A MODEL OF AUTOMATIC FIRE DETECTION AND SUPPRESSION SYSTEM WITH IMPROVED EFFICIENCY

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ABSTRACT

This work develops an improved automated fire management scheme on leveraging mathematical formulations by integrating signal detection filters for the detection of predetermined signal properties, adopting a scheme for energy release prediction as an efficient means of reducing both rate of false alarm/the rate of failure to alert and finally tuning the microcontroller using PID control. These three formulations are then enshrined and implemented through the control program in the microprocessor of the proposed system. These mathematical formulations would help improve the overall response of the system by ensuring it minimizes to the barest minimum, cases of false alarm triggering and false response to what is not fire. The simulation model leveraging on the mathematical models of the algorithms enumerated then characterizes the behaviour of the system. The simulation model is characterized with PROTEUS ISIS 7.8 to give a true life scenario. The proposed system would work in real time when fire is detected, alert the occupant and start suppression immediately, thereby minimizing collateral damage and fatality.

Keywords: Fire Alarm, Signal Filters, Energy Release Prediction, PID Control, Microprocessor.

1.0 INTRODUCTION

The problem of low productivity and loss posted by many companies/industries today in Nigeria can be as a result of loss of valuable industrial equipment and manpower due to lack effective and efficient fire detection and suppression systems. In other words adequate and sufficient measures to control and manage fire outbreaks in our homes, offices industries/companies etc. have continued to undermine production, profit and developments in the country due to the negative effects imposed by this hazard. More so, the huge losses experienced by business owners and properties which has been affected by fire outbreak has rendered many people jobless ,homeless and has also contributed to huge economic loss to the country.

This ugly situation created by fire disaster has led to the quest for more proactive system to control emergency such as fire outbreak in our homes, offices, churches and industries by exploring the capability of an automatic fire management systems since it may not be feasible for humans to monitor this physical condition such as fire especially in some remote and restricted areas.
It is then of very high importance to deploy effective and sustainable automatic/intelligent fire system which can detect, alert and suppress it thereby protecting human lives, economic loss and property.

A fire detection and suppression system is a specialized system which may incorporate some mechanical functions of a valve, piping and pressure gauge, etc. The existing fires suppression systems are mostly manual and therefore their time response is slow. There is need for an automated system which would enable faster response (since it is automated) and would have the ability to send SMS sent out to any authority responsible for fire control while the valve opens automatically, allowing spray of water on the particular area or zone where the fire is detected.

This system is programmed to spray water and observe the temperature and other parameters like energy level, once these parameters like temperature returns to normal, the fire sprinkler system automatically stops.

2.0 LITERATURE REVIEW

Leonardo da Vinci designed a sprinkler system in the 15th century. Da Vinci automated his patrons' kitchen with a supper-over and a system of conveyor belts. In a comedy of errors, everything went wrong during a huge banquet when a fire broke out; the sprinkler system worked all too well causing a flood that washed away all the food and a good part of the kitchen. This system too failed to address the issue of water control (Hall *et al*., 2013.)

Ambrose Godfrey created the first successful automated sprinkler system in 1723.He used gunpowder to release a tank of extinguishing fluid. The world first modern recognizable sprinkler system was installed in the Theatre Royal, Drury Lane in the United Kingdom in 1812 by its architect. The system was designed by Sir William Congreve using a perforated pipe along a ceiling and a valve place outside the house. (Gelb, *et al.*,)The apparatus consisted of a cylindrical airtight reservoir of 400 hogsheads (95,000 liters) fed by a 10-inch (250mm) water mains which branched to all parts of the theater, a series of smaller pipes fed from the distribution pipe were pierced with a series of ½ inch(13mm)holes which pours water in the event of fire. This system failed to address the problem of detecting a fire outbreak.

