IEEE

NATIONAL UNIVERSITY LVIV POLYTECHNIC 1816

IEEE UKRAINE SECTION

MEMS TECH

AGH

2021 IEEE XVIIth International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH)

Proceedings

Ministry of Education and Science of Ukraine

Lviv Polytechnic National University, UKRAINE

IEEE Ukraine Section (West) MTT/ED/AP/EP/SSC Societies Joint Chapter

2021 IEEE XVIIth International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH)

PROCEEDINGS

Polyana, May 12-16, 2021

Lviv, 2021

Organized by:

CAD Department of Lviv Polytechnic National University, Ukraine
Wroclaw University of Science and Technology, Poland
AGH University of Science and Technology, Poland
IEEE Ukraine Section (West) MTT/ED/AP/EP/SSC
Societies Joint Chapter

Technical Co-Sponsors:

Lviv Polytechnic National University
IEEE Ukraine Section
IEEE Ukraine Section (West) MTT/ED/AP/EP/SSC
Societies Joint Chapter

2021 IEEE XVIIth International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH)

PROCEEDINGS

IEEE Part Number: **CFP2164A-ART**
ISBN (IEEE): **978-1-6654-2410-3**

CONTENTS

Development of Multiband Flame Detector with Fuzzy Correction Block

Andrii Kushnir
SPAFA Department
Lviv State University of Life Safety
Lviv, Ukraine
andpetkushnir@gmail.com

Bohdan Kopchak
ECS Department
Lviv Polytechnic National University
Lviv, Ukraine
kopchakb@gmail.com

***Abstract* — The main advantages of flame detector are high sensitivity and low inertia. The main limitation of the use of flame detector is the presence of artificial and natural electromagnetic interference it can respond to. The intelligent multiband flame detector with infrared and ultraviolet sensors is proposed using a fuzzy correction (FC) block synthesized on the basis of the fuzzy logic theory. The input values of the FC block are the values of the wavelength signals of infrared and ultraviolet radiation and the flame flicker frequency. The FC block processes these signals in accordance with the developed algorithm. A model of this multiband flame detector has been developed in the MATLAB software environment. The results of simulation studies have shown that the FC block distinguishes different stages of changes in the wavelength of infrared and ultraviolet radiation and the flicker frequency. The block forms the required output signal based on the compiled rule base. This makes it possible to detect a fire with high accuracy without false alarms.**

***Keywords* — fire detection system, fire detector, flame detector, multiband flame detector, infrared flame detectors, ultraviolet flame detectors, fuzzy logic.**

I. Introduction

The operation of heat detectors and smoke detectors is based on the detection of fire due to rising temperatures and the ingress of smoke particles into the sensitive element This affects the time they detect ignition. The detector is triggered with a significant delay if the ignition source is not located close to it. Therefore, it can be difficult to quickly organize fire extinguishing operation and evacuation of people. The reliability of the fire detection system mainly depends on the fire detector location [1] and the algorithm of its operation [2-4]. There is another principle of fire detection - based on the registration of electromagnetic radiation generated by both open flames and smoldering hearth. This is the principle of flame detector operation (Fig. 1). These detectors should be designed according to the requirements [5]. Physical principles which are used in the flame detector can significantly quicker detect fires compared with other types of the fire detector. The main advantages of the flame detector are its high sensitivity and low inertia. The height, volume, shape of the room, design features of the ceiling of the room, air currents, etc. do not significantly affect the time of fire detection. This is the only fire detector, which can be used in open space. Flame detectors are used to protect oil, gas and chemical industries, aircraft hangars, warehouses, open areas where a large number of flammable liquids and substances are stored, paint&varnish workshops, gas stations, etc.

The main limitation of the use of flame detector is the presence of artificial and natural electromagnetic interference, which can trigger response of a fire detector without the presence of a flame. High level of electromagnetic radiation, which adversely affects the operation of the flame detector, is created by artificial light sources, sunlight, heated bodies (radiators, running engines), welding, the reflection of radiation by mirror surfaces, etc.

