INTELLIGENT CLASSIFIER FOR INCIPIENT PHASE FIRE IN BUILDING

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INTELLIGENT CLASSIFIER FOR INCIPIENT PHASE FIRE IN BUILDING

by

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LIST OF ABBREVIATION

.EXE	Executable File Format
AFD	Automatic Fire Detection
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
AQI	Air Quality Index
AUBE	International Conference on Automatic Fire Detection
BOMBA	Malaysian Fire and Rescue Department
BP	Back- Propagation
C	C Programming Language
CCD	Charged- Coupled Device Camera
CEASTech	Centre of Excellence for Advanced Sensor Technology
CG	Conjugate Gradient
cm	Centimetre
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DTA	Determination of Temperature Anomalies
EN54	European Standard 54
etc	Et cetera
EWFD	Early Warning Fire Detection
F_{crit}	Critical Value of F
FFA	Fuzzy Finite Automata
FkNN	Fuzzy k Nearest Neighbour Network
FTIR	Fourier Transform Infrared
FVC	Fractional Voltage Change
g	Gram
GC- MS	Gas Chromatography- Mass Spectrometer
GUI	Graphical User Interface
H_2O	Water
HMM	Hidden Markov Model
IAQ	Indoor Air Quality

IR	Infrared
kNN	k Nearest Neighbour
m	Metre
m^3	Metre Cube
MATLAB	MATLAB Analysis Software
ml/min	Millilitre per Minute
MLP	Multilayer Perceptron
MOX	Metal Oxide
NIST	National Institute of Standards and Technology, USA
NO_2	Nitrogen Dioxide
O_2	Oxygen
O_3	Ozone
ºC	Degree Celcius
PC	Principal Components
PCA	Principal Component Analysis
PEN3	Portable Electronic Nose
PLC	Programmable Logic Controller
PM_{10}	Particulate Matter up to 10 Micron
PMF	Probability Membership Function
PNN	Probabilistic Neural Network
ppm	Parts per million
PVC	Polyvinyl Chloride
RBF	Radial Bias Function
RGB	Red, Green, Blue Colour Model
RH	Relative Humidity
RLSSV	Relative Logarithmic Sum Squared Voltage
RLV	Relative Logarithmic Voltage
RM	Ringgit Malaysia
RS232	Serial Port
RSSV	Relative Sum Squared Voltage
RV	Relative Voltage
S1	Sensor 1
Sec	Second

SI	Similarity Index
SMC	Sensor Module Cloud
SMS	Short Messaging System
SSFP	Semi Supervised Fire Predictor
SVM	Support Vector Machine
SVD	Singular Value Decomposition
T	Temperature
UAV	Unmanned Aerial Vehicle
USB	Universal Serial Bus
VOC	Volatile Organic Compounds
WinMuster	WinMuster Analysis Software
YCbCr	Luma and Chroma Colour Components