A large furniture factory had repeatedly burned down and in a bid to forestall further collateral damage Hiram Stevens Maxim was consulted on how to prevent a repeat occurrence. As a result of this, Maxim invented the first automatic fire sprinkler. It would douse the areas that were on fire. Maxim was unable to sell the idea elsewhere, but when the patent expired the idea was used.(Wormald, *et al.*,)

Philip W. Pratt of Abinghton, M.A. in 1872 first experimented with automatic sprinkler system, but was unable to sell his idea and the patent expired. Henry S. Parmalee of New Haven, CT, created and installed the first automatic fire sprinkler system in 1874, using solder that melted in a fire to plug holes in the otherwise open water pipes. At the time he was the president of Mathusek Piano Works. Parmelee invented his sprinkler system in response to exorbitantly high insurance rates. Parmelee patented his idea and had great success with it in the U.S. Parmelee called his invention the "automatic fire extinguisher". He then travelled to Europe to demonstrate his method to stop a building fire before total destruction (Casey, 1996.) .

His invention did not get as much attention as he had planned. Most people could not afford to install a sprinkler system. Once Parmelee realized this, he turned his efforts on educating the insurance companies about his system. He talked about how the sprinkler system would reduce the loss ratio, thus saving money for the insurance companies. He knew that he could never succeed in obtaining contracts from the business owners to install his system unless he could ensure for them a reasonable return in the form of reduced premiums.

In this connection he was fortunate enough to enlist the sympathies of two men, who both had connections in the insurance industry. The first of these was Major Hesketh, who, in addition to being a cotton spinner in a large business in Bolton, was Chairman of the Bolton Cotton Trades Mutual Insurance Company. The Directors of this Company and more particularly its Secretary, the late Peter Kevan, took an interest in Parmelee's early experiments, and eventually it was to Major Hesketh, its Chairman, that Parmelee owed his first order for the Sprinkler Installations which were installed in the Cotton Spinning Mills of John Stones & Company, at Astley Bridge, Bolton, to be followed soon afterwards by the Alexandra Mills belonging to Mr. John Butler of the same town. Although he got a contract through his efforts, the Bolton Cotton Trades Mutual Insurance Company was not a very big company outside of its local area. Parmelee needed a wider influence. He found this influence in James North Lane, the Manager of the Mutual Fire Insurance Corporation. This company was founded in 1870 by the Textile Manufacturers' Associations of Lancashire and Yorkshire as a protest against high insurance rates. They had a policy of encouraging risk management and more particularly the use of the most up-to-date and scientific apparatus for extinguishing fires. Even though he put tremendous effort and time into educating the masses on his sprinkler system, by 1883 only about 10 factories were protected by the Parmelee sprinkler (Casey, 1996).

Back in the US, Frederick Grinnell, who was manufacturing the Parmelee sprinkler, designed a newer and more effective version which became known as the Grinnell sprinkler. He increased sensitivity by removing the fusible joint from all contact with the water, and, by seating a valve in the center of a flexible diaphragm, he relieved the low-fusing soldered joint of the strain of water pressure. By this means the valve seat was forced against the valve by the water pressure, producing a self-closing action, so that the greater the water pressure, the tighter the valve. The flexible diaphragm had a further and most important function. It caused the valve and its seat to move outwards simultaneously until the solder joint was completely severed. Grinnell got a patent for his version of the sprinkler system. He also took his invention to Europe, where it was a much bigger success than the Parmelee version. Eventually, the Parmelee system was withdrawn, which left an open path for Grinnell and his invention, yet this system could not address the problem of sprinkler stoppage when normal temperature returns. Therefore this research has taking into account all this work and related work that has been done on automatic fire detection and suppression intelligent sprinkler system and then come up with a better reformed and speed oriented system that can help man to further strengthen the security of his immediate environment.

3.0 METHODOLOGY

In this proposed system is a simulation model is designed and characterized leveraging mathematical formulation in a embedded design.

