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SIMULATION ON SUPERCOMPUTER OF FIRE DETECTION SYSTEM HAVING TWO LEVELS OF TEMPERATURE SENSORS

Abstract. The article discusses the detection criteria for fire using two levels of temperature sensors at an optimal distance across a z-plane in a room. The values of standard deviation and rate of change of temperature across both levels of sensors were examined to discourse the benefits of the proposed criteria. The design and simulations were modelled in Fire Dynamics Simulator (FDS) and PyroSim on "Polytechnic" super computer to view results in the SmokeView.

Keywords: FDS, Modeling, PyroSim, SmokeView, Super Computer, Temperature, Fire Dynamics

1. Introduction

The ship building engineering has presented unique fire protection challenges with the rising trends in manufacturing giant ships. Specifically, modern cruisers and battle ships have become floating high-rise structures with five deck high mezzanines that run through the center of the ship. Ship fires are devastating, especially for passenger ships because it is difficult to safely evacuate people out at sea. It is also dangerous when a ship carries inflammable cargo such as gasoline and oil. To prevent such a devastative incidents, it is important that ships and vessels have adequate fire detection systems installed and that these systems are capable of quickly and accurately detecting the onset of a fire. Existing fire detection systems often generate fake fire alarms concluding to a wastage of precious fire-fighting resources. They also create anxiety among the crew on board and raise trivial attitude to actual fire. Another reason of inappropriate fire-fighting response is the old criterion of placement of sensors. Sensors are highly activated that can even show a slightest increase in a temperature which could be due to any un-wanted factor. This paper proposes a two level grid placement of temperature sensors in a room of Russia's Aurora cruiser. The criteria of detecting onset of a fire is given by the coordinates of the sensors, their standard deviation and rate of change in the temperature by time.

2. Selection of Software and Method of Modeling

2.1 Method of Modeling

There are three deterministic models to detect the thermos-gas fire parameters: integrated, zonal (zone) and field [1]. Each model was considered to select the one that will solve the given problem.

The integral method estimates the state of the gas environment calculating average values within a room. It is useful to calculate volume of large fire but does not account for heating and ventilation.

The zonal method divides the room in to zones. The upper level accounts for products of combustion and the lower level is undistributed air. It allows to investigate the average volume by time and the distribution of thermo-gas-dynamic parameters by the height of the convective column. The boundaries of zones are mobile however, the structure of the flow as well as heat and mass transfer values of all parameters are obtained only on the middle zone. Development of band models and theoretical procedures are discussed in Joness [2], Quintieris [3], Forneys [4] and [5].

The third type of model is the field model. The entire space is divided into a large number of small cells or zones. These cells are not connected with the thread structure. It is suitable for a fire development model with complex geometric configuration but it requires a lot of computing resources.

Conclusion: The field model is best suited for the case under investigation and resources of "Polytechnic" super computer will be used to solve the problem.

2.2 The Software

Fire Dynamics Simulator (FDS), is a computational fluid dynamics (CFD) field model of fire. It numerically solves a form of the Navier-Stokes equations which is appropriate for low-speed ($Ma < 0.3$), thermally-driven flow with an emphasis on smoke and heat transport from fires.

The Fire Dynamics Simulator (FDS), Kameleon FireEx (KFX) and SMARTFIRE are popular field model software available. The Fire Dynamics Simulator (FDS) is massively used and is freely distributable. It allows to predict the spread of smoke, temperature, carbon monoxide and other dangerous fire factors. It simulates the fire scenarios using computational fluid dynamics (CFD), optimized for low-speed temperature-dependent flows. This method is very useful to apply for various types of fire. It uses hydrodynamic model to calculate the movement of air currents caused by the fire. CFD accounts Navier-Stokes equations to describe the low-speed flows, caused by temperature changes, and allowing calculating the propagation of smoke and temperature distribution. PyroSim is a graphical user interface for FDS and its results are viewed in SmokeView.

Conclusion: Simulations can be performed in FDS to calculate fire dynamics in any room setting and results can be viewed in SmokeView.

