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Data Fusion and Internet of Things (IoT) Approach in Fire Disaster Management

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Abstract— This paper presents Data fusion and Internet of things (IoT) approach in Fire Disaster Management. Data fusion techniques in Internet of Things were used for predicting and detecting early fire outbreaks in households and industrial premises. Smoke, temperature and voltage measurement sensory data were used in the system for early fire detection. Action Research Methodology was adopted in carrying out research and UML was used as design tool. The architectural design consists of contextual information such as smoke, room temperature and electricity voltage level as an input. The system was implemented using JavaScript and PHP environment to verify the performance of the proposed system. Dynamic simulations were performed using a real time data obtained from River State Fire Service, Port Harcourt, Rivers State, Nigeria. The performance of the proposed system indicates that data fusion-based system with the use of smoke, temperature and voltage detector is able to detect fires more reliable and highly accurate from the fire detection unit than one sensory data. The results were promising indicating the real state of fire outbreak prediction

***Keywords*—** Data fusion, context awareness, Internet of Thing, multi-sensors, smart environments, disaster detection

I. INTRODUCTION

The advancement in the field of computers and usage of multi-sensor in IoT environments, context awareness and data extraction has attracted the attention of many researchers. The basic problem in multisensory systems is to integrate a sequence of observations from a number of different sensors into a single best estimate of the state of the environment. Therefore, data fusion has been proposed to address this situation. The multi-sensor system poses several challenges include getting actual information from big data with high accuracy, greater efficiency in processing power, decreasing in power consumption and so on. Data fusion includes the theory, techniques and tools used in combining sensory data into a common representational format [1]. Data fusion techniques are used for efficient data processing with lesser uncertainty and reduction in energy consumption [2]. It deals with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats, and their significance [3]. This type of systems are now widely used in various areas such as sensor networks, robotics, video and image processing, and intelligent system design, object recognition, environment mapping, and localization [4]. Internet of Things (IoT) is a network that connects uniquely identifiable things to the Internet. The Internet of Things connects real world objects to each other to form many embedded system including fields such as electronic and sensors through which the data can be transferred and received reliably [5]. IoT is a major producer of big data..Data in IoT is dynamic and heterogeneous which lead to inadequacy of simple single source analysis method [6]. Timely fusion, analysis of big data acquired from IoT for reliable, accurate and efficient decision making in ubiquitous environment is a great future challenges [7].

Disasters are hazardous events that are the result of the uncertainties of nature. When such disasters intersect with human society then it results in tremendous destruction, causing innumerable casualties, and also becoming a key driver of unfortunate consequences. Fire hazards are fatally dangerous and denigrating regarding business and homes, therefore devastating to human life. The obvious way to minimize this kind of loss is to respond to these emergency situations as quickly as possible. While the source of recurrent fire outbreaks in Nigeria is a known problem, no attempt has been made by the Government or private organizations to address this issue in the country, even till this present day. This paper presents the development of an optimizing predictive system, using a data fusion technique and Internet of Thing (IoT) for fire disaster management.

This was approached through the: development of a fire predictive system using a modified data fusion technique and evaluating the system, using acquired data from a reputable fire services companies that will be useful to safety management agent in predicting fire outbreak in the environment. This study will influence the development of preventive fire outbreak monitoring systems in several ways. In the first instance, it would enable fire-fighting professionals better understand and appreciate the value of preventive fire-outbreak monitoring using a model-based approach. Secondly, it will serve the purpose of real-time integration of computing with data from field and case studies. Using benchmarks and case histories will also assist Artificial Intelligence (AI) researchers and robotic software developers in building fire-monitoring systems in the future. The latest technologies, multi-function sensors, wireless sensors and real-time control via the internet will improve safety and reduce false alarms.

The rest of the paper is organized as followed: section I contains introduction, Section II contains the Related Work on the proposed systems, section III contains the methodologies of the system, section IV is the system design which contain the architectural design of the proposed system, section V describes the results and discussion, and section VI concludes the research work.