3.1 Integrated Formal Embedded Design and Simulation (IFEDS)

This research identifies an **Integrated Formal Embedded Design and Simulation** step by step starting from adaptation of mathematical models used for the proposed system to improve the fire detection capability by integrating signal detection filters for the detection of predetermined signal properties. This approach also adopts an algorithm for energy release prediction as an efficient means of reducing both rate of false alarm and the rate of failure to alert. These algorithms are then enshrined and implemented via the control program in the microprocessor of the system.
The simulation leveraging on the mathematical models enumerated then characterizes the behaviour of the system**.**

After the initial conceptualization of the proposed system, it would be followed by stage block by block design. These individual block designs would be simulated and characterized. A certain degree of formal design to gate level oriented design (design done at the component level with electronic with combinational and sequential logic) and programmable VLSI (Very Large Scale Integration) in the sense that mathematical equations for the improving the efficiency of the system viz; signal detection filter and algorithm for energy release detection (to reduce false alarms and false alerts).

The behaviour of the proposed system are embedded in the control code after gate level components are logically connected together and used to characterize various components in this system. For e.g. logical components where used in the design of the proposed system.(Wotapka, *et al.*,)

The proposed system would also have the ability to acquire temperature from the various sensor channels, store the data acquired in a standalone system that has ability to communicate with the remote agent while the system would control the fire in the vicinity with the aid of motorized sprinklers.

The proposed system also adopts a hybrid fire extinguishing systems. A relatively new fire suppression system that uses both water mist and inert gases to extinguish fires, often mixed together at the discharge nozzle. The combination of water and inert gas, working together in an extinguishing system has made hybrid water mist systems a unique classification of suppression systems.

Programmable microprocessor chips were embedded in this design to serve as the brain of the proposed system. All the logical components characterized or modelled to describe true life scenarios taking into cognizance the mathematical model for improved response to external stimuli and improved output by the system all run in a simulation environment so as to present an improved contextual model.

Proteus ISIS version 7.8 was used to develop a real life simulation scenarios using program description language which later was coded with Assembly language for embedded systems. All the logical components characterized or modelled to describe the real life scenarios. After the configurations, the model was run in a simulation environment depicting a contextual fire management scenario. The advantages of this particular approach are numerous in this methodology.

The simulation system is not faced with the problem of component failure (because virtual components are connected together under ideal conditions; factors like temperature, life span of components and others, do not come into play) or the issue of troubleshooting (in the eventuality of component or system failure, the fault would need to be detected and might even require a complete change of the affected component), which could adversely affect the overall performance of the system (Bakshi *et al.*,). Secondly, the algorithms and flowcharts used for the implementation of this methodology are much easy to comprehend. Thirdly, the code used to configure the brain of the model is machine language and after each block or module of the proposed system is developed, it is subject to review.

Again, components are easily modelled into proposed system thus enabling the designer to pass across the ideas used in conceptualizing the model. This method also leaves space for improvements in future work. The designer can incorporate more mathematical models for better responses by simply re-characterizing already existing logical components to suit his new ideas or concepts.

3.2 Tools used in design

- Program Description Language (PDL)
- Proteus 7.8 Isis
- MATLAB

3.2.1 Proteus 7.8 ISIS

This is the primary simulator used in this project. It gives the designer a platform whereby components at the gate level are logically connected together under a near ideal environment. The logical components can be characterized to emulate various stages of the design. Proteus Isis is used to develop a simulation model that can descriptively analyse the proposed system.
The proposed system also monitors the responses of the simulation model when behaving in the intended manner. It has tool boxes from which electronic, solid state or logical components can be brought together and logically connected to give us the desired results.

3.2.2 Program Description Language

For this proposed system**,** Program Description Language (PDL) which is a subset of C# can be implemented into any programming language of choice. It can be translated into VLSI languages or System on chip language or VHDL or VERILOG for Field Programmable Gate Arrays (FPGA) or Complex Programmable Logic Device (CPLD) but for the purpose of this research, assembly Language is used for the implementation of the code algorithm.

3.2.3 MATLAB

For this proposed system, MATLAB would be used to perform tuning technique for varying the parameters of the PID controller in order to achieve a desirable transient response of the system when subjected to a unit step input.

3.3 System Flowcharts

In the proposed system control process; the temperature sensors across the multi channels are used to acquire data about the current state of the environment under observation.