3. Discourse of Polytechnic Super Computing Capabilities

The supercomputer available in Polytech (codenamed Polytechnic) is capable of performing up to 1.2PFLOPS. It is made and managed by RSC group of Russian Federation. It is comprised of two independent super computing systems "RSC Tornado cluster system" and massively parallel "RSC PetaStream". The peak performance of RSC Tornado is 829 Teraflops which is the 3rd in Russian Top50 list of the most powerful supercomputers with 658 Teraflops performance at LINPACK test as well as it is ranked by Top500 and Green500 global ratings. It is the first project in Russia and CIS based on new Intel® Xeon® E5-2600 v3 server processors.

Polytechnic RSC Tornado includes 712 dual-processor nodes containing 1424 high-performance Intel® Xeon® E5-2697 v3 server processors (14 cores, 2.6 GHz frequency each), Intel® S2600KP and Intel® S2600WT server boards for this processor generation, and the latest Intel® SSD DC S3500 solid state drives for enterprise data centers. Resources of this supercomputer are used not only for relevant scientific research tasks but also for cloud, VDI (Virtual Desktop Infrastructure) and graphical services.

The total performance of RSC PetaStream is 258 Teraflops. Polytechnic RSC PetaStream supercomputer has demonstrated LINPACK performance of 170.5 Teraflops and has 8th position in the current edition of the local Top50 list. This SPbPU supercomputer system is based on 60-core Intel® Xeon Phi™ 5120D and Intel®Xeon® E5-2600 v2 family processors with Intel server boards and Intel SSD DC S3500 solid-state drives for enterprise data centers.

Polytechnic RSC Tornado and Polytechnic RSC PetaStream are combined into a single HPC solution at SPbPU supercomputer center with high-speed Infiniband FDR switching network. The new SPbPU supercomputer complex also includes a parallel data storage system with Lustre distributed file system that will support and use up to 1 Petabyte of data and a 0.5 Petabyte block-based storage for cloud environments. Both storages use server technologies based on Intel architecture. The computation power of this super computer is used in this simulation.

4. Model of the Room

The design of the room resembles to a room in Aurora cruiser. It is a rectangle of 5.4m in length and 5.2m in width. Table 1 shows the properties of material used in the design.

Table 1: Properties of material

Materials	**No. of items**	**Density** (kg/m^3)	**Specific Heat** (kJ/(kg·K))	**Conductivity** (W/(m·K))	**Emissivity**	**Absorption Coefficient** (1/m)
Foams	01	28.0	1.7	0.05	0.9	5.0E4

Yellow Pine	01	640.0	2.85	0.14	0.9	5.0E4
Steel	01	7850.0	0.46	45.8	0.95	5.0E4

The table 2 shows the properties of surfaces used in the design.

Table 2: Properties of surfaces

Surfaces	**No. of items**	**Thickness** (m)	**Composition**	**Heat Release Rate** (kW/m^2)
Pine	01	0.01	1.0 Yellow Pine	
Upholstery		0.1	1.0 Foam	
Burner	01			1000.0
Steel	01	0.0125	1.0 Steel	

The table 3 shows the properties of devices used in the design.

Table 3: Properties of devices

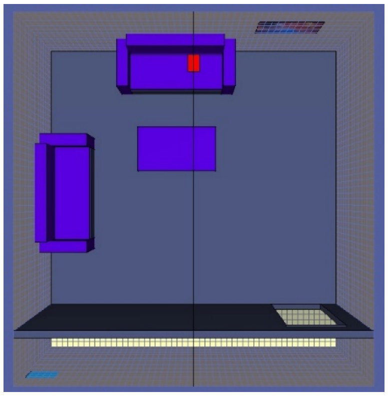
Devices	**No. of items**	**Density** (kg/m^3)	**Specific Heat** (kJ/(kg·K))	**Emissivity**	**Bead Diameter** (mm)
Thermocouple	18	8908.0	0.44	0.85	1.0

The table 4 shows properties of slice plane used on x-axis to animate and display data of defined gas phase quantity on SmokeView.