Pengelas Pintar Untuk Kebakaran Fasa Permulaan Dalam Bangunan

ABSTRAK

Pengesanan awal kebakaran adalah salah satu bidang yang mendapat perhatian dalam kajian kualiti udara dalaman. Kebolehan untuk memberikan indikasi awal kebakaran boleh membantu penghuni dalam bangunan untuk mengambil tindakan pantas untuk menghalang kebakaran tersebut. Kelewatan dalam mendapatkan indikasi sebegini bukan sahaja menyebabkan kemusnahan harta benda dan wang, tetapi ia juga menyebabkan kehilangan nyawa. Kajian ini adalah kajian di peringkat permulaan kebakaran bertujuan untuk mengesan kebakaran awal dan bahan yang terlibat (sumber api biasa dan bahan binaan bangunan) di fasa awal kebakaran menggunakan pengelas pintar. Pangkalan data *Indoor Air Quality* (IAQ) telah diwujudkan sebagai pangkalan data kajian, manakala pangkalan data *Portable Electronic Nose 3* (PEN3) diwujudkan sebagai pangkalan data untuk validasi pangkalan data IAQ. Kedua-dua pangkalan data tersebut mempunyai masukan penderia gas dari bahan kajian yang dipanaskan pada suhu berlainan dalam ruang kajian. Tujuh suhu, dari 50°C sehingga 250°C telah diuji. Untuk fasa kebakaran permulaan, data dari suhu 75°C sehingga 125°C menunjukkan keputusan yang ketara. Data tersebut telah dipraproses dan dinormalkan kepada lima jenis pencirian normal. Daripada lima jenis pencirian normal tersebut, hanya tiga jenis telah dipilih secara statistik untuk proses pemilihan ciri pelbagai peringkat dan penggabungan ciri yang dicadangkan. Sebagai hasil kepada proses yang dicadangkan tersebut, satu pencirian baru yang teguh iaitu, ciri IAQ-Hybrid telah diwujudkan. Ciri IAQ-Hybrid ini terdiri daripada komponen prinsip selepas pengurangan dimensi, digabungkan melalui teknik pengabungan ciri. Ujian ANOVA F dan Analisis Komponen Berprinsip telah digunakan untuk memilih data yang berguna dan tidak berlebihan untuk formulasi ciri yang dicadangkan. Ciri yang dicadangkan dan ciri- ciri normal lain (tiga jenis percirian normal yang telah dipilih secara statistik sebelum ini) telah diuji dengan pelbagai pengelas tanpa bimbingan, pengelas separa bimbingan dan pengelas bimbingan yang biasa digunakan. Keputusan eksperimen menunjukkan bahawa penggunaan ciri IAQ-Hybrid yang dicadangkan di dalam algorithma *Fuzzy k-Nearest Neighbour* (FkNN) telah memberikan ketepatan klasifikasi purata sebanyak 96.15% yang lebih baik berbanding kaedah penormalan ciri konvensional lain di dalam pengelas berbeza (82.26% sehingga 92.80%). Berdasarkan keputusan ketepatan klasifikasi, ciri dan pengelas terbaik telah dipilih untuk digunakan di dalam Penjangka Kebakaran Separa Bimbingan (SSFP) yang dicadangkan. Algorithma SSFP yang dicadangkan merangkumi dua bahagian. Bahagian pertama adalah pengesanan kebakaran fasa permulaan menggunakan indeks persamaan berdasarkan peraturan di dalam algorithma *Decision Tree* manakala bahagian kedua adalah pengelasan bahan kebakaran menggunakan ciri IAQ-Hybrid dan algorithma FkNN yang dipilih sebelum ini. Algorithma SSFP yang dicadangkan telah dilaksanakan dan diuji di dalam sistem IAQ. Pelaksanaan algorithma yang dicadangkan di dalam sistem IAQ ternyata berjaya. Kadar kejayaan pengesanan kebakaran dan klasifikasi bahan adalah 100% dan 83.33% masing- masing. Keputusan ujian menunjukkan bahawa semua kejadian kebakaran fasa permulaan telah dikesan dengan betul, walaupun terdapat dua kejadian di mana kesalahan klasifikasi telah berlaku untuk klasifikasi bahan kebakaran. Kaedah untuk penambahbaikan situasi ini telah dimasukkan dalam bahagian kesimpulan tesis ini.

Intelligent Classifier for Incipient Phase Fire in Building

ABSTRACT

Early fire detection is one of the most promising sub- fields in indoor air quality research. Ability to give early fire indication can help the building occupants to take responsive actions in order to prevent the fire. Delay in having such indication not only leading to property and money losses, but also life losses. This research is a preliminary research intended to detect the early fire and the material (common fire sources and building construction materials) involved in the fire using intelligent classifier. Indoor Air Quality (IAQ) database is formed as the testing database, while Portable Electronic Nose 3 (PEN3) database is formed to verify the IAQ database. The databases consist of gas sensor inputs from the test materials, heated up at different temperatures in the testbed. Seven temperatures, range from 50°C up to 250°C have been tested. For incipient phase fire, data for temperature range 75°C up to 125°C shows a very significant result. The data is pre-processed and normalised into five types of normalised features. Out of the five normalised features, only three were statistically selected for proposed multi- stage feature selection and feature fusion process. As an output to the proposed process, a new robust feature, IAQ-Hybrid feature is formed. IAQ-Hybrid feature is consisting of dimensionally reduced principal components fused by the feature fusion technique. ANOVA F- Test and Principal Component Analysis are used for selecting the useful and non- redundant data for the proposed feature formulation. The proposed feature and the other normalised features (three types of normalised features which were statistically selected earlier) are tested with various common unsupervised, semi- supervised and supervised classifiers. Experimental results show that the use of proposed IAQ-Hybrid feature in Fuzzy k- Nearest Neighbour (FkNN) algorithm yields a better mean classification accuracy of 96.15% compared to the conventional feature normalisation methods in other classifiers (82.26% to 92.80%). Based on the classification performance result, the best feature and the best classifier are selected to be implemented in the proposed Semi- Supervised Fire Predictor (SSFP). The proposed SSFP algorithm comprises of two parts. The first part is incipient phase fire detection using rule- based similarity index in Decision Tree algorithm, while the second part is the fire material classification using the previously selected IAQ-Hybrid feature and FkNN algorithm. The proposed SSFP algorithm is implemented and tested in the IAQ system. The implementation of the proposed algorithm in IAQ system is proven successful. The success rates of fire detection stage and material classification stage are 100% and 83.33% respectively. The test result shows that all events of incipient fire are correctly detected, although there were two incidents of misclassification happened for fire material classification. The measures to improve this situation are given in the conclusion of this thesis.