II. RELATED WORK

Data Fusion in the Internet of Things (IoT) plays a significant role in smart city application deployment. Smart city applications depend on sensor fusion capabilities in the cloud from diverse data sources. Concept of IoT and detail of ten different parameters that govern sensor data fusion evaluation framework were presented. The current state-of-the art in sensor data fusion was evaluated against sensor data fusion framework [8]. Context aware concept is adopted in combination with data fusion to address various challenges in IoT middleware. This project work focuses on middleware using context-aware mechanism and framework to get automated inferences of the surrounding environment. A novel Multi Sensor Data Fusion approach for context-aware system is proposed based on Dempster Shafer Theory (DST) [9]. A fire detection system with multi-sensor technology that applies the Dempster-Shafer theory to improve overall accuracy and the reliability of the entire system by minimizing the interval of uncertainty probability was presented. The proposed system operates in three stages: measurement, data reception and alarm activation, where an Arduino is tasked with measuring and interpreting the readings from three types of sensors; smoke, light and temperature sensor [10]. Scalability is a challenging task in a distributed environment which is also heterogeneous and dynamic such as IoT. In Internet of Things, a significant issue is that suddenly a number of sensors can awake and add several nodes. The data fusion algorithm must be efficient to deal with these kinds of situations. In order to address this issue, sub – optimal algorithms such as channel filter, Naïve fusion and Chernoff fusion data fusion approach were analyzed [11]. Data accuracy, data aggregation delays and network lifetime maximization are challenging in data fusion mechanisms where a small fraction of low-quality data in the fusion input may negatively impact the overall fusion result. A fuzzy-based data fusion approach for IoT is proposed with the aim of increasing the quality of service (QoS) by reducing the energy consumption of the sensor network. The proposed approach is able to distinguish and aggregate only true values of the collected data thus reducing the burden of processing the entire data at the base station [12]. In IoT environment information fusion can be used in various areas to enhance the IoT ubiquitous aspect. Timely fusion, analysis of big data acquired from IoT and other sources, to enable highly efficient, reliable, and accurate decision making and management of ubiquitous environments would be a grand future challenge. In this research work, data fusion for IoT with a particular focus on mathematical methods including probabilistic methods, artificial intelligence, theory of belief and specific IoT environments include, heterogeneous, nonlinear and object tracking environments were discussed [7]. Data fusion techniques are employed to provide a meaningful representation of the sensor outputs. In order to interpret the complex multidimensional information provided by these sensors, principles of data fusion and many of the foundation techniques that can be used to perform data fusion on wearable sensor data were presented. In order to augment wearable sensor technology potential directions for research and issues such as data collection, algorithm training, quality of data, infrastructure and the potential fusion of wearable sensors with other external data sources were described [13]. Smart environments will rely on smart sensing for constant data collection for event detection and prediction. The use of multi-UAVs to interconnect devices of wireless sensor networks during natural disaster management was proposed. This paper proposes an end to end smart system for disaster detection, prediction, and response for smart cities [14].

III. METHODOLOGY

The system explored two methodologies which are the research methodology and the system design methodology. For the research methodology, Active Research Method was used. Action Research (AR) Methodology was adopted in carrying out this research work. This is a collaborative progressive problem-solving methodology is well suited for researchers and organizational practitioners [15]. It follows “learning by doing” approach, that is to say that individuals or a team of researchers identifies a problem, do what they can to resolve the problem, see the level of success they have made so far, and if the target is not met, they try again. The

Susan cycle (spiral) approach was strictly followed, since the whole purpose of action research is to determine simultaneously an understanding of the social system and the best opportunities for change in any system [16], [17]. In-line with system design methodology, Rational Unified Process was used (RUP). The RUP aims at ensuring the production of high-quality software that meets the needs of its end-users, within a predictable schedule and budget [18]. RUP development team works in collaboration with the customers, partners, Rationale's product groups as well as Rationale's consultant organization, to ensure that the process is continuously updated and improved upon to reflect recent experiences and evolving and proven best practices [19]. An RUP activity creates and maintains models and emphasizes the development and maintenance of model semantically rich representations of the software system under development [20]. RUP is a guide for how to effectively use the Unified Modelling Language (UML).