This information gathered by these temperature sensors are in analogue form and so would be converted to digital form by a multi- channel analogue to digital converter after which the input is feed into a microprocessor (which has tuned with the PID control mechanism, has the signal detection filters and the energy model for release prediction) and displayed on the LCD which is close to the sensors in the proposed system**.**

At the same time this information is sent to a Remote Agent Monitor who in this case could be the fire-fighting agents for the worst case scenario.
Fig 1 gives a brief overview of the operations of the proposed system

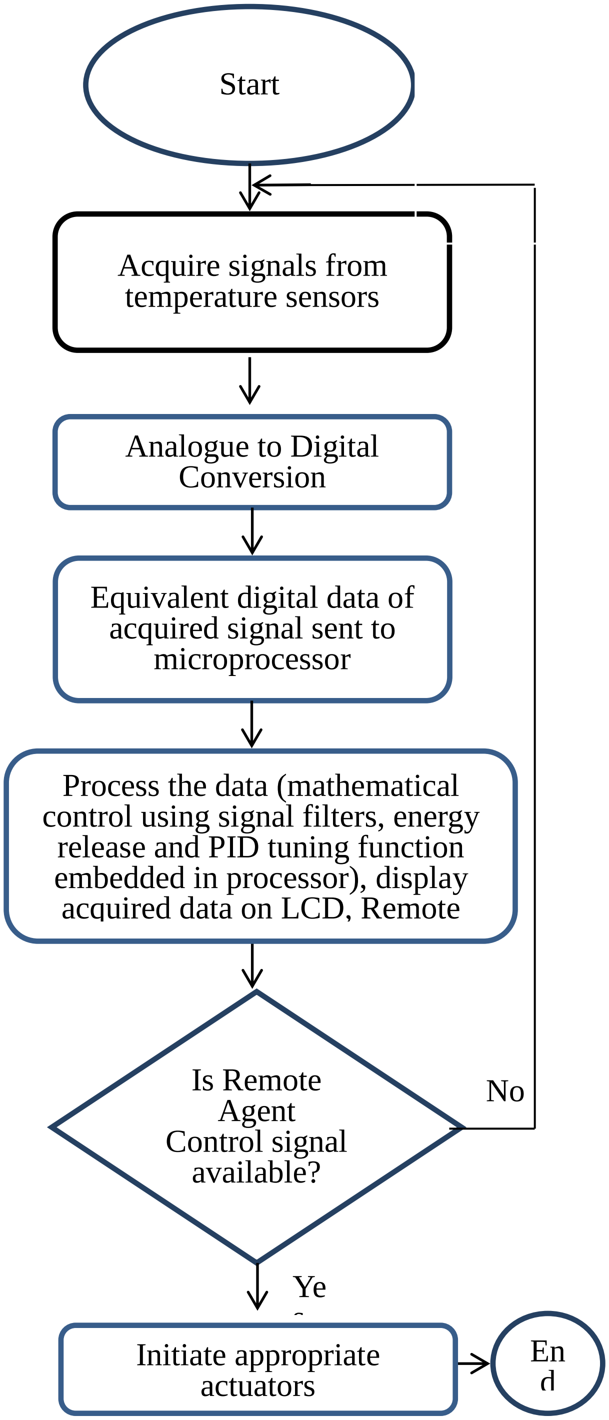


Figure 1: Flowchart for Proposed System Process.