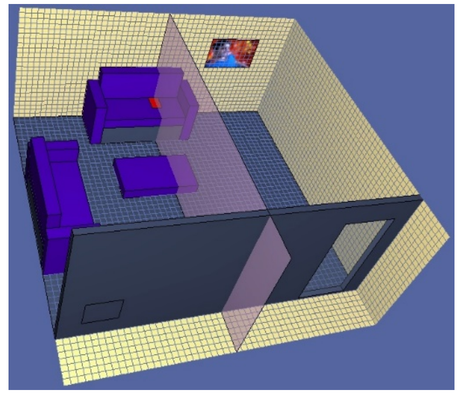
Table 4: Properties of slice plane

Results	**No. of items**	**Plane Value** (m)	**Gas Phase Quantity**
Slices	01	2.6	Temperature

The wall and floor has surface properties of steel with a 4.6m vent on the floor. A hole is created in the wall to show door which is 1.095m high and its lower is 0.05m raised from the surface. Couch-1, couch-2, and a pad are layered surfaces having the properties of foam and upholstery. A small 1000 kW/m^2 burner vent is located on couch-1 which is the source of fire and temperature. A photo vent is located 0.3m offset to the left armrest of couch-1 on x-plane at a height of 1.2m from the ground. There is one uniform mesh with 52, 54, and 24 cells on x, y, and z plane respectively. The dimensions of the mesh are 52m on x-plane, 54m on y-plane, and 24m on z-plane. A slice plane of 2.6m on x-axis is placed to display 2D contours in the SmokeView display of the results. In this analysis, we will save temperature data for future plotting. An open vent on mesh boundary exists on the model outside the door on y-plane is 0.45m wide and 0.4m high. Figure 1 (a, b) shows the design of the room.



a. Top view of room



b. Top side view of room

Figure 1: Design view of room

4.1 Placement of Temperature Sensors (Thermocouple)

The placement of two levels of temperature sensors is being proposed here as a criteria for detection of fire. A total of 18 sensors are placed across z-plane with each of nine sensors at a height of 1.2m and 2.1m on lower and upper levels respectively. The upper level is named first layer and the lower level is named as second layer. The sensors are 0.7m apart from the mesh boundaries except sensors THCP-A1, THCP-A2, THCP-B1, THCP-B2, THCP-C1, and THCP-C2 which are 0.7m apart from the wall. The distance among the sensors on y-plane is 1.6m and on x-plane is 1.9m respectively. Figure 2 shows the placement of temperature sensors in the room.

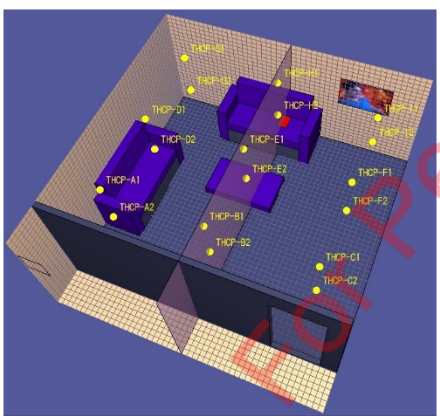


Figure 2: Arrangement of sensors on z-plane

4.2 Fire Detection Criteria

The criteria to detect fire is proportional to the two quantities i.e. standard deviation and rate of change in temperature. The standard deviation and average rate of change in temperature is calculated by Equation 1 and Equation 2.

Standard Deviation:

$$\boldsymbol{\sigma}\ (°\mathrm{C}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ Equation.1$$

Where, $\boldsymbol{\mu}$ is the mean of all temperature values, $\boldsymbol{x_i}$ are the individual values of temperature, and $\boldsymbol{N}$ is the total number of temperature values returned by simulation in 120 seconds.

Average rate of change:

$$\boldsymbol{m}\ (°\mathrm{C}/s) = \frac{Change\ in\ y}{Change\ in\ x} = \frac{f(b)-f(a)}{b-a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ Equation.2$$

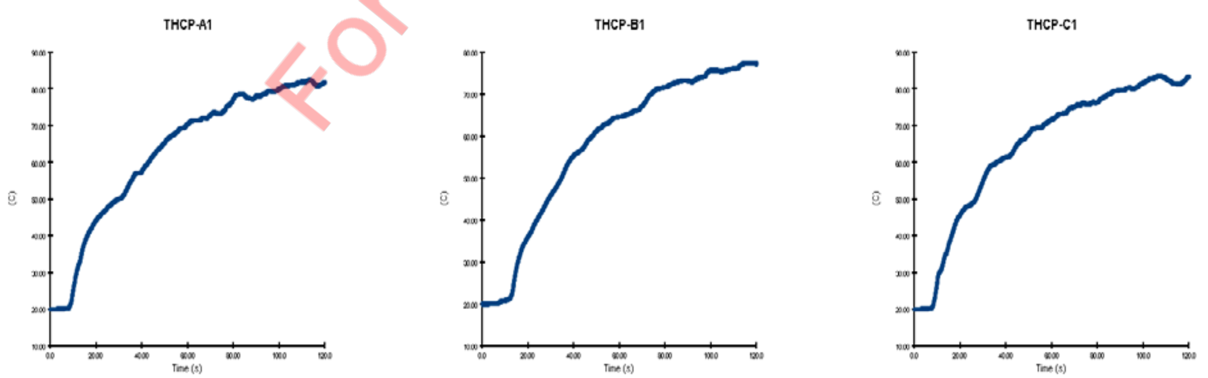
Where $\boldsymbol{f}(\boldsymbol{b})$ and $\boldsymbol{f}(\boldsymbol{a})$ are the upper and lower values of temperature and $\boldsymbol{b}$ and $\boldsymbol{a}$ are the upper and lower values for time.