IV. SYSTEM DESIGN

In the proposed system, wireless sensor hardware is trained using data fusion and Internet of Things. These sensors are placed in an unattended environment for fire prediction. The technique evolves using fusion level parameter which is the reference to get the decision that will be used for early fire prediction. When there is an input signal from the sensors, multi sensory data then filtered to avoid false positive alert. The three parameters used are smoke measure in percent, room temperature measured in degree and electricity voltage measured in voltage.

A. Effectiveness of Data Fusion and Internet of Things in Fire Outbreak Prediction System

To interpret the sensor data, three main hierarchical levels at which data fusion takes place are commonly used: signal level data fusion (sometimes referred to as direct or raw data fusion), feature level fusion, and decision (symbolic or inference) level fusion. Signal level fusion can be applied to combine commensurate data i.e. data measuring the same property directly.

Decision level fusion is performed at the highest level of abstraction from sensor data and can be based on raw data, features extracted from the raw data, and symbols defined at the feature level fusion to make higher level deductions. Probabilistic methods are commonly used at the decision level due to the high levels of uncertainty. However other methods that are also tolerant of uncertainty can also be used including artificial intelligence, internet of things. Signal level fusion method combines commensurate information by taking an average of all the sensors reading. The contribution of the "worst" sensor's error will be alleviated in the final estimate, although not eliminate it completely. To reduce the impact of large erroneous sensor readings weighted averages can be used.

Mathematical model of data fusion is given below:

In the Data fusion system, the detection values of each sensor; room temperature (T_x), electricity voltage (V_x) and smoke (S_x) were acquired by data fusion decision centre. These values were considered and multiplied with correction factor of each parameter and final decision "FD" was determined. The correction factor is ranging from 0 to 1to achieve more or less equalized sensitivity.

The general fire detection algorithm with sensor fusion;

$$FD = (AvgT_x.CF_t + AvgS_x.CF_s + AvgV_x.CF_v)/3 \quad (1)$$

Where

$AvgT_x$ is the average temperature sensor readings

$AvgS_x$ is the average smoke sensor reading

AvgV_x is the average voltage detector readings

CF_t is correction factor for temperature sensors readings

CF_s is correction factor for smoke sensor readings

CF_v is correction factor for voltage detector readings

If FD > Threshold values

There is a fire

B. Fire Disaster Predicting System Using Data Fusion and Internet of Things

The system is desired to monitor the environmental condition for change in smoke, temperature and voltage level over time and trigger alert once approaches a restricted value or a set threshold.

The architecture of system is shown below.

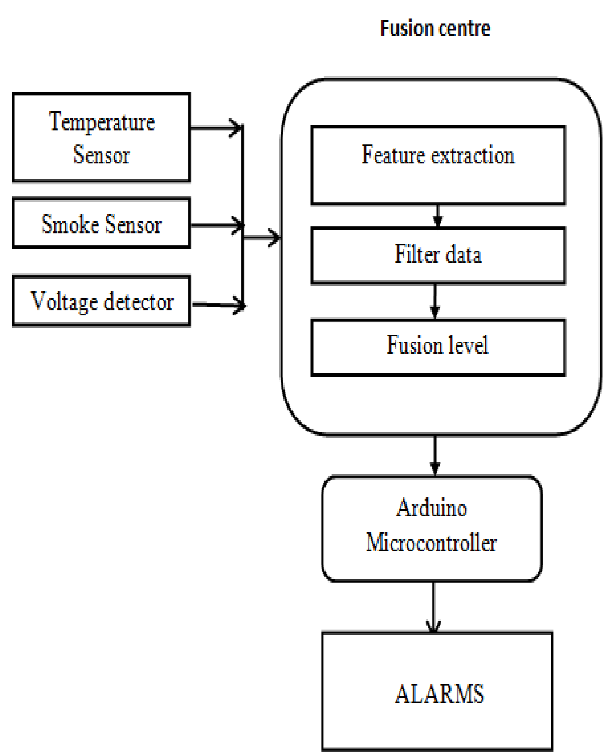

Figure 1: Proposed System Architecture

The wireless sensor network collects sensing data, analyses it and accurately trigger a fire alarm. The system performs different parameter measurements for early detection of fires. When the output value is above the threshold range the sensors will be activated and give the signal to the microcontroller. The controller will activate the buzzer system and alert the station.