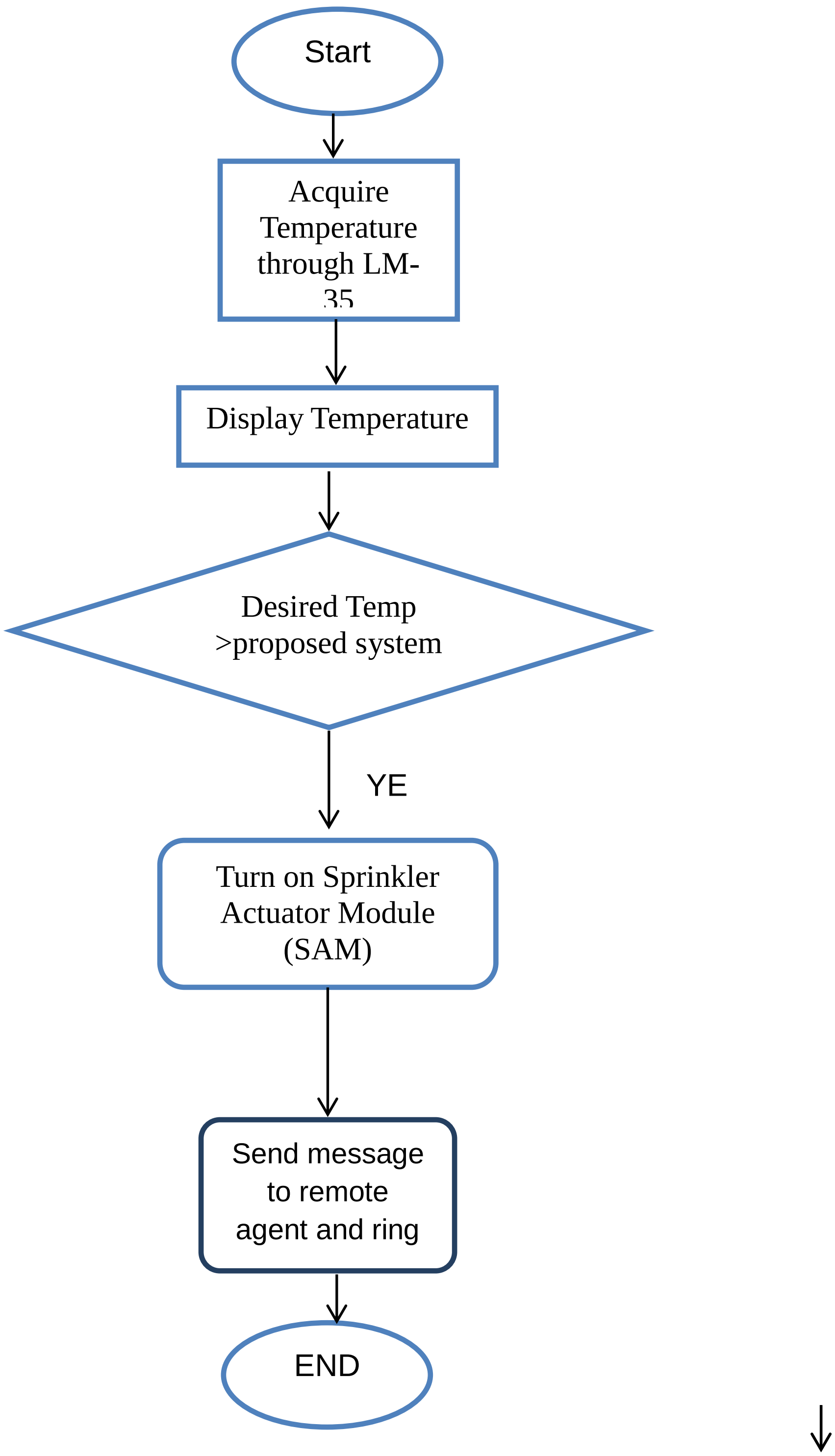


Figure 2: Flow Chart for Control in a Single Channel.

3.4 Design of Data Logging Section of proposed system

The purpose of data acquisition is to measure physical parameters from real world. Data acquisition system measures the physical parameters and displays the current value of the parameter using a computing device.

Data acquisition systems usually comprises of sensors, data acquisition hardware (DAQ unit) and a computing device. The computing device can be anything such as micro-controller, computer or Programmable Logic Controller (PLC).

A data logger on the other hand is a data acquisition system that has the ability to store the measured data and computes the data as per the requirement of the specific application as a standalone device without been tethered to a PC .