Fig. 1. The 40/40L4 flame detector series of company "Spectrex"

II. Analysis

The hearth fire with natural open flame has two characteristic features, that is the electromagnetic radiation of the flame and the flame flicker frequency. It is known that the flame is accompanied by characteristic radiation in both ultraviolet (UV) and infrared (IR) spectra. The IR spectrum of the sun or hot objects differs from the spectrum of fires. Due to these different characteristics, the flame detector can distinguish real fires from deceptive phenomena. Thus, the range of IR radiation from heated objects is shifted in the direction of increasing the wavelength of about 5.1 μm or more, and from the sun in the direction of decreasing the wavelength of 1.1 μm or less.

……………………………………………………..

……………………………………………………

IR flame detector detects flame with or without smoke generation. UV flame detectors can detect all types of open fires. However, these detectors respond to the combustion of liquids (eg spirit), gas (eg hydrogen), and substances that burn without smoke. Thick smoke, dust, or water vapor may prevent the passage of UV radiation to the flame detector. Powerful sources of ultraviolet radiation, such as welding flames, mercury or discharged lamps, flashes, lightning, high-voltage arcs, static discharges, and ionizing radiation (radioactivity or X-rays), can cause false alarms.

Multiband flame detectors with two or more sensors are used to reduce false alarms from extraneous sources, not related to the fire[9, 10]. They analyze both IR radiation and UV radiation, have several sensors that measure IR radiation in different wavelength ranges.

……………………………………………………………

A FC block for multi-sensor fire detector with smoke and heat sensors based on the theory of fuzzy logic with the Mamdani algorithm is proposed and synthesized in the paper [12]. This detector makes it possible to distinguish different stages of temperature change and smoke in the rooms. This makes it possible to detect ignition at an early stage and make the right decision to eliminate it.

…………………………………………………………

III. PROBLEM STATEMENT

The work aims to build and research the algorithm of the FC block for a multiband flame detector with IR and UV sensors. Based on the developed algorythm, multiband flame detector must distinguish between IR and UV radiation of flame, flame flicker frequency, and radiation from external sources not related to fire. This will reduce the false alarms of this detector.

IV. SOLVING THE PROBLEM

To reduce the false alarms of flame detector, which responds to IR and UV radiation from third-party radiation sources not related to fire, a FC block based on fuzzy logic has been synthesized. Based on the signals received from the sensors and the developed algorithm, the detector must recognize the conditions of the fire with high accuracy.

……………………………………………………………..

The input values of the FC block are the values of the wavelength signals of IR and UV radiation, the flicker frequency (*f*) of the flame coming from the sensors. To correct the wavelength ranges and flame flicker frequencies, the input block also receives a signal from the control and indicating equipment. The output value of the FC block is the signal, which informs about the state on the object.

2. Determining of algorithmic freedom degrees.

FC block settings are as follows:

………………………………………………

3. Determining of parametric freedom degrees.

3.1. Determining of the possible changes range of output and input variables.

The results of analysis and experimental studies of classical detectors discussed above enable to determine the intervals of change of input and output values. Let us assume that for the FC block the wavelengths of IR and UV radiation vary in the range [0, 10], as well as the flame flicker frequency [0, 10]. These intervals correspond to certain values of the intervals of wavelengths of IR and UV radiation and the flame flicker frequency. Analysis of changes in IR and UV radiation of flame and flame flicker frequency makes it possible to determine the interval of change of the initial value "Fire probability" as [0, 1].

3.2. Determining the parameters and the shapes of the membership function.

It should be noted that the values of the wavelength ranges of IR and UV radiation of flame and the flame flicker frequency, which will be specified below in the simulation process, can be refined and changed.

……………………………………………………

The parameters of the terms are given in Table I.

