories. i referred to the index of the 36 dimensional vectors (e.g. 000, 001, 002,…). Two sets of frequency of dimensional vector were used to calculate Euclidean Distance value ($d_{E(x,y)}$).

$$d_{E(x,y)} = \sqrt{\sum_{i=1}^{36}(x_i - y_i)^2} \tag{1}$$

When all Euclidean Distance values for different fire categories werecalculated, the results were summarized as a Euclidean distancedistribution diagram shown as in Figs. 15-16. For SD diagram, itwas divided into four ranges which were flaming fire (10-35), smoldering fire (25-50), joss stick (45-80) and steam (0-15). For HD diagram, there were 4 ranges as well which were flaming fire (25-45), smoldering fire (0-15), joss stick (10-30) and steam (10-30).

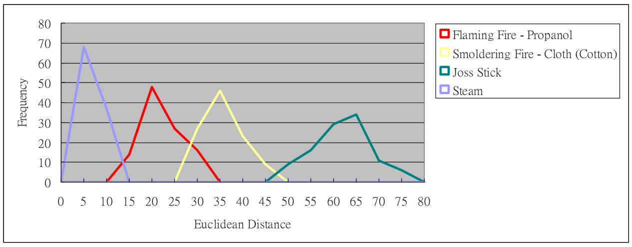

Fig. 15. Euclidean distance distribution diagram for SD.

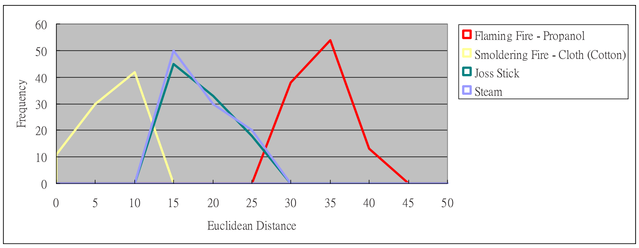

Fig. 16. Euclidean distance distribution diagram for HD.

In order to test the effectiveness of this new fire alarm judgment system, 30 learning samples of each fire category were collected for testing (Total: 120 sets). The sample size of each fire category is shown in Table 4. After collecting all these 30 learning samples of each, the time series of signal pattern were converted into a gradient histogram for feature extraction and that to discriminate the learning samples belong to which type of fire category by using Euclidean Distance Methodformula as shown in Eq. 2. In Eq. 2, the mean vector x_m of feature vector for three fire categories were obtained from previous 15 sets testing. The Euclidean Distance values ($d_E(x)$) for learning samples were defined by the mean vector and the input feature vector of the learning samples. The fire category (l^*) of the learning samples then was distinguished with the minimum distance for all categories by using Eq. 3.

$$d_{E(x)} = \sqrt{\sum_{i=1}^{36}(x_i - x_m)^2} \tag{2}$$

$$l^* = \arg min\{d_E(x)\} \tag{3}$$

With the 30 learning samples of each fire category completed, it showed that the accuracy by using smoke detector in flaming fire, smoldering fire, joss stick (non-fire) and steam (non-fire) are 94%, 90%, 80% and 86% respectively as shown in Table 4. The accuracy by using multi-sensor detector is 100%, 96%, 90% and 94% in flaming fire, smoldering fire, joss stick (non-fire) and steam (non-fire) respectively as shown in Table 4. The disparity is around 6% to 10% for different fire category – that means the multi-sensor had higher accuracy since it was able to have both smoke and heat detected. The Euclidean Distance value would fall into the same fire category range in SD and HD Euclidean distance distribution diagram at the same time. Thus, with the comprehensive coverage of multi-sensor detector, the fire alarm just becomes more sensitive so as to reduce the false alarm problem effectively.

Table 4. The comparison of the accuracy for smoke detector and multi-sensor detector

Test No.	1	2	3	4
Test Category	Flaming Fire	Smoldering Fire	Non- Fire	Non- Fire
Fuel Source	Propanol	Cloth(Cotton)	Joss Stick	Steam
Quantity	180 g	30 g	×8	500 g
Test Condition	Pan size: 300 mm	Cut to paper chip (100 mm×20 mm)	Whole joss stick	Electric kettle
Test Location	Same			
Nomber of Test Samples	30			
Accuracy by using Smoke Detector	94%	90%	80%	86%
Accuracy by using Multi-sensor Detector (Smoke & Heat)	100%	96%	90%	94%

7. Conclusions

Since the conventional judging rule of the fire alarm was not able to judge whether there was a fire and led to false alarm problem, it is crucial to propose a new and more intelligent fire alarm judgment system to classify fire class and non-fire class. The Euclidean Distance Method seems a better way for discriminating true fire and non-fire signals [19]. In the present study, the accuracy of using smoke detector was over 80%. While using multi-sensor (combining smoke and heat detector) the accuracy is over 90%. The disparity is around 6% to 10% for different fire category. It reflects that this new fire alarm judgment system is more effective.