Data logger is an electronic device that automatically records, scans and retrieves the data with high speed and greater efficiency during a test or measurement, at any part of the plant with time. The type of information recorded is determined by the user in this case temperature, therefore it can automatically measure electrical output from any type of temperature transducer and log the value. A data logger works with temperature sensors to convert physical temperature and stimuli into electronic signals such as voltage or current. These electronic signals are then converted into binary data. The binary data is then easily analysed by software and stored on memory for post process analysis.

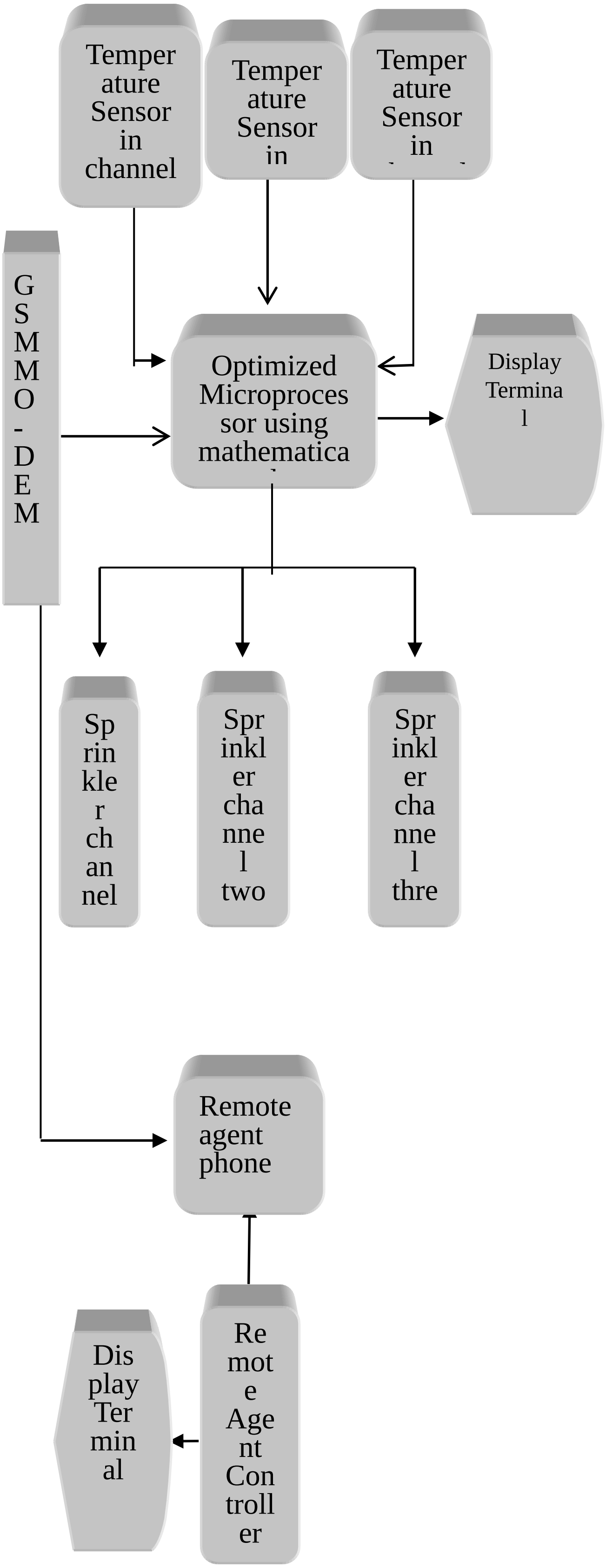


Figure 3: Block Diagram of the Proposed System Showing the Flow of Information from Rooms Under Observation to Remote Agent Centre.

In this proposed system include (as summarized in fig 3):

- Display Terminal: It shows the current status of data of the system been acquired in real time and the general status of the system at any given point in time.
- Temperature Acquisition Modules: The Temperature Acquisition module (TAM) consists of the temperature sensors in multiple channels in the proposed system**.** The role of TAM is to acquire real time temperature data from the room under observation. The microcontroller can now decide on the next line of action based on the information it gets.
- Sprinkler Actuator Modules: The Sprinkler Actuator Modules (CAM) consists of motorized muzzle devices which make use of hybrid fire extinguishing systems which is a relatively new fire suppression system that uses both water mist and inert gases to extinguish fires, often mixed together at the discharge nozzle. They receive instructions directly from the microprocessor which is activated by control signals from that optimized processor.

