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Mathematical Foundation Based Inter-Connectivity modelling of Thermal Image processing technique for Fire Protection

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Abstract

In this paper, integration between multiple functions of image processing and its statistical parameters for intelligent alarming series based fire detection system is presented. The proper inter-connectivity mapping between processing elements of imagery based on classification factor for temperature monitoring and multilevel intelligent alarm sequence is introduced by abstractive canonical approach. The flow of image processing components between core implementation of intelligent alarming system with temperature wise area segmentation as well as boundary detection technique is not yet fully explored in the present era of thermal imaging. In the light of analytical perspective of convolutive functionalism in thermal imaging, the abstract algebra based inter-mapping model between event-calculus supported DAGSVM classification for step-by-step generation of alarm series with gradual monitoring technique and segmentation of regions with its affected boundaries in thermographic image of coal with respect to temperature distinctions is discussed. The connectedness of the multifunctional operations of image processing based compatible fire protection system with proper monitoring sequence is presently investigated here.

The mathematical models representing the relation between the temperature affected areas and its boundary in the obtained thermal image defined in partial derivative fashion is the core contribution of this study. The thermal image of coal sample is obtained in real-life scenario by self-assembled thermographic camera in this study. The amalgamation between area segmentation, boundary detection and alarm series are described in abstract algebra. The principal objective of this paper is to understand the dependency pattern and the principles of working of image processing components and structure an inter-connected modelling technique also for those components with the help of mathematical foundation.

Keywords: inter-connectivity, event-calculus, thermal imaging, abstract algebra, mathematical foundation, DAGSVM.

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1. Introduction

In the field of image processing, though technical as well as theoretical advancement and researches have been quite performed, the functional approach for inter-connectivity analysis especially for image segmentation and intelligent classification with boundary detection techniques in the light of mathematical foundation perspective is yet to be investigated. The functional model of intelligent classification of imaging parameters as well as its developments are only either investigated or applied by various hybridized and unique models, but the foundational aspect of interconnected links and the flow of propagation among multiple functions and variables between each operations implemented in field of imaging especially in thermal imageries are still required to be cultivated more elaborately. In the area of image segmentation and boundary detection process, many theoretical as well as numerical combined approaches have been proposed and implemented, e.g., Markov Random Filed Model with Kullback–Leibler distance

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measurement technique for structural segmentation [5] in early age; but any mathematical based interoperability method to analyze the inter-related dependency among the different components and models are still needed to be investigated more wisely.

Many researches in image processing (area segmentation, boundary detection, contour division, noise reduction, resolution enhancing) have been carried out to establish the temperature-color perspective in thermography e.g., common infrared color imaging technique [6, 11, 12] used to detect the fire temperature where the thermal affected areas are indicated by edge detection technique. The fire break out state in underground coal seam has been tracked by infrared telescopic camera from LANDSAT satellite [6] launched by NASA. The temperature distribution model for under coal pile has been recognized by chromatics thermal camera [11], [12].

The various imaging techniques such as segmentation, edges, denoising, etc., has been enhanced [1, 2, 16, 17, 19] by different mathematical interpolations and models. The edge detection of objects in medical imagery has been implemented [1], [16] on an MRI image of brain and an x-rayed image of a grain for experiment. The furnace flame recognition approach based on image processing technique has been introduced [2] to measure the combustion stage of flame inside the boiler. The theoretical developments of mathematical interpolations based on probabilistic distribution models implemented in MATLAB [17], [19] has been introduced for different image processing technique such as sharpening, object detection, feature extraction etc.

Technical approaches for various image processing functions have been theoretically developed [3, 4, 5, 7, 10] for supportive imaging tools strictly based on numerical formation. The mathematical developments of contour variation based on color values [3], [4], [5] in image has been introduced and simulated in MATLAB platform. The edge of object in image has been detected [7], [10] by the probability density function based chromatic value of objects in image.

The video sequences based fire detection technique has been introduced [9, 13, 14, 15, 18] by using infrared CCD cameras. The boundary area of flame in video image captured in CCD cameras [9], [13], [14], [15] which are installed at different location in a furnace has been detected by different image processing techniques like region growing, Gaussian field, Markov distribution etc. The recognition of fire in a video sequence has been detected [18] by the chromatic value of the flame.

Various mathematical operations [19] e.g., Fourier transformation, Laplace transformation, Gaussian function, Poisson filter for noise reduction process, numerical formulation, set theory, Minkowski fields which are generally implemented in various fields of image processing technique e.g., contrast sketching, histogram equalization, colour space changing, resolution enhancement, object tracking, positioning of the object, image skeletoning, colour to gray conversion, pattern identification etc.,

However, NO mathematical models to indicate the dependency between those variables in their image processing techniques in the light of mapping are found in their studies. Mathematical foundation models for image processing especially for thermal image processing technique is not implemented from mapping perspective yet. The mapping in image processing could be used to connect the missing link among different models of image processing techniques by approach used of abstract algebra [20]. The mathematical design is the most crucial component in image processing to pilot the general practices in appropriate direction. The abstract algebra would be taken as the Highest Form of interoperable platform between any mathematical model especially used in image processing in this investigation. The certain mathematical operations basically used in image processing technique such as Gaussian distribution, fuzzy model, Markov field or partial differential equation would be inter-mapped with the help of metaphoric elements of abstract algebraic method.

The functional mapping in image processing will be compared into multiple abstract algebraic parameters e.g., domain, set, category etc., so that the abstract algebra could be implemented to describe the area segmentation as well as boundary detection method together and found the flow of basic processes in thermographic imaging for series of alarm generation for fire protection in real-life environment. The entanglement mapping technique among abstractive groups will be analyzed by functional characteristics of convolution property so that the code of DAGSVM based intelligent alarming system and region and boundary segmentation models based on temperature classification would be applied in MATALB platform. The core approach for the proper mathematical foundation based inter-connected model investigated would basically dependent on the pattern of temperature distribution points between reference and fire break-out temperature of an image of artificially ignited coal captured by self-assembled infrared camera.

The rest part of this paper is organized according to the following sections of design. The basic framework design of this investigation is presented in Section II. Basic orientation of event calculus and its implementation on step-by-step temperature distingusion technique is introduced in Section III. The details of functional platform of DAGSVM and its convolutive operation for temperature based alarm generation model have been investigated in Section IV. The canonical application on area segmentation and boundary detection approach based on temperature-chromatics relation are modeled in Section V. The abstractive algebraic method of the inter-connected foundation between implemented multiple functions in image processing and alarm based temperature classification model are studied in Section VI. The experiment and the respective results of the introduced methodology on obtained thermal image of coal are represented in Section VII. And it's concluded in Section VIII.

2. The Basic Framework Design of the Introduced Method

The design of the framework deals with the external skeleton of this investigation which discusses the basic establishment of the investigation from obtaining of image to produced result. The thermal image processing for temperature monitoring technique is designed by abstract algebraic formulation mentioned as: $\boldsymbol{f_{th}}: \boldsymbol{A_p} \longrightarrow \boldsymbol{B_p}$

Where,

- A_p = fire broke out condition
- B_p = result and anomaly point
- f_{th} = temperature increment based thermal imaging

In the above elements, the real-life scenario (A_p) and introduced thermal image processing technique (f_{th}) as well as experimental (B_p) output from the process are represented in canonical form. The block diagram shown in the Fig 1 below is categorized into 3 basic sections as: (A_p) indicates hardware setup for obtaining temperature value of coal by thermal camera in practical background, section (f_{th}) shows the designed technique and coding according to the theoretical analysis (T_e) of the image processing model and the tentative result indicated in B_p:

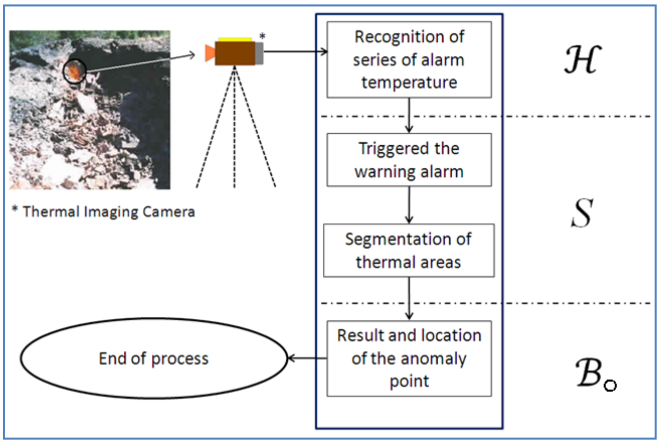

Figure 1. Basic flow of the investigation

The complete morphism structure of the model in mathematical abbreviation is indicated below:

$$\boldsymbol{f_{th}}: \boldsymbol{A_p} \xrightarrow{\boldsymbol{T_e}} \boldsymbol{B_p}$$

Where, $\boldsymbol{S}$ is the convolution operation of theoretical development (T_e) for the thermal imaging technique (f_{th}) together as: $S = [f_{th} \star I_m]$. So, image processing technique is morphism from hardware setup for obtaining parameters to final result. The step-by-step flow of connectivity among multiple operations of fire protection technique investigated are linked as the sequence indicated: event-calculus for alarm generation $\xrightarrow{to}$ DAGSVM process for corresponding alarm levels $\xrightarrow{to}$ partial derivative based area segmentation $\xrightarrow{to}$ boundary detection technique $\xrightarrow{to}$ integration of multiple operations in a single interface $\xrightarrow{to}$ compare the mechanism with the produced result.