A. Data Acquisition Centre

These consist of smoke, temperature and voltage detection sensor: this sensor is responsible for detecting change in smoke, temperature and voltage in the households or factory premises.

B. A Microcontroller

This governs the wireless sensing device and controls the data acquisition from the specified sensors, the signal processing, data management and communications. The output signal of the analog sensor is converted to a binary value the analog to digital converter of the microcontroller.

Figure 1 captures a typical scenario in which wireless sensors are deployed to monitor environment for early fire prediction. The data fusion subsystem keeps track of the sensed signals in the memory module and then passes these signals to the control subsystem (prediction module), which combines the individual parameter corresponding to each piece of contextual information into a value that would be used to indicate situations that poses danger and the one that does not.

V. RESULTS AND DISCUSSION

To evaluate the performance of the system, the system was tested using feature dataset from River State Fire Service, Port Harcourt, Nigeria. Results of tests have been tabulated in fig. 1 using the specified network parameters (see fig. 2). The results show simulation reports after several runs of system. In the proposed system, three parameters were used namely; electricity voltage (v), room temperature (degree) and smoke (percent); a threshold is set for each parameter. The system was tested in a confined environment with three sensor nodes, which are arranged in 2 meters apart to each other. The sensor node is implemented for detection of smoke level, room temperature and the electricity voltage. Sensors detect and sense environment for parametric level which is compared to the minimal threshold value pre-set before sending a signal to the control room.

A. Detecting Fire Outbreak

The proposed hardware and software solutions were validated and the functional performance features of the devices such as range, flexibility and robustness were assessed. The use of smoke, temperature and voltage detectors increases the reliability of the system and reduces the false alarms. The alarm detection algorithm relies on the joint detection of the three parameters. The detector constantly monitors the three input variables and makes a real-time selection of a suitable linear combination. The set threshold is given to be 0 -89 for normal while 90 and above for fire outbreak prediction. For electricity voltage, when the voltage is 270v and above, the system predicts danger, room temperature when the heat in the room rise to 40 degree and above, likelihood of danger and smoke is set to be 60 percent and above which poses threats of fire outbreak. Using electricity voltage, room temperature and smoke level to monitor the context, state of 0-89 is normal, if it is greater than or equal to 90 there is likelihood for fire outbreak. The system will indicate Danger else it should show Normal. Therefore at 90 and about node sensor are likely to show danger and should be attending to immediately before it will lead to fire outbreak.

Table 1. Simulation Result

Time (hrs)	**Room Temperature (degree)**	**Electricity voltage (v)**	**Smoke (percent)**	**Result**
1.00	31	210	10	84
2.00	26	220	5	83
3.00	34	360	80	**158 Danger**
4.0	29	110	3	47
5.0	15	240	3	86
6.0	31	210	2	81
7.0	21	200	4	75
8.0	20	215	5	80
9.0	39	210	74	**107 Danger**
10.0	20	240	9	89
11.0	35	230	1	88

Table 2: Threat Events Prediction Table based on simulation Result

Input Parameters		**Label**	**Output (percent)**		**Label**
Electricity Voltage (V)	0 - 270	Normal	Result	0-89	Normal
	270 - Above	Danger		90-Above	Danger
Room Temperature (Degree)	0 - 40	Normal			
	40 – Above	Danger			
Smoke (Percent)	0 - 59	Normal			
	60 – Above	Danger			

To evaluate the performance of the system, the system was tested using feature dataset from River State Fire Service, Port Harcourt, Nigeria. Results of tests have been tabulated in Table 4.1 using the specified network parameters. The results show simulation reports after several runs of system.