Microprocessor: It is this processor that coordinates all the logical operations of the proposed system**;** it senses real time temperature data from the temperature acquisition modules TAM, decides the next line of action to be carried out based on the information received and coordinates data that is sent to the Remote Agent. It is the brain behind the system. In our proposed work we optimize the response the microprocessor by leveraging on some mathematical formulations as clearly stated in the work

3.5 Program Description Language (PDL) for the Proposed System

Assembly language used in the characterization of the proposed system. A brief program description language is presented below. It summarizes the assembly language codes used to implement the system

3.5.1 Proposed system PDL

```
    START
Acquire temp across all channels with temp sensors
                DO
                        Convert analogue temp to digital signal.
                        Send data to optimized processor.
                        Process data.
                        Display data.
                        Perform desired OP via SAM.
                        Send to Remote Agent.
                END DO
            END
```

3.5.2 REMOTE AGENT CONTROL PDL

```
START
        Check for data from rooms
                DO
                        Receive signal
                        If
                                Signal persists
                                Mobilize quick response
                        Else
                                Do not action
                        End if
                END DO
END
```

3.6 Characterization of the Proposed System with Proteus 7.8 Isis

Proteus 7.8 Isis was used to characterize proposed system (see appendix for schematic capture). Proteus 7.8 provides the platform through which the proposed system was characterized.

Typical applications of Proteus 7.8 Isis include standard-based electronic and logical component feature characterization. The Proteus 7.8 Isis environment is organized into; probe/simulation environment, component editor, sub circuit editor with a comprehensive collection of simulation tools that was used to characterize the proposed system. The Proteus 7.8 Isis environment provides several modules for the simulation comprising a vast enterprise of digital and analogue tools which with friendly graphical user interface can be manipulated to achieve desired results. Key features of Proteus 7.8 Isis include;

- Detailed simulation log
- Hierarchical modes and options
- Flexibility (enabling one to manipulate custom designs and values to achieve desired target).
- An interactive animation process (allowing variable's manipulation)
- Graphic specifications

The characterization of tuning of the microcontroller with PID control mechanism is done in MATLAB. Emphasis was laid on overshoot, rise time, peak time and settling time.
The MATLAB SIMULINK was used to characterize the improved PID control for the microcontroller of the proposed system. Key features of MATLAB include:

- Object orientation
- Hierarchical modes
- Graphic specifications
- Flexibility to develop detailed custom models
- An integrated post-simulation analysis tool
- Interactive analysis

Project editor, m-script editor, model editor, function block parameter editor, probe/simulation environment and analysis environment. Also, the environment provides several modules for the simulation comprising a vast enterprise of engineering tools ranging from electronics, fuzzy logic, automation, mechanical to even biomedical engineering function design block sets.

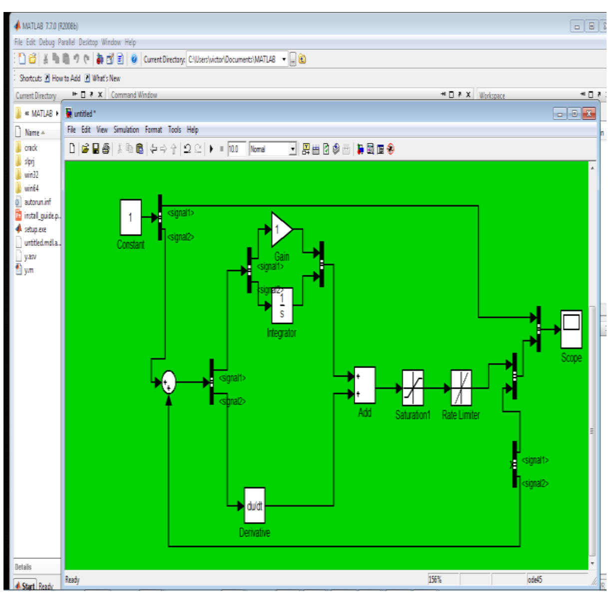


Figure 4: Simulink Block Diagram of Proposed System.