5. Simulation

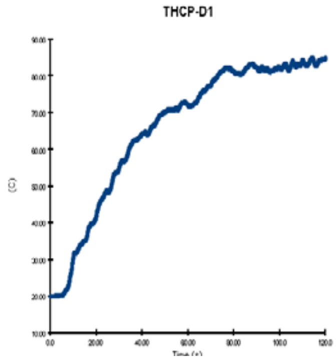
A fire simulation of 120 seconds on the super computer "Polytechnic" was performed to discuss our results through temperature graph, standard deviation of all temperature values of a sensor and rate of change in temperature by time. The simulation returned 1001 values of temperature (°C) in 120 seconds.

6. Results

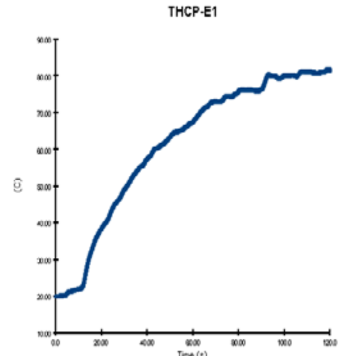
The results indicate that thermocouples (temperature sensors) placed on the upper level showed steady climb of temperature with a high standard deviation and rate of change as compare to the lower level sensors that showed sudden up and down trends of non-linearity on the graph. Figure 3 (a, b, c, d, e, f, g, h, i) and Figure 4 (a, b, c, d, e, f, g, h, i) shows graphical representation of temperature on each sensor of upper and lower level respectively.



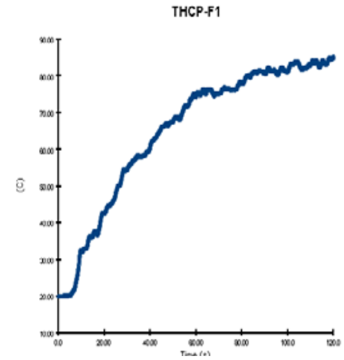
a. Temperature sensor A1 **b.** Temperature sensor B1 **c.** Temperature sensor C1