In the proposed system, three parameters were used namely; electricity voltage (v), room temperature (degree) and smoke (percent); a threshold is set for each parameter. The system was tested in a confined environment with three sensor nodes, which are arranged in 2 meters apart to each other. The sensor node is implemented for detection of smoke level, room temperature and the electricity voltage. Sensors detect and sense environment for parametric level which is compared to the minimal threshold value pre-set before sending a signal to the control room.

Table 2 further shows the breakdown of the predicted output of Table 1. Hence, giving the threshold values for each input parameter and the label which can be either 'Normal' or 'Danger' when the sensors senses a given threshold value.

B. Graphical Representation

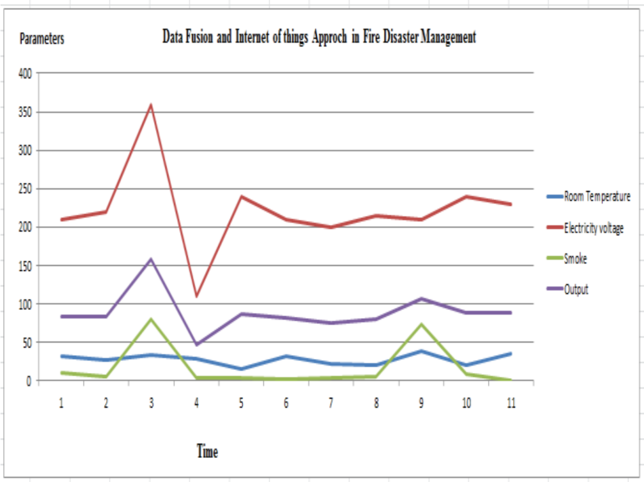

Figure 3: Graphical Representation of the Data

A plot of the predicted output parameter against time is shown in Figure 3. Firstly, the red line indicates the rising and dropping of electricity voltage at different time intervals, the green line indicates smoke level, the blue line indicates the room temperature in degree and the purple indicate danger (Output) in at different time interval.

At 1pm, the electricity voltage was at 210v while the smoke was at 10 percent and the room temperature rise to 31 degree given an output of 84 indicates no threat at this point. The sensor is not activated because is below the threshold value set for danger.

At 3pm, the electricity voltage rises to 360v and temperature is 34 degree causing smoke to increases to 80 percent. Within the same time interval, the sensor was activated and send a threat alert to the control room because it's about the threshold value set for electricity voltage, a likelihood of fire outbreak.

At 4pm, the room temperature was at 29 degree while the electricity voltage was at 110 v and smoke drop to 3 percent resulting to an output of 47 meaning no danger or likelihood of fire outbreak.

At 9pm, smoke rise to 74 percent causing the sensor to be activated because is above the threshold value for smoke while the electricity voltage is at 210v and room temperature rise to 39 degree. At this point the output was 107, thus the systems send an alert to the control room predicting fire outbreak.

C. Evaluation of the Result

In this project, we developed a predictive system using data fusion technique to predict fire outbreaks. The Data fusion approach has the primary advantage of evolving a set of sub-optimal states with the hope that this will gradually generate the most likely candidate (optimal) state that best describes the input observation and hence give a more accurate result or prediction and avoiding false alarm system compared to when using only internet of thing in predicting fire outbreak.

VI. CONCLUSION

Fire outbreaks are serious problem in societies that may lead to large loss of lives/ or properties. In Nigeria, for instance there have been increases in damages due to fire outbreaks particularly in households, industrial and busy environments. This system would enable fire-fighting professionals better understand of the fire outbreaks and appreciate the value of preventive fire-outbreak monitoring using a model-based approach. The performance of the proposed system indicates that data fusion-based system with the use of smoke, temperature and voltage detector is able to detect fires more reliable and highly accurate from the fire detection unit than one sensory data. The results were promising indicating the real state of fire outbreak prediction.

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