CHAPTER 1

INTRODUCTION

1.1 Overview

Fire handling is crucial for the development of human civilisation. Fire is considered one of the main causes for lives and property losses among different types of disasters.

Having proper control over it is extremely important to overcome the worrying statistics of total fire cases reported. According to the latest data from Fire Safety and Rescue Department (BOMBA) of Malaysia's Annual Report, in 2014 alone, there were 54540 fire cases reported (Fire and Rescue Department, Malaysia, 2014). Out of the stated 54540 cases, 16039 cases happened in the buildings or closed spaces. 5677 cases happened due to the building and its contents, 130 cases happened due to the failures in machines, 1429 cases happened due to tools and utilities, 6 cases happened due to chemical substances, 549 cases happened due to gases, and the remaining 8248 cases happened due to the other causes. Most of the fire cases happened in residential buildings, shops, factories, storage facilities, institutional buildings, offices, gathering places and other types of buildings.

The assessment of property losses carried out by BOMBA indicated that fire outbreaks directly contributed towards property damages of approximately RM7.483 billion over a five-year period (Fire and Rescue Department, Malaysia, 2014). In the year 2014, RM2.8 billion worth of property was damaged in in- building fire. Looking closely, there was an exponential rise in the worth of damages, starting from RM756 million in year 2010 up to RM2.8 billion in 2014.

In the like manner, the number of effected fire victims is at a critical concern level, with 1347 casualties reported over the last five-year period (year 2010 - 2014). In year 2010, an alerting 171 deaths was recorded and a total number of 161, 250, 237 and 528 death cases were respectively numbered from year 2011 to year 2014. Moreover, year 2014 recorded a drastic increase in the number of fire victim, doubling the statistics of cases recorded in year 2013 (Fire and Rescue Department, Malaysia, 2014). Sadly, almost all the cases could have been avoided if pre- warning concerning the fire had been given to the occupants in the building (Anderson & Ezekoye, 2013).

As of present, various parties, in numerous ways, have intervened to curb the escalating building fire hazards. Intervention from the fire safety and rescue department, the insurance agencies, stricter building safety rules and regulations, prevention measures and education, improvisation in the materials and goods used in the building, and the inventiveness of the building to have a better resistance to the fire, have helped in easing the losses suffered in the in- building fire (Anderson & Ezekoye, 2013). Although all these interventions and improvisations have helped to reduce the effect of post- fire damages, they are not sufficient and in most cases, not helpful for early fire prediction and prevention. The negligence of society to focus on early fire identification can be costly in this modern era, especially with sophisticated, complex and costly technologies involved in our daily life (Anderson & Ezekoye, 2013).

Over the last decade, researches on early fire sensing, especially systems involving an array of gas sensors and improved detection algorithms, has drawn significant attention from both researchers and engineers. Narrowing down to this research, this research work aims to enhance the existing indoor air quality system with an added fire detection capability and fire material prediction. In accordance to that, various intelligent methods are tested and the optimum classifier is suggested. Assorted gas sensing and artificial intelligence have been utilised. Moreover, the features extracted from the fire test samples are utilised to develop the classification models. The proposed models are then trained and tested for implementation. The models are designed to suit the building structures in Malaysia. The main motivation and objectives of this research work has been discussed in this chapter.

1.2 Problem Statement

Existing fire alarms have limited capability to detect fire at an early phase. The limited and improper sensors in the fire detection system could lead to further harms, this is because, the alarming system is only activated when higher smoke density or temperature is detected. Therefore, the chances of the system creating false fire alarm is high. On the other end, having an effective fire alarm with advanced detection algorithms are proven to be expensive. These are some of the reasons why most shop lot and office owners in Malaysia neglect the significance of a proper fire sensing alarms in their premises. To overcome this situation, many fire detection systems were proposed by past researchers and fire safety devices manufacturers, but not all are capable at performing early fire prediction and detection. In the market, most of the systems are incorporated with computationally complex algorithms, and thus, are highly priced. Therefore, it is clear that a practical solution should be identified to best resolve this problem. Thus, this research aims to find the optimal algorithm to predict the event of fire more precisely and faster which can be easily incorporated in the current air quality monitoring device. The proposed algorithm will detect fire at an early stage from the smell of scorching materials and latter predict the burning material efficiently.