3. Event Calculus Based Fire Alarm Generation

Now, determining the proper alarm sequence with respect to different level of temperature increment is designed by event calculus (I_tF) [21] based event detection technique in this investigation as follows:

- $A_L = \{A_1, A_2, A_3, A_4\}$ [generating alarm sequence]
- $T_r = \{T_0, T_1, T_2, T_3, T_4, T_F\}$ [temperature increment sequence], T_0 = initial temperature and T_F = fire ignition point of coal
- $t = \{t_0, t_1, t_2, t_3, t_4, t_f\}$ [time variation sequence]

Where, temperature T_0 is considered as the reference point for beginning of monitoring process at time of detection t_0 and temperature T_F is considered as fire break out point of coal at time t_f. The clauses in event-calculus used in this investigation to map relation between the variables are mentioned below:

- initiate(α, β, τ) = event β (alarm) start to occur after action α happens at time τ (t)
- initiate(T_1, A_1, t_1) = alarm A_1 starts to occur after T_1 temperature obtained at the time t_1 moments
- initial(α, τ) = action α (triggering of alarm) starts at time τ (t)
- initial(F_1, t_0) = action F_1 starts at the time of t_0
- holdAt(α, τ) = event α held at the time τ
- terminate (α, β, τ) = event β (alarm) stops after action α at time τ (t)
- terminate(T_2, A_1, t_2) = alarm A_1 stops after T_2 temperature obtained at t_2 moment
- happen(α, τ) = α occurs at time τ
- happen(A_1, T_1) = A_1 alarm generated at detection time of temperature T_1
- clipped(τ_1, β, τ_2) = event β terminated between τ_1 and τ_2 time interval
- $\tau_1 < \tau_2$ = τ_1 time comes before τ_2

Since temperature, as an intensive parameter, for which the alarm series is dependent on the occurrence of temperature detection event, event-calculus is implemented. The occurrence of events could be directly factorized from the moment of obtained temperature values by parametric technique. The time between the interval of each point of temperature measurement = 1 hour. The relation between the detected temperature and time is represented as: T_{0+1} temperature detected at time t_{0+1} hour.

Now, the formation of event calculus for A_1 alarm generation at time t_1 for T_1 temperature detection is described as: initiate $(\boldsymbol{T_1}, \boldsymbol{A_1}, \boldsymbol{t_1}) \longleftarrow (\boldsymbol{t_0} < \boldsymbol{t_1}) \wedge$ happen $(\boldsymbol{A_1}, \boldsymbol{T_1})$; so, for alarm ($A_1$) is generated when the temperature (T_1) is detected at time (t_1).

The 2nd formation of Event calculus for A_2 alarm generation at time t_2 for T_2 temperature: initiate $(\boldsymbol{T_2}, \boldsymbol{A_2}, \boldsymbol{t_2}) \longleftarrow$[terminate$(\boldsymbol{T_2}, \boldsymbol{A_1}, \boldsymbol{t_2})$] $\wedge$ $(\boldsymbol{t_1} < \boldsymbol{t_2})$ $\wedge$ happen$(\boldsymbol{A_2}, \boldsymbol{T_2})$; so, for alarm (A_2) after terminating of alarm (A_1) is generated when temperature (T_2) is detected at the time (t_2).

The 3rd formation of Event calculus for A_3 alarm generation at time t_3 for T_3 temperature: initiate $(\boldsymbol{T_3}, \boldsymbol{A_3}, \boldsymbol{t_3}) \longleftarrow$[HoldAt$(\boldsymbol{F_3}, \boldsymbol{t_2})\wedge$terminate$(\boldsymbol{T_3}, \boldsymbol{A_2}, \boldsymbol{t_3})$] $\wedge$ $(\boldsymbol{t_2} < \boldsymbol{t_3})$ $\wedge$ initial$(\boldsymbol{F_4}, \boldsymbol{t_2})$ $\wedge$ ~clipped$(\boldsymbol{t_2}, \boldsymbol{F_4}, \boldsymbol{t_3})$ $\wedge$ happen$(\boldsymbol{A_3}, \boldsymbol{T_3})$; so, for alarm ($A_3$) after terminating of alarm (A_2) is generated when temperature (T_3) is detected at the time (t_3).

The 4th formation of Event calculus for A_4 alarm generation at time t_4 for T_4 temperature: initiate $(\boldsymbol{T_4}, \boldsymbol{A_4}, \boldsymbol{t_4}) \longleftarrow$[terminate$(\boldsymbol{T_4}, \boldsymbol{A_3}, \boldsymbol{t_4})$] $\wedge$ $(\boldsymbol{t_3} < \boldsymbol{t_4})$ $\wedge$ happen$(\boldsymbol{A_4}, \boldsymbol{T_4})$; so, for alarm ($A_4$) after terminating of alarm (A_3) is generated when temperature (T_4) is detected at the time (t_4).

The 5th formation of Event calculus online monitoring upto time t_4 for T_4 temperature arrive at the ignition point: initiate$(\boldsymbol{online}) \longleftarrow$ $(\boldsymbol{t_4} < \boldsymbol{t_f})$ $\wedge$ terminate $(\boldsymbol{T_F}, \boldsymbol{A_4}, \boldsymbol{t_f})$; so, at the time ($t_4$).

With all combination of alarms through event calculus is defined as: complete (alarm) $\longleftarrow$ [initiate$(\boldsymbol{T_1}, \boldsymbol{A_1}, \boldsymbol{t_1})$ $\wedge$ terminate$(\boldsymbol{T_2}, \boldsymbol{A_1}, \boldsymbol{t_2})$] $\wedge$ [initiate$(\boldsymbol{T_2}, \boldsymbol{A_2}, \boldsymbol{t_2})$ $\wedge$ terminate$(\boldsymbol{T_3}, \boldsymbol{A_2}, \boldsymbol{t_3})$] $\wedge$ [initiate$(\boldsymbol{T_3}, \boldsymbol{A_3}, \boldsymbol{t_3})$ $\wedge$ terminate$(\boldsymbol{T_4}, \boldsymbol{A_3}, \boldsymbol{t_4})$] $\wedge$ [initiate$(\boldsymbol{T_4}, \boldsymbol{A_4}, \boldsymbol{t_4})$ $\wedge$ terminate $(\boldsymbol{T_F}, \boldsymbol{A_4}, \boldsymbol{t_f})$] $\wedge$ initial$(\boldsymbol{online}, \boldsymbol{t_4})$ $\wedge$ $(\boldsymbol{t_0} < \boldsymbol{t_1} < \boldsymbol{t_2} < \boldsymbol{t_3} < \boldsymbol{t_4} < \boldsymbol{t_f})$.

However, time difference between two respective alarms is less than 1 hour; the situation is considered as critical: *If [time(A_2) or t_2] – [time(A_1) or t_1] < 1 hr.; condition ⟶ critical. Or, [time(A_2) – time(A_1)] ∩ [time(A_3) – time(A_2)] ∩ [time(A_4) – time(A_3)] < 1 hr. Or, [t_2 – t_1] ∩ [t_3 –t_2] ∩ [t_4 –t_3] < 1 hr → Condition is Critical.*

4. Mapping between DAGSVM and Event-Detection Technique

In directed binary acyclic graph which is rooted with k leaves, contains $\frac{k(k-10)}{2}$ no. of internal nodes where each node is the binary SVM classes [22]. The respective prototype structure of DAGSVM is shown in Fig. 2 below:

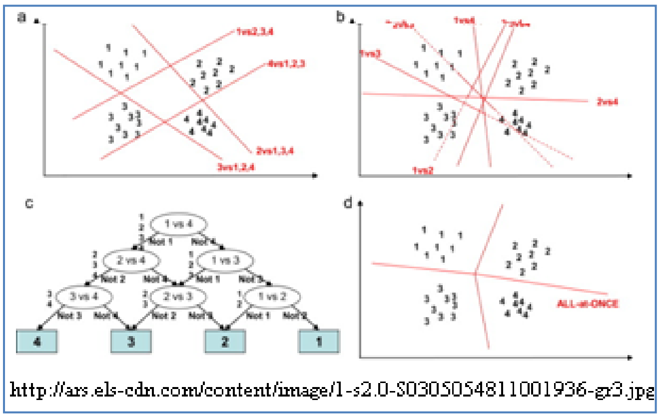

Figure 2. Prototype of general DAGSVM model

The processing function of DAGSVM is analyzed in the light of mathematical foundation for establishing relation with event-calculus technique. The tetra stages of alarm series are defined according to the significance of fire break-out possibility indicated as: A_1⟶Primary tolerance temperature, (PTT); A_2⟶Critical tolerance temperature, (CTT); A_3⟶Yellow alarm signal, (YL); A_4⟶Red alarm signal, (RL). The corresponding structure of DAGSVM based on event-calculus model for alarm generation is shown in the Fig. 3 below:

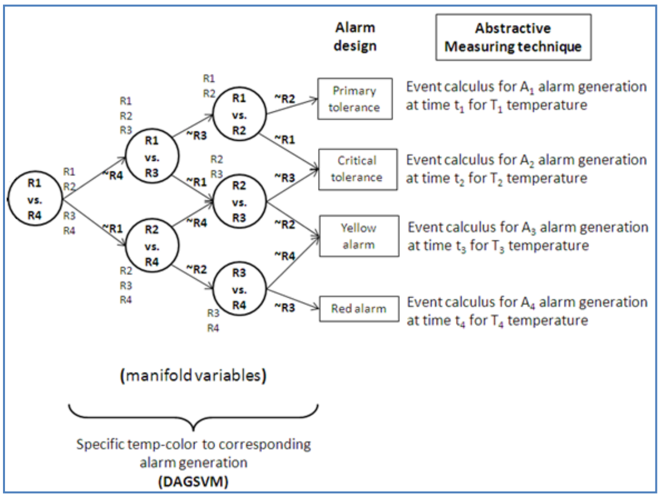

Figure 3. DAGSVM with event-calculus

The flow of DAGSVM mechanism is formulated in mathematical interpretation for establish the inter-related mapping between event-calculus and temperature classification model for alarms. DAGSVM [23] process is in the light of mathematical foundation is formed with NOT (~) function for individual alarm variables and binary operation (⊗) for separating different level of alarms. The operational flow of DAGSVM begins with the group of alarms indicates as: $A_L \in D_{AP}$ (A_1, A_2, A_3, A_4) = {~A_1}⊗{~A_2}⊗{~A_3}⊗{~A_4}, where functional technique of DAGSVM is denoted as, D_{AP} which indicates the classification process between the alarm sets.

The alarm sequence would be generated in chronological order according temperature increasing pattern indicated as: $T_i \longrightarrow alarm\ (A_i)\ |\ i \in [1,2,3,4]$. To entangle from event-calculus to DAGSVM classification with respective pseudo-code for corresponding alarms, a new convolutive function *gen()*is introduced to mapping the interface between event calculus and DAGSVM process indicated as: *gen*[*initiate*(*temperature*, *DAGSVM-code*, *time*)]. D_{AP} = classification alarms series with respect to temperature by DAGSVM mechanism. The *gen()* function which is convoluted of detection of events by event-calculus and DAGSVM classification based alarm-code technique is defined according to the development of time (dt) in mathematical structure indicated as below:

$$gen[initiate(T, C_d S, t)] = \int_{I_n T}^{F_r T} intiate(T, A_L, t).D_{AP}(A_L)dt \quad ...\ (1)$$

Where, I_nT = reference temperature and F_rT = fire ignition temperature. The pseudo code for DAGSVM model (C_dS) for *gen()* function for detection of alarms' temperature is indicated as follows.

The *gen()* function for red alarm temperature detection code of DAGSVM is denoted as: R_eA

```
// pseudo code for red alarm,
```
$\boldsymbol{R_e A: T_4 \longrightarrow R_4}$
```
Compare class = R1 and class = R4
If class ≠ R1
Compare class = R2 and class = R4
AND if class ≠ R2
Compare class = R3 and class = R4
AND if class ≠ R3
Class = R4
Alarm: RED alarm
```

The *gen()* function for yellow alarm temperature detection code of DAGSVM is denoted as: Y_lA

```
// pseudo code for Yellow alarm,
```
$Y_l A: T_3 \longrightarrow R_3$
```
Compare class = R1 and class =R4
If class ≠ R1
Compare class = R2 and class = R4
AND if class ≠ R4
Compare class = R2 and class = R3
AND if class ≠ R2
Class = R3
Alarm: yellow alarm
```

The *gen()* function for critical tolerance temperature detection code of DAGSVM is denoted as: C_tA

```
// pseudo code for critical tolerance
```
$C_t A: T_2 \longrightarrow R_2$
```
Compare class = R1 and class = R4
If class ≠ R4
Compare class = R1 and class = R3
AND if class ≠ R1
Compare class = R3 and class = R2
AND if class ≠ R3
Class = R2
Alarm: critical tolerance alarm
```

The *gen()* function for primary tolerance temperature detection code of DAGSVM is denoted as: P_mA

```
// pseudo code for primary tolerance
```
$P_m A: T_1 \longrightarrow R_1$
```
Compare class = R1 and class = R4
If class ≠ R4
Compare class = R1 and class = R3
AND if class ≠ R3
Compare class = R1 and class = R2
AND if class ≠ R2
Class = R1
Alarm: primary tolerance alarm
```

So, the *gen()* function is formulated with respect to abstractive algebra as: *gen():event-calculus* $\longrightarrow D_{AP}$. So, the generation of alarm, *gen()* is morphism from detection of certain temperature increment occurrence by event-calculus to DAGSVM classification, D_{AP} for respective alarm generation. So, the classification of the alarms by event-calculus based DAGSVM technique (D_{AP}) is formulated as: $D_{AP}(A_1,A_2,A_3,A_4) = \{\sim gen(initiate(T_1,P_mA,t_1))\} \otimes \{\sim gen(initiate(T_2,C_tA,t_2))\} \otimes \{\sim gen(initiate(T_3,Y_lA,t_3))\} \otimes \{\sim gen(initiate(T_4,R_eA,t_4))\}$.

The pseudo code for each stage of alarm series by DAGSVM classification is defined under a group $\{C_dS\}$ as indicated below:

$$\{\boldsymbol{R_e A, Y_l A, C_t A, P_m A}\} \in \boldsymbol{C_d S}$$

The combination of pseudo code for DAGSVM (C_dS) with event calculus technique (I_tF) is morphism from the temperature increment (ΔT) to alarm levels (A_L) formulated according to the mathematical foundation indicated as follows:

$$(\boldsymbol{C_d S} \times \boldsymbol{I_t F}): \boldsymbol{\Delta T} \longrightarrow \boldsymbol{A_L}$$

Where, ΔT = indicates the variation of temperature detected by thermal imaging camera.

5. Mathematical Foundation for Image Area Segmentation

To establish the relationship between temperature increasing based sequential alarm stages and affected thermal region with its boundary in the image, the partial differentiation [24] is implemented as the analyzing factor in this investigation. The total region in the thermal image captured by thermographic camera [25] is denoted as 'R' which patterned all information about the temperature of the object in the form of pixel-color. The functionality of the thermal region, R as an image is defined as follows:

$$R = \int_{I_n T}^{F_r T} posit[chrom(temp)]\, dT$$

Where,

- chrom(temp) = the artificial coloring of pixels for respective temperature values between 55℃ to 120℃
- posit[chrom(temp)] = coordinate position of that pixel in the image according to the temperature pattern of the object.
- dT = changing of temperature (T)

The partially derivation is applied to segment different level of temperature area in this study. The mathematical model is also formulated to compute the boundary detection technique of the affected areas as well.

So, the thermal areas are differentiated with respect to increasing pattern of temperature calculated by derivative model between the interval of alarms indicated as: $\left[\frac{\partial R}{\partial T}\right]_{I_nT}^{F_rT}$, So, from reference to fire broke-out temperature is distinguished into 4 intermediate alarm intervals: T_1 = primary tolerance temperature; T_2 = critical tolerance temperature; T_3 = yellow alarm temperature; T_4 = red alarm temperature. The partial derivative equation of temperature based area segmentation will be formulated as, $X(R)=\frac{\partial(\boldsymbol{R})}{\boldsymbol{\partial T}}\Big|_{T_4}^{\boldsymbol{F_rT}} \cup \frac{\partial(\boldsymbol{R})}{\boldsymbol{\partial T}}\Big|_{T_3}^{T_4} \cup \frac{\partial(\boldsymbol{R})}{\boldsymbol{\partial T}}\Big|_{T_2}^{T_3} \cup \frac{\partial(\boldsymbol{R})}{\boldsymbol{\partial T}}\Big|_{T_1}^{T_2} \cup \frac{\partial(\boldsymbol{R})}{\boldsymbol{\partial T}}\Big|_{\boldsymbol{I_nT}}^{T_1}$, where $I_nT = T_0$ as initial reference temperature and $F_rT = T_F$ as fire broke out temperature mentioned in the event-calculus process. The integration of all segmented areas with respect to temperature variation is combined with union operation (∪) of abstract algebra for mathematical foundation. Segmentation of temperature affected area before reference points ($<I_nT$) is indicated as: $\frac{\partial(\boldsymbol{R})}{\boldsymbol{\partial T}}\Big|_{\boldsymbol{<I_nT}}^{\boldsymbol{I_nT}}$

But, segmentation of thermal region according to temperature variation is not possible to calculate by single factor, region (R), of partial differentiation in theory also. Some valuable parameters in image processing e.g. pixel position information in large image-coordinate (P_x), variation of pixel position with respect to its color (C_h) and variation of color according to temperature (T) etc., are required to be considered for better analyzing of the image processing model. So, the differentiated factor of area segmentation technique is analyzed according to multiple factors indicated as: $\left[\frac{\partial R}{\partial T}\right]_{I_nT}^{F_rT} = \left[\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})} \times \frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})} \times \frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}\right]_{I_nT}^{F_rT}$, where $\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})}$ = Certain thermal area, *R* with respect to position of pixels (P_x) is denoted as: d_i; $\frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})}$ = variation of pixel area (P_x) with respect to color (C_h) is denoted as: v_i; $\frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}$ = chromatics variation (C_h) with respect to temperature *T* is denoted as: c_i.