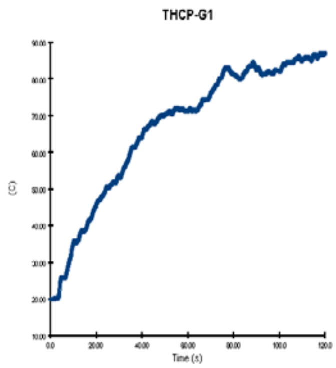
d. Temperature sensor D1



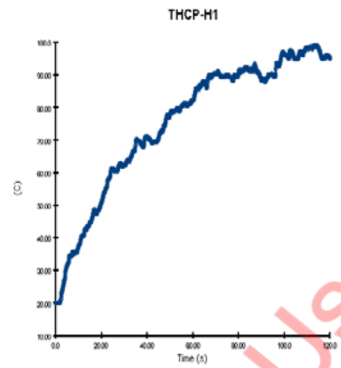
e. Temperature sensor E1



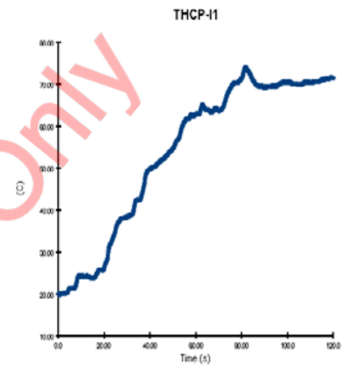
f. Temperature sensor F1



g. Temperature sensor G1

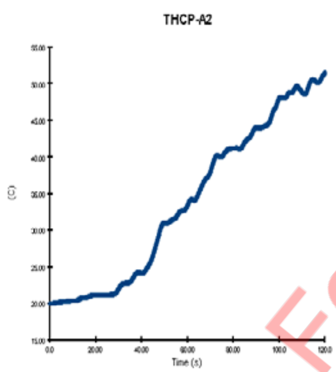


h.Temperature sensor H1

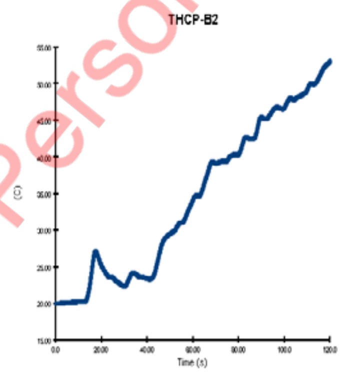


i. Temperature sensor I1

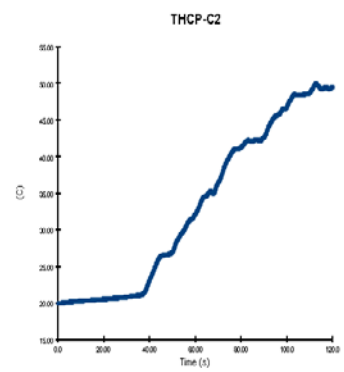
Figure 3: Graphical representation of temperature data on the upper level



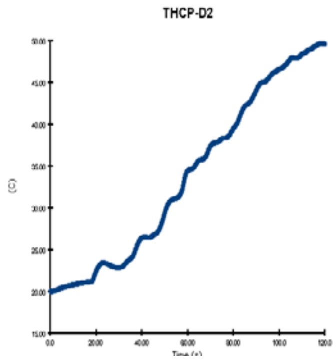
a. Temperature sensor A2



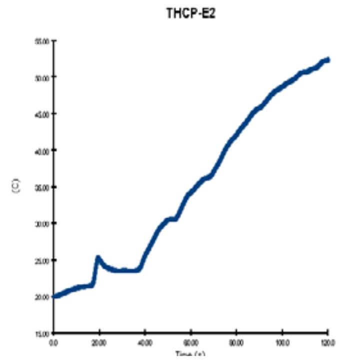
b. Temperature sensor B2



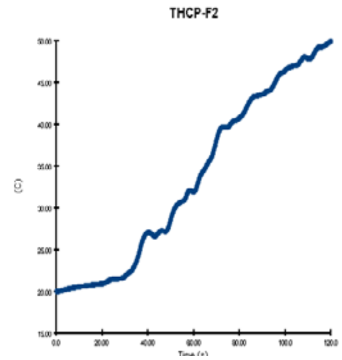
c. Temperature sensor C2



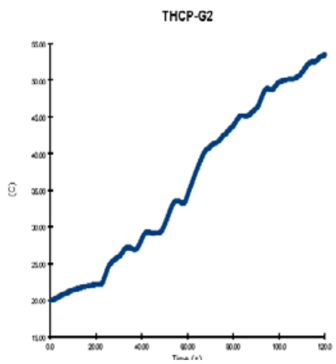
d. Temperature sensor D2



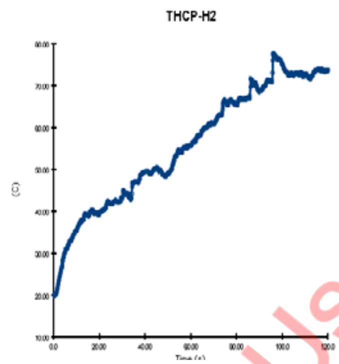
e. Temperature sensor E2



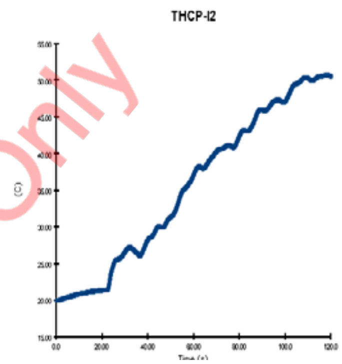
f. Temperature sensor F2



g. Temperature sensor G2



h. Temperature sensor H2



i. Temperature sensor I2

Figure 4: Graphical representation of temperature data on the lower level

The table 5 shows values of standard deviation on each temperature sensor.