1.3 Significance of the Study

This research work will be helpful for Malaysians in various ways. The primary advantage is to help the building occupants in a case of fire by giving reliable indication that fire is about to start in the building. The scorching smell of fire is the earliest indication of fire and at this phase, there will be no visible sign of smoke been generated. Having an intelligent system to detect the fire at the earliest possible stage will help the occupants to evaluate the situation and to take the necessary actions in safeguarding themselves and their properties. The algorithm in the proposed system will continuously check for the fire signatures from the indoor air quality and alarm the system when any fire pattern is detected. The common fire patterns were pre- trained in the system. The system will intelligently compare the current reading to the pre- trained reading. The algorithm is designed and tested in such a way that it can be used in any local buildings pervasively. Therefore, it will indirectly reduce the fire cases in Malaysia as well as help in saving valuable lives and properties. Another advantage of the proposed system would be, in terms of the fire material prediction. The proposed system has the capability to identify types of materials involved in the fire. Ten material samples "smellprint" which consisted of various commonly available fire sources and building construction materials have been trained in the system. Once the fire is detected, the smell will be analysed for similarity of pre- trained smell. When the particular smell matches one of the trained material "smellprint", the end user will be alerted. This information is extremely useful, especially to the firefighters to use suitable or fitting fire extinguisher to put out the fire. This is because, the use of incorrect fire extinguisher can cause fire to spread to the other parts of the building. For example, in the case of fire involving oil, where the panicked occupants may tend to use water in the effort to put it out. Next, in the case of fire involving a blend of materials or unknown materials, the proposed classifier will choose the dominant group or include it under “Unknown Material” group. Thus, having this feature is useful. In addition, the technology used in this system has its own advantages. Such as, the utilisation of an improved array of sensors or better known as electronic nose provides better detection and prediction of fire. Looking at commercial systems, the limited number of sensor is rather inconvenient for life- threating situations like a fire breakout because it requires faster responses to solve it. Contrarily, the use of electronic nose in fire detection is considered a perfect solution since sniffing is the primary way humans detects the event of fire. Therefore, an electronic nose is used in this system. Other technologies such as wireless data collection and monitoring features can be installed in this system also to ensures the expandability of the system. The proposed system is easy to be installed and functions as a user- friendly assistant to anyone, with or without any experience in handling technology stuffs.

1.4 Scope of the Research

This research work is a preliminary work in detecting incipient phase fire in building using Indoor Air Quality (IAQ) device. IAQ device was developed and deployed in Centre of Excellence for Advanced Sensor Technology (CEASTech) lab. The main function of the IAQ device is to evaluate the indoor air quality using the Air Quality Index (AQI). Although the primary aim of the IAQ device is to calculate the AQI of the area, its function can be further expanded by introducing new features into it. One of the feature that can be included is the fire detection capability. Since the IAQ device is using an array of eight metal oxide and electrochemical gas sensors in its design, it is easier to be incorporated for fire detection application since the main indication of fire is the release of by- product gases such as carbon dioxide. But, in order to understand the nature of fire, the strength, the limitation of using these sensors for detecting fire and the suitability of instilling the fire detection capability in IAQ device, the researchers have proposed an experimental procedure referring to EN54 Fire Test Materials standard.

This experiment has been carried out in a standard room- sized testbed in CEASTech lab. The parameters such as the room temperature, air ventilation function and the humidity have been controlled accordingly. Five factors influencing the incipient phase fire detection are experimented, namely, the effect of different distances from the source, the effect of different heights from the source, the effect of different temperature points, the effect involving various types of fire sources and building construction materials, and the effect of having various sensor selection in its design. 11 measurement points are finalised based on the evaluation done on the testbed in accordance to EN54 standard. The distance of the measurement points is 1m, 1.7m and 2.4m from the source. Three heights are tested, 0.7m, 1.4m and 2.1m from the floor. Out of the 11 measurement points tested, only one suitable measurement point is selected for classification test using intelligent classifiers since the main aim of this research is to find the best feature and best classifier for incipient phase fire.

Ten types of material, consist of seven fire sources and three building construction materials, are used to evaluate the mentioned factors. Each material is heated in vacuum oven at seven temperature points, starting from 50°C up to 250°C. When each pre- set temperature point is reached, the temperature controller will stop. The valve is opened and the pump is turned on to push the scorched smell to be sniffed by IAQ and Portable Electronic Nose 3 (PEN3) devices. Based on the data collected using IAQ and PEN3 devices, IAQ and PEN3 databases are developed.