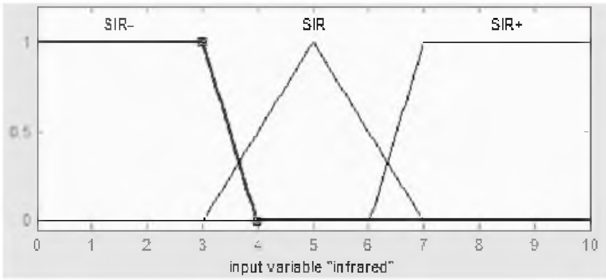

Fig. 2. MF of input variable "IR radiation"

TABLE I. *PARAMETERS OF MF OF INPUT VARIABLE "IR RADIATION"*

Term	Term form	Characteristic points
SIR(–)	trapezium	[-3, 0, 3, 4]
SIR	triangle	[3, 5, 7]
SIR(+)	trapezium	[6, 7, 10, 13]

…………………………………………………………..

Thus, the points [-3, 0, 3, 4] correspond to the following values: -3 - 3.55 µm (this value is conditional to realize the trapezoid according to the theory of fuzzy sets and it does not affect the result), 0 - 3.4 µm, 3 - 4.0 µm, 4 - 4.2 µm. By the term, SIR, which varies in interval [3, 5, 7], we mean the values of such wavelength IR radiation which are in the range of the reaction of the fire flame detector. The flame detector responds to the wavelength of IR radiation from 4,0 to 4,8 µm. Thus, the points [3, 5, 7] correspond to the following values: 3 - 4.0 µm, 5 - 4.4 µm, 7 - 4.8 µm. By the term, SIR(+), which varies in the interval, [6, 7, 10, 13] we mean the values of such wavelength IR radiation which are higher than the value of the maximum value at which the flame detector responds.

………………………………………………..

The parameters of the terms are given in Table II.

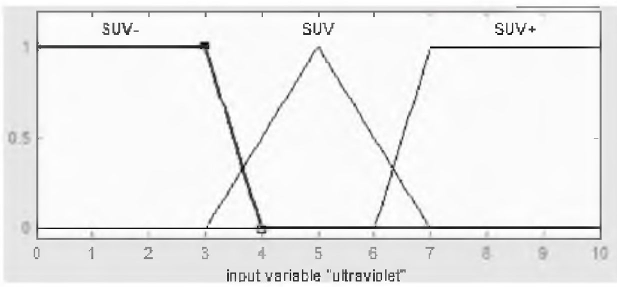

Fig. 3. MF of input variable "UV radiation"

TABLE II. *PARAMETERS OF MF OF INPUT VARIABLE "UV RADIATION"*

Term	Term form	Characteristic points
SUV(-)	trapezium	[-3, 0, 3, 4]
SUV	triangle	[3, 5, 7]
SUV(+)	trapezium	[6, 7, 10, 13]

The flame detector responds to the wavelength of UV radiation from 0.18 to 0.22 µm. Explanation of the terms of UV radiation SUV (+), SUV, and SUV (-) is analogical to the terms of IR radiation SIR(–), SIR and SIR(+). The points [-3, 0, 3, 4] correspond to the following values: -3 - 0.1 µm, 0 - 0.12 µm, 3 - 0.18 µm, 4 - 0.2 µm; [3, 5, 7] – 3 - 0.18 µm, 5 - 0.22 µm, 7 - 0.26 µm; [6, 7, 10, 12] – 6 - 0.24 µm, 7 - 0.26 µm, 10 - 0.32 µm, 12 - 0.34 µm.

………………………………………………………………..

The parameters of the terms are given in Table III.