Table 5: Values of standard deviation ($\boldsymbol{\sigma}$) on each temperature sensor

	THCP-A1 (ºC)	**THCPB1** (ºC)	**THCP-C1** (ºC)	**THCP-D1** (ºC)	**THCP-E1** (ºC)	**THCP-F1** (ºC)	**THCP-G1** (ºC)	**THCP-H1** (ºC)	**THCP-I1** (ºC)	**THCP-A2** (ºC)	**THCP-B2** (ºC)	**THCP-C2** (ºC)	**THCP-D2** (ºC)	**THCP-E2** (ºC)	**THCP-F2** (ºC)	**THCP-G2** (ºC)	**THCP-H2** (ºC)	**THCP-I2** (ºC)
$\boldsymbol{\sigma}$	18.8	18.5	18.9	19.7	19.6	19.2	18.8	21.0	18.0	10.8	10.7	11.0	10.2	10.9	10.4	11.1	14.5	10.5

The table 6 shows values of rate of change on each temperature sensor.

Table 6: Values of rate of change ($\boldsymbol{m}$) on each temperature sensor

	THCP-A1 (ºC/s)	**THCPB1** (ºC/s)	**THCP-C1** (ºC/s)	**THCP-D1** (ºC/s)	**THCP-E1** (ºC/s)	**THCP-F1** (ºC/s)	**THCP-G1** (ºC/s)	**THCP-H1** (ºC/s)	**THCP-I1** (ºC/s)	**THCP-A2** (ºC/s)	**THCP-B2** (ºC/s)	**THCP-C2** (ºC/s)	**THCP-D2** (ºC/s)	**THCP-E2** (ºC/s)	**THCP-F2** (ºC/s)	**THCP-G2** (ºC/s)	**THCP-H2** (ºC/s)	**THCP-I2** (ºC/s)
$\boldsymbol{m}$	0.507	0.501	0.501	0.520	0.533	0.515	0.508	0.565	0.488	0.309	0.303	0.312	0.292	0.312	0.298	0.318	0.412	0.303

The value of standard deviation and rate of change on THCP-H2 located 0.6m (practically closest to fire) above the fire is 14.5ºC and 0.41ºC/s respectively. Whereas, the sensor THCP-H1 located 1.5m above the fire showed a standard deviation and rate of change of 21.0ºC and 0.56ºC/s respectively. The low value of standard deviation on THCP-H2 despite closest to fire is due to the high radiations of heat that produce sharp incline and decline in temperature which is also evident from the graphical data. The rate of change is also very high on top level of sensors. The fire therefore, is located in $0.6m^3$ proximity of sensor across x-y-z plane. To conclude, the onset of fire is close to sensor THCP-H2 that shows high fluctuation in rate of change with time.

7. Advantages of the Proposed Criteria

The lower level sensors deflect a temperature change quickly which may be used as a criteria for temporary heat change due to any un-wanted factor. Proportionating the data of the two different level sensors in an if-else-criterion is useful to nullify the fake alarms. This technique can also be applied on the data of all sensors to rely in an and-or-mechanism to initiate a fire emergency response. Moreover, it can detect the onset of fire in the range of a sensor through examining the highest value of rate of change. A criteria can also be set to not alarm till the slope or rate of change of temperature is constant.

8. Conclusion

The article discussed how to detect fire using standard deviation and rate of change using two levels of temperature sensors. The upper level sensors showed a high standard deviation and rate of change in temperature as compared to the lower level sensors which concludes a fact that a small deviation in temperature does not always mean a fire unless it is seconded by the data of another level sensor. PyroSim is used to model the entire simulation on FDS's Navier-stokes equation whereas, SmokeView illustration was used to view results of the simulation. The super computer polytechnic was used for the simulation.

9. Future Research

This research presents useful insights in to fire simulation and temperature. It is interesting to find out a temperature threshold in the premises especially when various heat producing equipment is present in the experimental model. The information when combined with data of upper and lower level can then be used to trigger a fire emergency response.

The known coordinates of the sensors, the fire, and the temperature data on a timeline can be trained on a neural network to devise an intelligent machine which shall track temperature changes to predict fire and its coordinates in the model.

10. References

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