In future, when the detectors collect the other signals, the fire panel will calculate the Euclidean Distance of the signal and refer to the Euclidean distance distribution diagram. The fire alarm will be triggered if the Euclidean distance falls into flaming or smoldering fire range. Otherwise, it will not trigger the fire alarm if the Euclidean Distance values fall into non-fire range such as joss stick and steam. It means that the signal pattern is diversified towards fire class and non-fire class. By knowing the pattern, we can distinguish the fire source and reduce the false alarm problem. On the other hand, a multi-sensor detector (Smoke and Heat) for alarm system is able to minimize possibility of false alarm and enhance the accuracy of the fire alarm because the alarm will be triggered only when both detectors send out similar signal pattern like the flaming fire. It will be useful to improve the accuracy and reliability of fire detectors.

References

[1] British Standards, BS5445 Components of Automatic Fire Detection System – Part 1: Introduction. 1977.
[2] British Standards, BS5839 Fire Detection and Fire Alarm Systems For buildings – Part 1: Code of Practice for System Design, Installation, Commissioning and Maintenance. 2008.
[3] National Fire Protection Association, NFPA Fire Analysis and Research – Unwanted Fire Alarm, 2011.
[4] Hong Kong Fire Services Department, "Hong Kong Fire Services Review 2006." Retrieved from http://www.hkfsd.gov.hk/home/chi/review_06.html., on 8 October, 2011.
[5] Hong Kong Fire Services Department, "Hong Kong Fire Services Review 2007." Retrieved from http://www.hkfsd.gov.hk/home/sc/review_07.html., on 8 October, 2011.
[6] Hong Kong Fire Services Department, "Hong Kong Fire Services Review 2008." Retrieved from http://www.hkfsd.gov.hk/home/chi/review_08.html., on 8 October, 2011.

[7] Hong Kong Fire Services Department, "Hong Kong Fire Services Review 2009." Retrieved from http://www.hkfsd.gov.hk/home/sc/review_09.html., on 8 October, 2011.
[8] Hong Kong Fire Services Department, "Hong Kong Fire Services Review 2010." Retrieved from http://www.hkfsd.gov.hk/home/images/review_10/ebook/book_tc.html., on 8 October, 2011.
[9] Derbel, F., 2004, Performance Improvement of Fire Detectors by Means of Gas Sensors and Neural Networks, Fire Safety Journal 39, p. 383.
[10] Chena, S., Hovdeb, D. C., Petersona, K. A., Marshall A., 2007, Fire Detection Using Smoke and Gas Sensors, Fire Safety Journal 42, p. 507.
[11] Lai, C. M., Chen, K. J., Chen, C. J., Tzeng, C. T., Lin, T. H., 2010, Influence of Fire Ignition Locations on the Actuation of Smoke Detectors and Wet-type Sprinklers in a Furnished Office, Building and Environment 45, p. 1448.
[12] National Fire Protection Association, NFPA 72 – National Fire Alarm Code Handbook (Fifth Edition), 2007.
[13] British Standards, BS5445 Components of Automatic Fire Detection System – Part 7: Point-Type Smoke Detectors Using Scattered Light, Transmitted Light or Ionization, 1984.
[14] British Standards, BS5445 Components of Automatic Fire Detection System – Part 9: Methods of Test of Sensitivity to Fire, 1984.
[15] Underwriters Laboratories Inc. UL 268 - Smoke Detectors for Fire Alarm Systems (Sixth Edition), 2011.
[16] Underwriters Laboratories Inc. UL 260 - Dry Pipe and Deluge Valves for Fire-Protection Service (Seventh Edition), 2011.
[17] British Standards, EN54 - Components of Automatic Fire Detection System Part 9: Methods of Test of Sensitivity to Fire, 1984.
[18] Klote, J. H., Milke, J. A., 1992, Nature of Smoke in "Design of Smoke Management Systems", pp. 9-11.
[19] Tsuruoka, S., Wakabyashi, N., Yoshikawa, T., 2002, A Statistical Judgment System for the Time Series of Smoke Density Using Gradient Histogram, Dept. of Electrical and Electrical Engineering, Mie University, Tsu, Mie, Japan, pp.514-8505.
[20] Mori, S., Hishida, H., Yamada, H., 1999, Optical Character Recognition, John Wiley and sons.