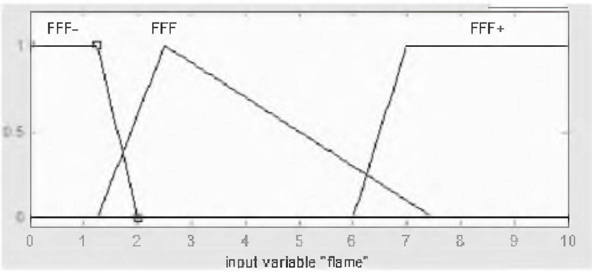

Fig. 4. MF of input variable "flame fricker frequency"

TABLE III. *PARAMETERS OF MF OF INPUT VARIABLE "FLAME FRICKER FREQUENCY"*

Term	Term form	Characteristic points
FFF(-)	trapezium	[-3, 0, 3, 4]
FFF	triangle	[3, 5, 7]
FFF(+)	trapezium	[6, 7, 10, 13]

The points [-3, 0, 1.25, 2] correspond to the following values: -3 - -0.05 Hz, 0 - 0.0 Hz, 1.25 - 5 Hz, 2 - 8 Hz; [1.25, 2.5, 7.5] – 1.25 - 5 Hz, 2.5 - 10 Hz, 7.5 - 30 Hz; [6, 7.5, 10, 12] – 6 - 24 Hz, 7.5 - 30 Hz, 10 - 40 Hz, 12 - 48 Hz.

……………………………………………………………

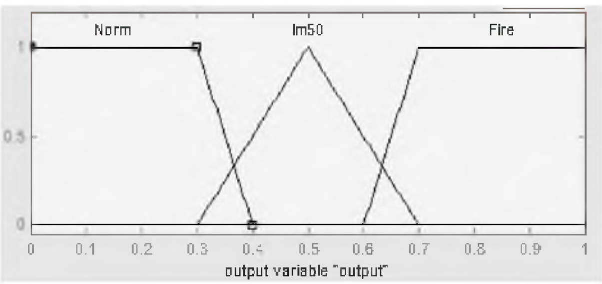

Fig. 5. MF of the output variable "Output"

TABLE IV. *PARAMETERS OF MF OF OUTPUT VARIABLE "OUTPUT"*

Term	Term form	Characteristic points
Norm	trapezium	[-0.1, 0, 0.3, 0.4]
Im50%	triangle	[0.3, 0.5, 0.7]
Fire	trapezium	[0.6, 0.7, 1.0, 1.1]

3.3. Formation of fuzzy rules base.

………………………………………………………

TABLE V. *FUZZY RULES*

IR radiation	UV radiation	Flame flicker frequency	Output
SIR(-)	SUV(–)	FFF(-)	Norm
SIR(-)	SUV(–)	FFF	Norm
SIR(-)	SUV(–)	FFF(+)	Norm
SIR(-)	SUV	FFF(-)	Norm
SIR(-)	SUV	FFF	Norm
SIR(-)	SUV	FFF(+)	Im50%
SIR(-)	SUV(+)	FFF(-)	Norm
SIR(-)	SUV(+)	FFF	Im50%
SIR(-)	SUV(+)	FFF(+)	Im50%
SIR	SUV(–)	FFF(-)	Norm
SIR	SUV(–)	FFF	Norm
SIR	SUV(–)	FFF(+)	Norm
SIR	SUV	FFF(-)	Norm

V. IMPLEMENTATION MODEL IN MATLAB SIMULINK

To develop models of the FC blocks we have used the fuzzy package in MATLAB software environment. Fig. 7, fig. 8, and fig. 9 show the window of the output signal surface (corresponding to - "Norm", "Fire probability 50%", "Fire"), formed by the FC block at different values of wavelengths of IR and UV radiation and the flame flicker frequency.

………………………………………………………………

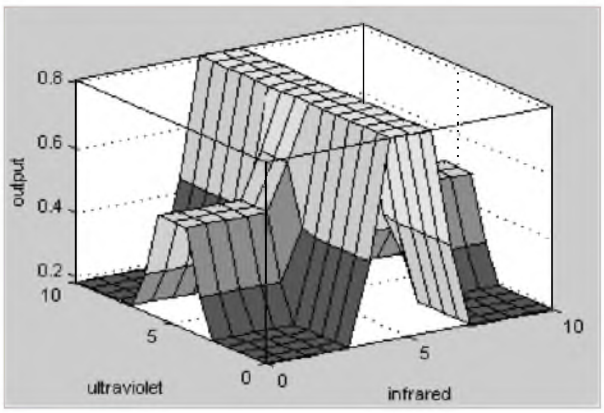

Fig. 6. Dependence of the output signal of FC block on the change of the input signals "IR radiation" and "UR radiation". Input signal "Flame fricker frequency" remains unchanged at 15 Hz