So, the complete thermal region {R} in the image differentiated partially with respect to temperature variation intervals between <InT and FrT point and other derivative factors is defined as:

$$X(R) = \left[\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})} \times \frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})} \times \frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}\right]_{T_4}^{F_rT} \cup \left[\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})} \times \frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})} \times \frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}\right]_{T_3}^{T_4} \cup \left[\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})} \times \frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})} \times \frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}\right]_{T_2}^{T_3} \cup \left[\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})} \times \frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})} \times \frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}\right]_{T_1}^{T_2} \cup \left[\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})} \times \frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})} \times \frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}\right]_{I_nT}^{T_1} \cup \left[\frac{\partial(\boldsymbol{R})}{\partial(\boldsymbol{P_x})} \times \frac{\partial(\boldsymbol{P_x})}{\partial(\boldsymbol{C_h})} \times \frac{\partial(\boldsymbol{C_h})}{\boldsymbol{\partial T}}\right]_{<I_nT}^{I_nT} \quad \ldots (2)$$

Now, for detecting the edge of the different level of temperature affected areas according to the compatible region (R) in the image is formulated by boundary function indicated as: $B_n = e\left(\left[\frac{\partial R}{\partial T}\right]_{<I_nT}^{F_rT}\right)$

Where, $[e(Z)]_{T_1}^{T_2}$ = boundary of the affected region (Z) between the temperature interval [T_2 ~ T_1]. So, the complete boundary of the thermal region {R} in the image with respect to temperature intervals between <InT and FrT is indicated as follows:

$$B_n = e\left(\left[\frac{\partial R}{\partial T}\right]_{T_4}^{F_rT}\right) \cup e\left(\left[\frac{\partial R}{\partial T}\right]_{T_3}^{T_4}\right) \cup e\left(\left[\frac{\partial R}{\partial T}\right]_{T_2}^{T_3}\right) \cup e\left(\left[\frac{\partial R}{\partial T}\right]_{T_1}^{T_2}\right) \cup e\left(\left[\frac{\partial R}{\partial T}\right]_{I_nT}^{T_1}\right) \cup e\left(\left[\frac{\partial R}{\partial T}\right]_{<I_nT}^{I_nT}\right) \ldots (3)$$

So, the mapping-flow between recognition of temperature affected area with area segmentation based on thermal-chromatics variation is designed by partial differentiation technique linked together as: *differential mathematical process: complete thermal image ⟶ temperature based segmented image*

6. Integration Multiple Functions and Foundation of Inter-Mapping

Mathematical foundation based computational process investigated - event-calculus based DAGSVM classification for alarm generation **and** partial differentiation based thermal area segmentation with boundary detection in obtained image - are conjugated together in this section with functional assistance of abstract algebraic technique. To design the complete inter-connective architecture of the introduced technique, previous event-calculus based DAGSVM classification for alarms and partial differentiation (P_DE) based thermal area segmentation with boundary detection process are conglomerated each-other by intersection, union (∪, ∩) operation in set theory.

So, the interconnectedness of DAGSVM based alarm classification and thermal area segmentation [27] with edge detection (B_n) at temperature interval between initial (I_nT) to primary tolerance point (T_1) denotes is indicated as: $\boldsymbol{gen}(\boldsymbol{initiate}(\boldsymbol{T_1}, P_mA, \boldsymbol{t_1})) \cap \left[\frac{\partial R}{\partial T}\right]_{I_nT}^{T_1} e\left(\left[\frac{\partial R}{\partial T}\right]_{I_nT}^{T_1}\right)$. By the same technique, other DAGSVM classification functions combined with boundary detection and area segmentation at different level of alarm intervals is shown in the formulation below:

$$\begin{aligned} \boldsymbol{T_h E} = \\ \left\{ \frac{\partial R}{\partial T}\bigg|_{\boldsymbol{T_4}}^{\boldsymbol{F_r T}} \cap e\left(\left[\frac{\partial R}{\partial T}\right]_{T_4}^{F_r T}\right)\right\} \cup \left\{\boldsymbol{gen(initiate(T_4, R_e A, t_4))} \cap \right. \\ \frac{\partial R}{\partial T}\bigg|_{\boldsymbol{T_3}}^{\boldsymbol{T_4}} \cap e\left(\left[\frac{\partial R}{\partial T}\right]_{T_3}^{T_4}\right)\Bigg\} \cup \left\{\boldsymbol{gen(initiate(T_3, Y_l A, t_3))} \cap \right. \\ \frac{\partial R}{\partial T}\bigg|_{\boldsymbol{T_2}}^{\boldsymbol{T_3}} \cap e\left(\left[\frac{\partial R}{\partial T}\right]_{T_2}^{T_3}\right)\Bigg\} \cup \left\{\boldsymbol{gen(initiate(T_2, C_t A, t_2))} \cap \right. \\ \frac{\partial R}{\partial T}\bigg|_{\boldsymbol{T_1}}^{\boldsymbol{T_2}} \cap e\left(\left[\frac{\partial R}{\partial T}\right]_{T_1}^{T_2}\right)\Bigg\} \cup \left\{\boldsymbol{gen(initiate(T_1, P_m A, t_1))} \cap \right. \\ \frac{\partial R}{\partial T}\bigg|_{\boldsymbol{I_n T}}^{\boldsymbol{T_1}} \cap e\left(\left[\frac{\partial R}{\partial T}\right]_{I_n T}^{T_1}\right)\Bigg\} \cup \left\{\frac{\partial R}{\partial T}\bigg|_{\boldsymbol{<I_n T}}^{\boldsymbol{I_n T}} \cap e\left(\left[\frac{\partial R}{\partial T}\right]_{<I_n T}^{I_n T}\right)\right\} \ldots (4) \end{aligned}$$

For designing a complete interfacing between event-calculus based DAGSVM classification for alarm series and partial differentiation based thermal area segmentation with boundary detection technique at a same level of temperature, intersection operation (⋂) of abstract algebra [28] is implemented to formulate the inter-connectivity equitation of the model.

For designing proper interfacing between DAGSVM classification based thermal area segmentation and boundary detection at a same level of temperature, the intersection operation (⋂) **and** for integrating the same functional components for different stages of temperature according to alarm intervals, the union operation (⋃) of abstract algebra is implemented to establish the mathematical entanglement model of designed architecture. In the other way, the intersection operation (⋂) is used to represent the interoperability factor between multiple functions at a same level known as horizontal interoperability and the union operation (⋃) is used to represent the interoperability factor between multiple functions at different stages known as vertical interoperability.

Abstract algebraic operations – intersection, union – are implemented as the convolutive function between horizontal and vertical interoperability technique in the proposed model as indicated below:

$$\boldsymbol{T_h E} = \int_{\boldsymbol{<I_n T}}^{\boldsymbol{F_r T}} \boldsymbol{gen(A_L) \star X(R) \star B_n(e)} \ldots (5)$$

Where, the inter-dependency between functional elements of gen(A_L) – alarm classification, X(R) – area segmentation, B_n(e) – boundary detection process within the interval of temperature point (<I_nT) to (F_rT) is indicated by asterisk (⋆) in this foundation.