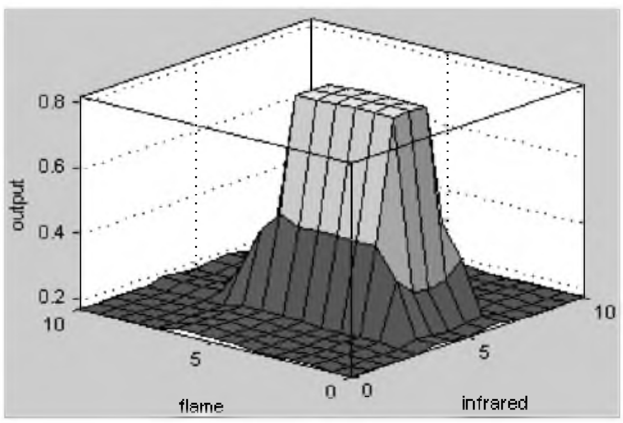

Fig. 7. Dependence of the output signal of FC block on the change of the input signals “IR radiation” and “Flame fricker frequency”. Input signal “UR radiation” remains unchanged at 0,14 μm

…………………………………………………….

A model of flame detector with the FC block was developed in the Simulink package MATLAB software environment. Fig. 10 demonstrates the results of the study of flame detector with a FC block using the Mamdani algorithm, forms, and parameters of input and output MF given in the Table. I-IV.

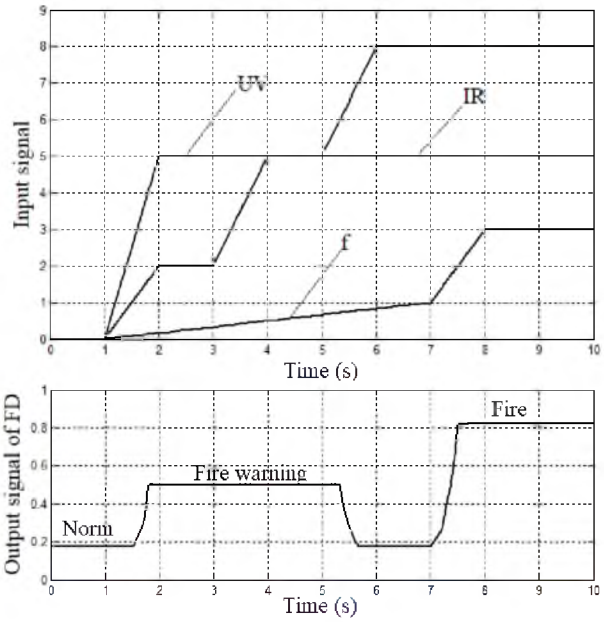

Fig. 8. Simulation results of flame detector operation

……………………………………………..

VI. Conclusions

1. A FC block using the fuzzy logic and the Mamdani algorithm is developed for a multiband flame detector with IR and UV radiation sensors. Forms and parameters of input and output MF are set. Based on the knowledge of the expert, a base of fuzzy rules is compiled which describes possible occurrent on the object.

2. A model of a multiband flame detector with sensors of IR and UV radiation and a FC block has been developed. The results of simulation studies have shown that the FC block enables recognizing different stages of changing the wavelength of IR and UV radiation and the flicker frequency, and, based on the developed algorithm, it generates the output signal. This reduces the false alarm of this detector from third-party sources of radiation not related to the fire.

References

[1] Fire detection and fire alarm systems - Part 14: Guidelines for planning, design, installation, commissioning, use and maintenance, (CEN/TS 54-14:2018).