Now, the segmentation of a certain temperature (T_x) affected region with certain chromatics value (m_x) in the thermal image of coal on the basis of partial differentiation technique is defined in the canonical formation indicated as below:

$$C_x A = \int_{T_x} posit[chrom(temp)]dT$$

$$or, C_x A = \frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial T}}\bigg|_{T_x}$$

$$or, C_x A = \frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial(A_S)}} \times \frac{\boldsymbol{\partial(A_S)}}{\boldsymbol{\partial(C_h)}} \times \frac{\boldsymbol{\partial(C_h)}}{\boldsymbol{\partial T}}\bigg|_{T_x}$$

The boundary (B_x) of the segmented region at the certain temperature (T_x) according to the boundary detection technique is defined as follows:

$$B_x = e\left[\int_{T_x} A_S(m_x)\right]$$

$$or, B_x = e\left[\frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial T}}\right]_{T_x}.$$

$$or, B_x = e\left[\frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial(A_S)}} \times \frac{\boldsymbol{\partial(A_S)}}{\boldsymbol{\partial(C_h)}} \times \frac{\boldsymbol{\partial(C_h)}}{\boldsymbol{\partial T}}\right]_{T_x}$$

Now, the output image at a certain temperature point (T_x) from the thermal image of coal on the basis of abstract algebraic approach is defined in the mathematical foundation indicated as below:

$$C_x T = \frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial T}}\bigg|_{T_x} \cap e[A_S(m_x)]_{T_x}$$

$$C_x T = \frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial(P_x)}} \times \frac{\boldsymbol{\partial(P_x)}}{\boldsymbol{\partial(C_h)}} \times \frac{\boldsymbol{\partial(C_h)}}{\boldsymbol{\partial T}}\bigg|_{T_x} \cap e[A_S(m_x)]_{T_x}$$

Where, $C_x T$ = segmented area in the thermal image of coal at a certain temperature (T_x) with respect to position of the pixel in the thermal image= $\frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial(P_x)}}$, variation of pixel area with respect to pixel color = $\frac{\boldsymbol{\partial(P_x)}}{\boldsymbol{\partial(C_h)}}$, chromatics variation with respect to temperature = $\frac{\boldsymbol{\partial(C_h)}}{\boldsymbol{\partial T}}$ at that certain temperature point and boundary detection, B_x: $e\left[\frac{\boldsymbol{\partial(R)}}{\boldsymbol{\partial T}}\right]_{T_x}$.

7. Obtained Thermal Images and Simulation of Results

The variation of pixel color with respect to temperature differences, implemented in this investigation as: $\frac{\boldsymbol{\partial(C_h)}}{\boldsymbol{\partial T}}$, is obtained by the self assembled thermal imaging camera "Thermocam V2.0" brought from a German organization entitled "Cheap-Thermocam". The color-temperature scale for representing various temperature affected areas by different chromatic values is standardized by the software platform provided by the manufacturer of the thermal camera devices downloaded from "http://www.cheap-thermocam.net". The parts of the camera are brought from foreign organization and assembled & tested in the parent institute. The pixel color variation with respect to temperature: $\frac{\boldsymbol{\partial(C_h)}}{\boldsymbol{\partial T}}$ is scaled by the simulator provided by manufacturer. The image of the self-assembled thermal imaging camera and its parts are shown in the Fig. 4 below:

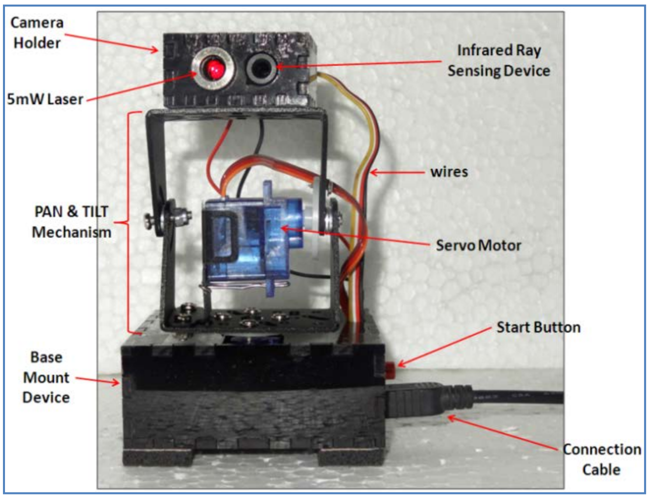

Figure 4. DAGSVM with event-calculus

For obtaining the thermal image of an object, the heated coal is considered as the prime elements in this investigation. The distance between heated coal and thermal imaging camera is 1.65 meter and the size of the object, configured in this experimental setup, is measured according to the characteristics of the infrared sensor with 1.78 ratio scales [29]. The corresponding image of the configured experimental environment is shown in the Fig.5 below:

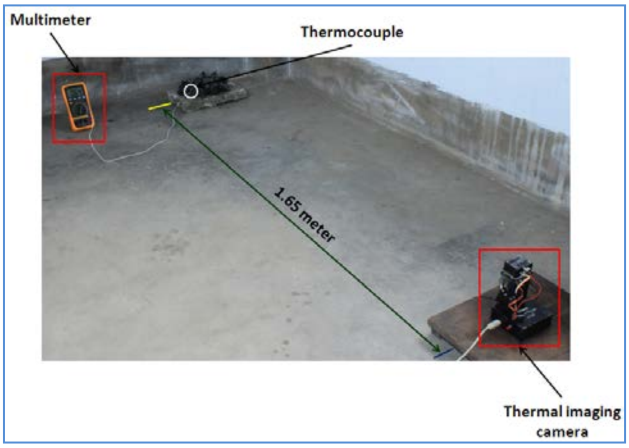

Figure 5. Experimental setup with distance of 1.65 meter

The detailed connection of wires in the thermal imaging camera is shown in the Fig. 6 below:

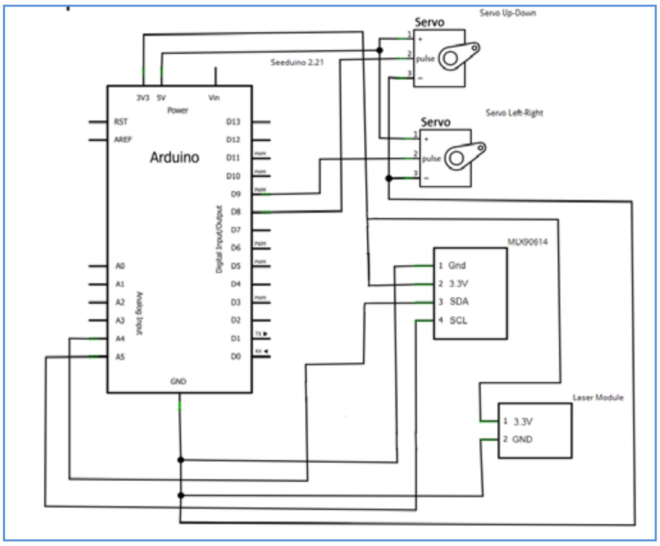

Figure 6. Wire diagram of the camera

For controlling of the total mechanism of the thermal imaging camera device, Arduino UNO R3 [30] with 8-bit Atmel AVR microcontroller [31], single-board microcontroller interface is embedded in this circuitry. For detection of thermal signature of any body, MLX90614ESF-BCI model [32] infrared sensor is deployed in the circuit to capture the emitted infrared radiation [33] from the target object. The movement of the infrared device is mounted on a platform supported by two 4.8 Volt servo motors [34] for horizontal and vertical movement of the platform. To locate the position of the infrared sensor form where thermal signature value would be taken is spotted by a 5 mW red dot laser [35].

The obtained thermographic image of ignited coal is shown along with the temperature-chromatics scale standardized by the camera manufacturer and coded in 32 bit Java Virtual Machine [36] based **.jar** file where the minimum temperature and maximum temperature **30.52 °C** and the maximum temperature **110.87 °C** as indicated in the Fig. 7 below:

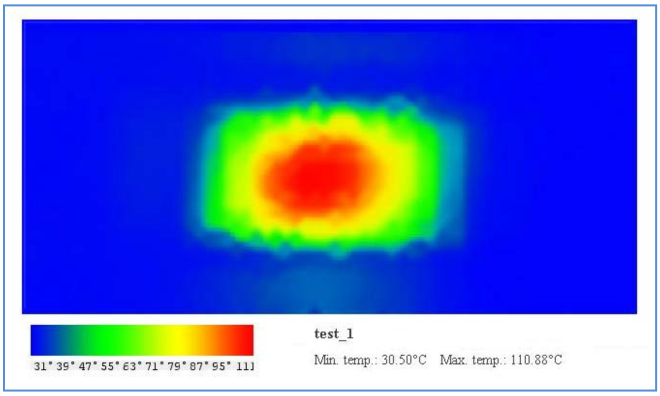

Figure 7. Obtained thermal image from camera

Now, for the analyzing the obtained thermal image according to the designed methodology, the region in the thermographic image is represented as "*R*" as shown in the Fig. 8 below:

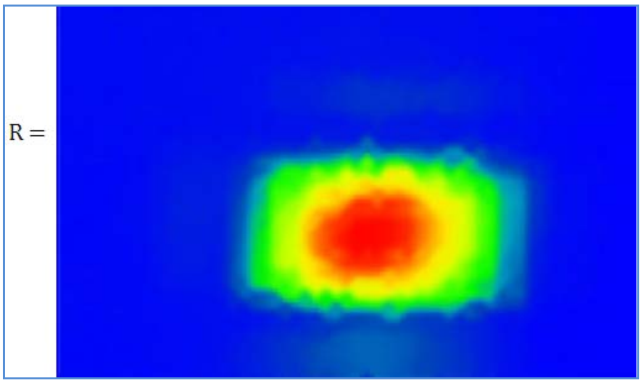

Figure 8. Temperature affected area for calculation

The pattern of the temperature distribution and its classification with respect to the interval of alarm-temperature levels is shown in Fig. 9 below:

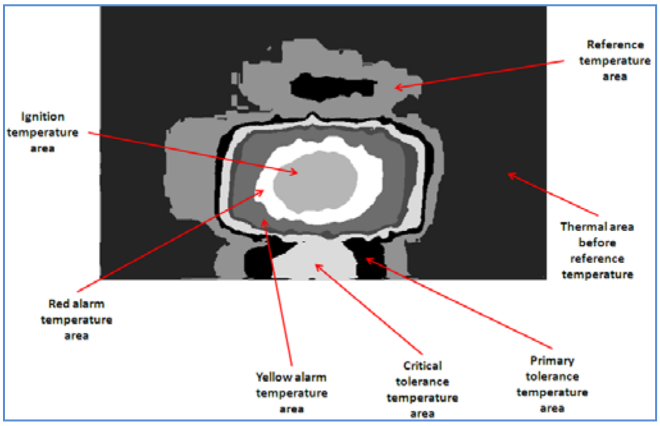

Figure 9. Segmentation of thermal image into respective temperature affected region

Now, analyzing the region of thermographic image [37] according to the introduced technique between temperature interval of ($<I_nT$) and (I_nT) is simulated in MATLAB [38] platform. The boundary of the certain temperature affected area with respect to derived equation of boundary detection process is shown in Fig. 10 as follows:

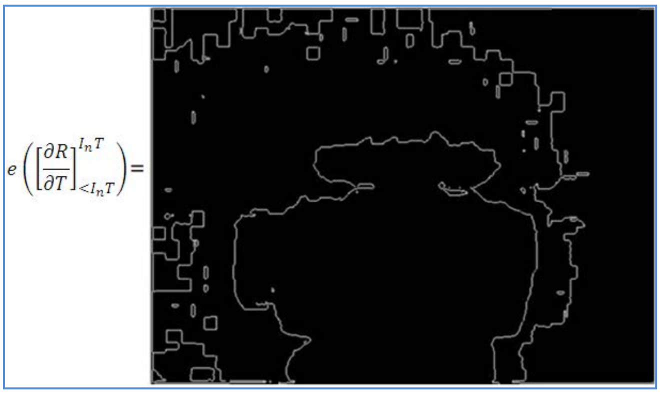

Figure 10. Temperature affected area at the reference point

In the above figure, the consequent equation $e\left(\left[\frac{\partial R}{\partial T}\right]_{<I_nT}^{I_nT}\right)$ represents the thermal affected area at that certain temperature level. With the combination between the partial deferential equation based area segmentation method and certain thermal chromatics value, : (0,12,241) shown in the thermographic image is implemented by the mathematical foundation based Color-Temperature Relationship process: $\left[\frac{\partial(C_h)}{\partial T}\right]_{<I_nT}^{I_nT}$ combined together at **reference temperature level** as shown in Fig 11 below:

$$\frac{\partial(R)}{\partial(P_x)} \times \frac{\partial(P_x)}{\partial(C_h)} \times \frac{\partial(C_h)}{\partial T}\bigg|_{<I_nT}^{I_nT} =$$

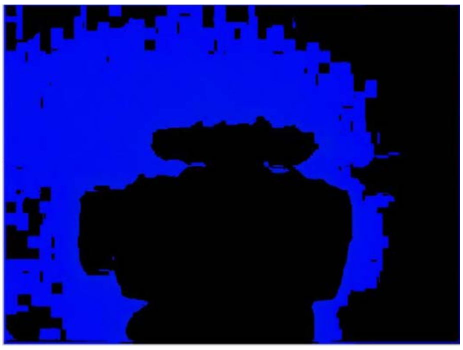

Figure 11. Chromatics value for reference temperature level with canonical formation

Analyzing of the region of thermographic image [37] between the temperature interval of initial (I_nT) and primary tolerance point (T_1), boundary of the certain temperature affected area with respect to derived equation of boundary detection process is shown in Fig. 12 as follows:

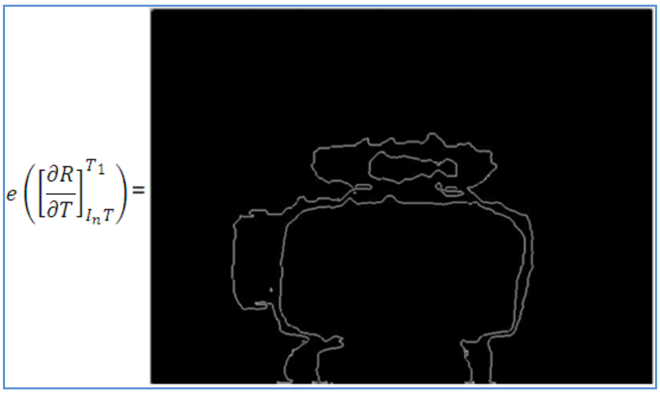

Figure 12. Temperature affected area at the primary tolerance level

In the above figure, the consequent equation $e\left(\left[\frac{\partial R}{\partial T}\right]_{I_nT}^{T_1}\right)$ represents the thermal affected area at that certain temperature level. With the combination between the partial deferential equation based area segmentation method and certain thermal chromatics value, : (2,24,221) shown in the thermographic image is implemented by the mathematical foundation based Color-Temperature Relationship process: $\left[\frac{\partial(C_h)}{\partial T}\right]_{I_nT}^{T_1}$ combined with **Primary Tolerance Level** as shown together in the Fig. 13 below:

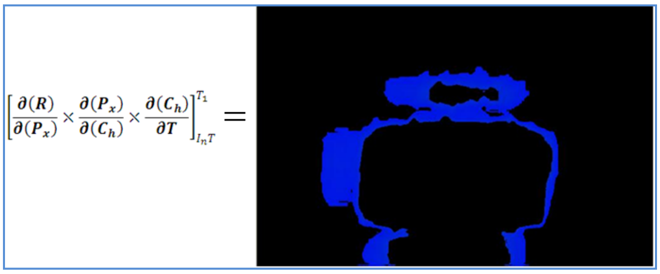

Figure 13. Chromatics value for Primary tolerance temperature level with canonical formation

At this point of temperature, the primary tolerance alarm would be triggered according to the event-calculus based DAGSVM technique. Analyzing of thermal region between the temperature interval of primary (T_1) and Critical tolerance point (T_2), boundary of certain temperature affected area with respect to derived equation of boundary detection process is shown in Fig. 14 as follows:

Figure 14. Temperature affected area at the critical tolerance level

In the above figure, the consequent equation $e\left(\left[\frac{\partial R}{\partial T}\right]_{T_1}^{T_2}\right)$ represents the thermal affected area at that certain temperature level. With the combination between the partial deferential equation based area segmentation method and certain thermal chromatics value, : (0,138,186) shown in the thermographic image is implemented by the mathematical foundation based Color-Temperature Relationship process: $\left[\frac{\partial(C_h)}{\partial T}\right]_{T_1}^{T_2}$ combined with **Critical Tolerance Level** as shown together in the Fig. 15 below:

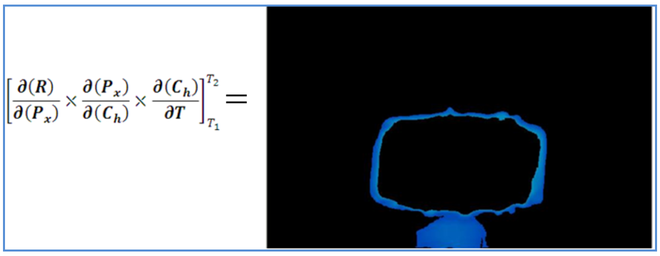

Figure 15. Chromatics value for critical tolerance temperature level with canonical formation

At this point of temperature the critical tolerance alarm would be triggered as designed model. Analyzing of thermal region between the temperature interval of critical tolerance (T_2) and yellow alarm point (T_3), boundary of certain temperature affected area with respect to the derived equation of boundary detection process is shown in Fig. 16 as follows:

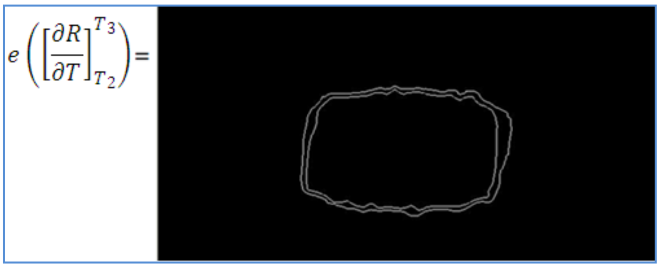

Figure 16. Temperature affected area at the yellow alarm level

In the above figure, the consequent equation $e\left(\left[\frac{\partial R}{\partial T}\right]_{T_2}^{T_3}\right)$ represents the thermal affected area at that certain temperature level. With the combination between the partial deferential equation based area segmentation method and certain thermal chromatics value, : (0,189,130) shown in the thermographic image is implemented by the mathematical foundation based Color-Temperature Relationship process: $\left[\frac{\partial(C_h)}{\partial T}\right]_{T_2}^{T_3}$ combined with **Yellow Alarm Level** as shown together in the Fig. 17 below:

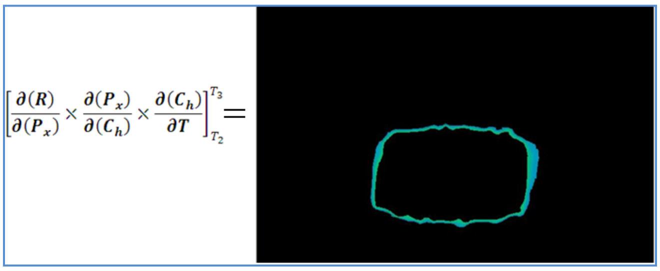

Figure 17. Chromatics value for yellow alarm temperature level with canonical formation

At this point of temperature the yellow alarm would be triggered according to the designed model. Analyzing of thermal region between the temperature interval of yellow alarm (T_3) and red alarm point (T_4) is simulated and the boundary of the temperature affected area with respect to the derived equation of boundary detection process is shown in Fig. 18 as follows:

Figure 18. Temperature affected area at the red alarm level

In the above figure, the consequent equation $e\left(\left[\frac{\partial R}{\partial T}\right]_{T_3}^{T_4}\right)$ represents the thermal affected area at that certain temperature level. With the combination between the partial deferential equation based area segmentation method and certain thermal chromatics value, : (106,255,2) shown in the thermographic image is implemented by the mathematical foundation based Color-Temperature Relationship process: $\left[\frac{\partial(C_h)}{\partial T}\right]_{T_3}^{T_4}$ combined with **Red Alarm Level** as shown together in the Fig. 19 below:

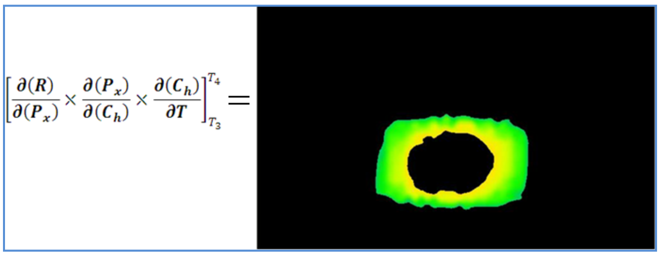

Figure 19. Chromatics value for red alarm temperature level with canonical formation

At this point of temperature the red alarm would be triggered and the monitoring sequence would be continuous. Analyzing of thermal region between the temperature interval of red alarm (T_4) and fire-break out point (F_rT) is simulated and the boundary of the temperature affected area with respect to the derived equation of boundary detection process is shown in Fig. 20 as follows:

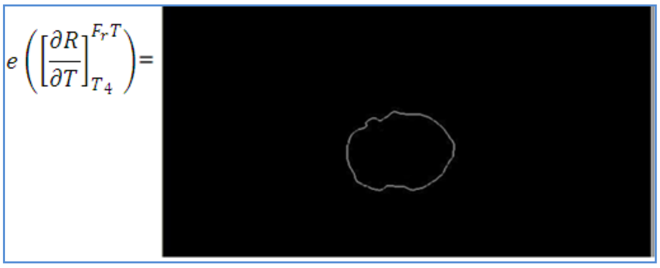

Figure 20. Temperature affected area at the fire ignition level

In the above figure, the consequent equation $e\left(\left[\frac{\partial R}{\partial T}\right]_{T_4}^{F_rT}\right)$ represents the thermal affected area at that certain temperature level. With the combination between the partial deferential equation based area segmentation method and certain thermal chromatics value, : (255,148,4) shown in the thermographic image is implemented by the mathematical foundation based Color-Temperature Relationship process: $\left[\frac{\partial(C_h)}{\partial T}\right]_{T_4}^{F_rT}$ combined with **Fire Broke-Out Level** as shown together in the Fig 21 below:

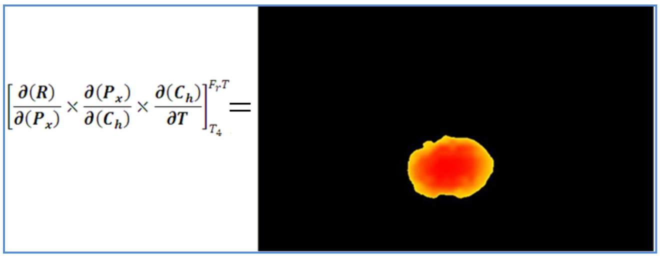

Figure 21. Chromatics value for fire ignition level with canonical formation

The certain thermal color value in the thermographic image of coal in simulated in MATLAB defined in mathematical foundation process: $\left.\frac{\partial(R)}{\partial T}\right|_{T_x}$ for a certain point of temperature (T_x = 74°C) obtained from the thermal-color scale of thermal imaging camera, m_x is independent of chromatics since the image processing is directly interconnected with the temperature value as well.

So, the combined figure between the certain temperature-affected regions of coal and thermal chromatics value at that certain temperature point (T_x) is shown in the Fig. 22 below:

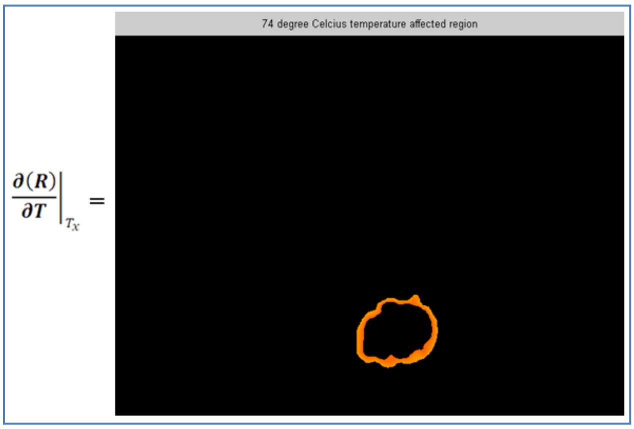

Figure 22. Certain temperature affected region on the thermal image at (74°C)

The affected area in the thermal image where the temperature is above fire break out point, known as anomaly point, is formulated by mathematical foundation model as indicated below:

$$A_{np} = \frac{\partial(R)}{\partial(P_x)} \times \frac{\partial(P_x)}{\partial(C_h)} \times \left.\frac{\partial(C_h)}{\partial T}\right|_{F_rT}^{>F_rT} \ldots (6)$$

The location of the thermal anomaly point is indicated in a black square in Fig 23 below:

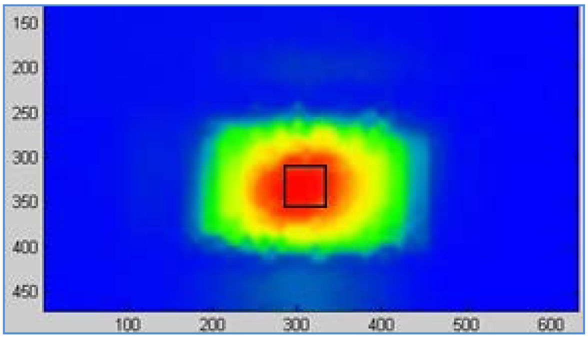

Figure 23. Anomaly point of coal fire thermal image

The more than 25 sets of physical temperature values with respect to the surface of coal for measuring the spontaneous combustion effect in side of the coal using HTC, DM – 86 multimeter [40] based the thermocouple device are indicated in the Table 1 below:

Table 1. Comparative temperature reading between thermocouple and camera

Temp at edge		**Temp at centre**	
temp in thermocouple (°C)	temp in camera (°C)	temp in thermocouple (°C)	temp in camera (°C)
43	38.7	105	65.5
94	36.2	83	45.1
…	…	…	…
44	38.7	57	48.9

The HTC, multimeter DM – 86 with the thermocouple is used to take the temperature value at the surface of the coal manually. The sets of the temperature values obtained by the both DM – 86 multimeter based thermocouple and "Thermocam $V_{2.0}$" thermal imaging camera are compared in MATLAB and the respective result are shown in the Fig. 25 below:

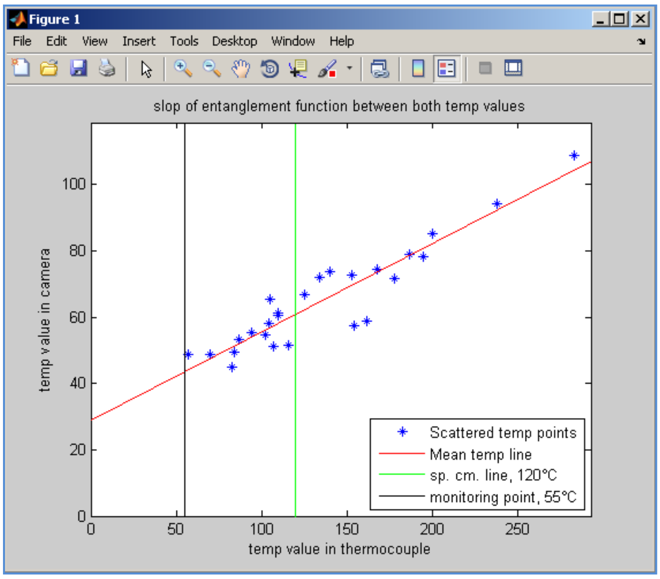

Figure 24. Compared graph of temperature value between camera and thermocouple

The respective temperatures in the thermal imager for the reference (55°C) and spontaneous combustion ignition point (120°C) of coal detected by the thermocouple measured with respect to intersection points between the mean temperature line calibrated according to the both temperature valves and reference value and spontaneous combustion ignition point-lines are taken as the graph plotting technique as described in the fig 26 below:

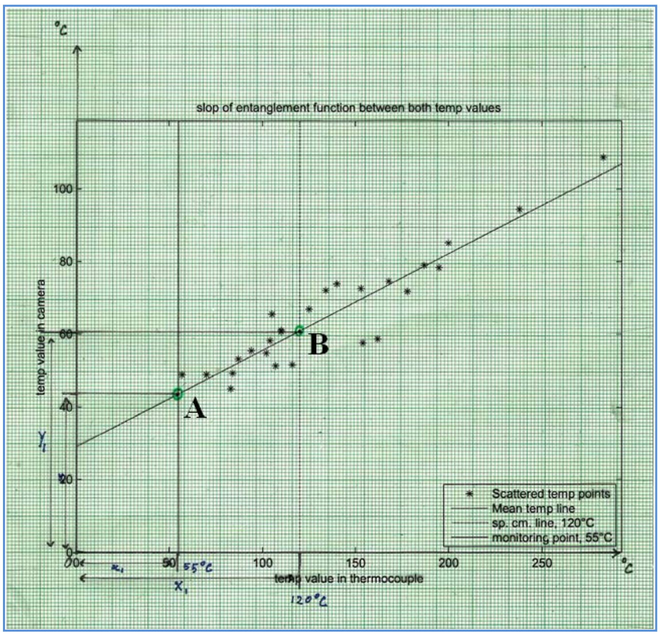

Figure 25. Respective temperature points detected by the camera

So, the relation between the function of both temperature values (reference, 55°C and ignition point, 120°C) are calculated by the 2D Euclidean Coordinate geometric method for a straight line passing through two coordinate (A, B) whose coordinate values are $\{x_0 = 55, y_0 = 45\}$ and $\{x_1 = 120, \ y_1 = 61\}$ respectively. So, the relation between the variables of the both temperature scale are indicated in coordinate geometry based mathematical formation as below:

$$(y - y_0)(x_1 - x_0) = (y_1 - y_0)(x - x_0)$$
$$(y - 45)(120 - 55) = (61 - 45)(x - 55)$$
$$65y = 16x + 2045$$
$$y = 0.2461x + 31.4615$$

So, the slope between the function of both temperature value is, m = 0.2461 and attribute, c = 31.4615. The relation between the function of the both temperature values obtained by the "Thermocam $V_{2.0}$" and DM – 82, thermocouple based temperature value is indicated as below:

Thermographic temp value = 0.2461 × thermocouple temp value + 31.4615 … (7)

8. Conclusion

In this paper, the image processing approach founded on mathematical interpretation bridges a dynamic missing-links between real-life scenario of image segmentation process and logical foundation of image processing technique which is not still investigated yet. The current work explains the implementation of mathematical abbreviations for founding of inter-connected flow between event-calculus based DAGSVM technique with area segmentation and boundary detection in thermal images of heated object and described its application in temperature monitoring process for detecting fire break out possibility. The flow of mathematical models implemented in each theoretical step of the introduced technique and the applicability of image processing including hardware, software as well as an intelligent alarming system for fire monitoring is considered as the principal research constituent for this investigation. The designed model would be capable to integrate the image segmentation process with intelligent classification techniques by mathematical foundation approach. This methodology is useful to recognize the fire break out condition as well as tracing of the critical temperature point of spontaneous combustion especially in coal seams.

So, the relation between the differently obtained temperature-sets is integrated by 2D Coordinate geometric method in the form of canonical to represent interconnection between them. The slope in the straight-line equation between two temperature measurement functions indicates the increasing pattern of the temperature value detected by thermographic camera with respect to thermocouple based temperature measured value in experiment. The mathematical formulation based 2 dimensional entanglement technique between two or multiple different parameter and their dependable functions is introduced in this investigation.

Appendix.

The determination of temperature values for different alarm intervals are calculated by the PID (proportional – integral – derivative) [39] control technique. The increasing of alarm sequence with respect to increment of temperature is based on derivative approach of PID. However, the complete monitoring technique is computed on the basis of integral approach of PID control model. To determine the various temperature ranges of different alarm intervals, arithmetic functions are implemented in this investigation. The values of different alarm levels temperature are calculated as: primary tolerance temperature, (T_1): $I_nT + 1 \times (F_rT - I_nT)/5$; critical tolerance temperature, (T_2): $I_nT + 2 \times (F_rT - I_nT)/5$; yellow alarm temperature, (T_3): $I_nT + 3 \times (F_rT - I_nT)/5$; and red alarm temperature, (T_4): $I_nT + 4 \times (F_rT - I_nT)/5$. The complete and sequential flow of the designed process for protection from fire in coalmines is constructed on two major parallel propagations of works and their combined practices in image processing technique as represented in the figure below:

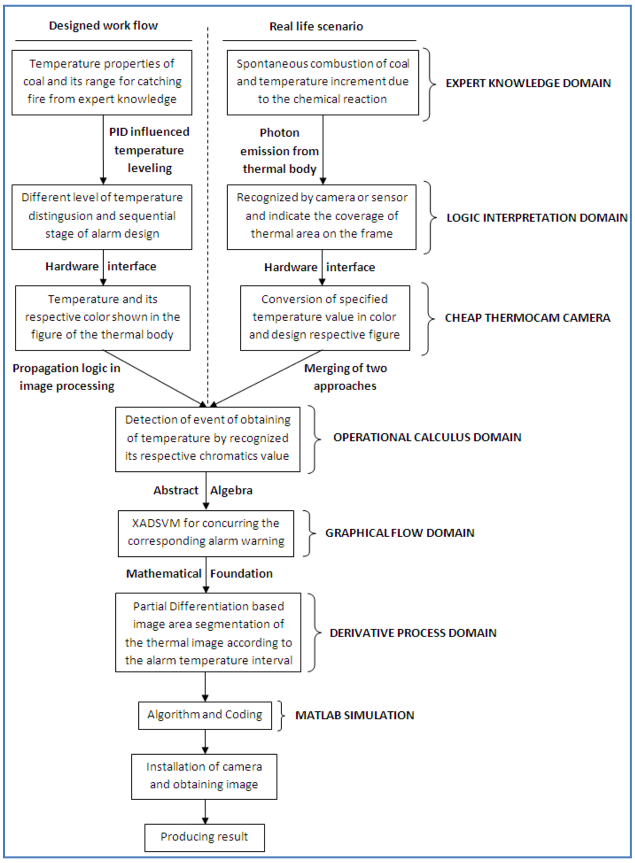

Figure 26. Complete sequence of work of the investigation

As well as, the critical situation could also be considered if the temperature measured crosses more than one alarm level in the next phase of monitoring within 1 hour of interval, the situation is considered as critical and triggers the red alarm. The conditions are considered as the threshold parameters for designing the critical response as indicated below:

- A_p = fire broke out condition
- B_p = result and anomaly point
- f_{th} = temperature increment based thermal imaging
- Initial temperature (InT), t_0 – critical tolerance temperature alarm (CTT), t_2
- Primary tolerance temperature alarm (PTT), t_1 – yellow alarm temperature (YT), t_3
- Critical tolerance temperature alarm (CTT), t_2 – red alarm temperature (RT), t_4

The logic flow diagram for designed the critical response situation is shown as follows:

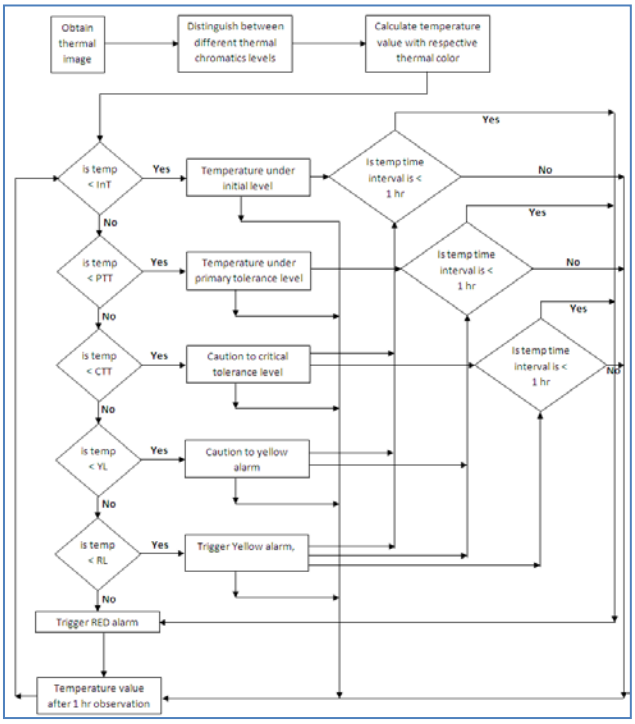

Figure 27. Logic flow for detection of critical situation

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