4.0 RESULTS

The results obtained from the simulation model test bed are presented in the appendix. Figure a clearly illustrates the proposed system when it has not been initialized. It can be seen that the various temperature sensors, SAM and the Remote Agent in an in active state

Figure b in the appendix clearly illustrates what happens just after initialization; at this stage of the process, temperature data is acquired and processed then sent to the Remote Agent in real time over a GSM network.

Figure c in the appendix illustrates when the control actions on the proposed system is taken place as a result of the control signal from the optimized processor

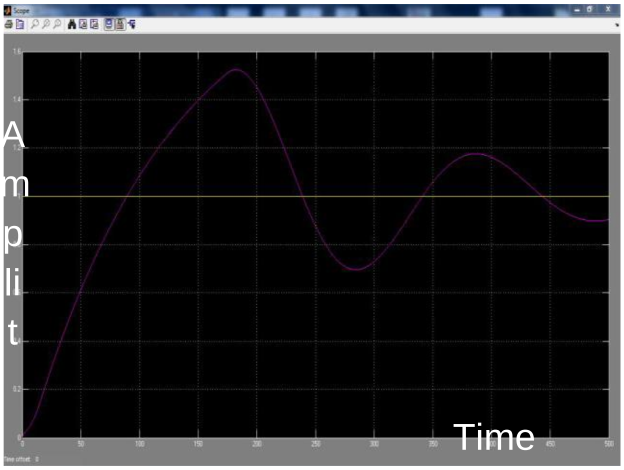


Figure 5: Scope of the unit step response of the system for test 1.

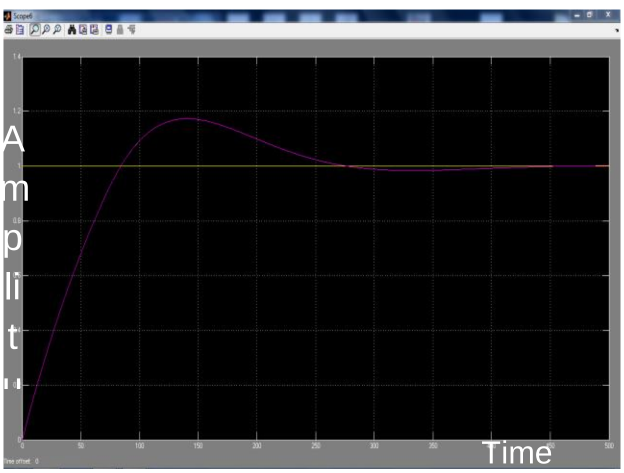


Figure 6: Scope of the unit step response of the system for test 2.

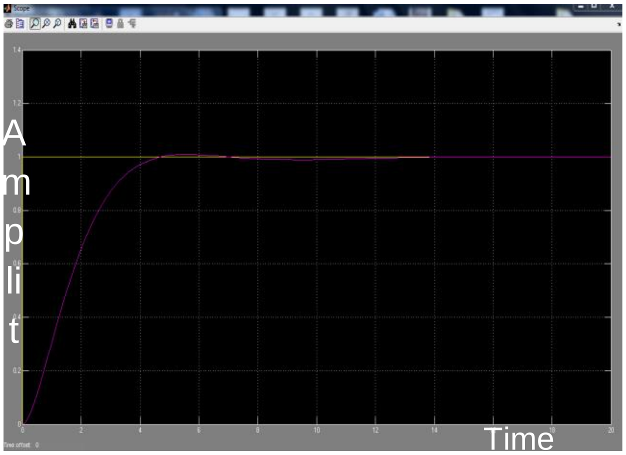
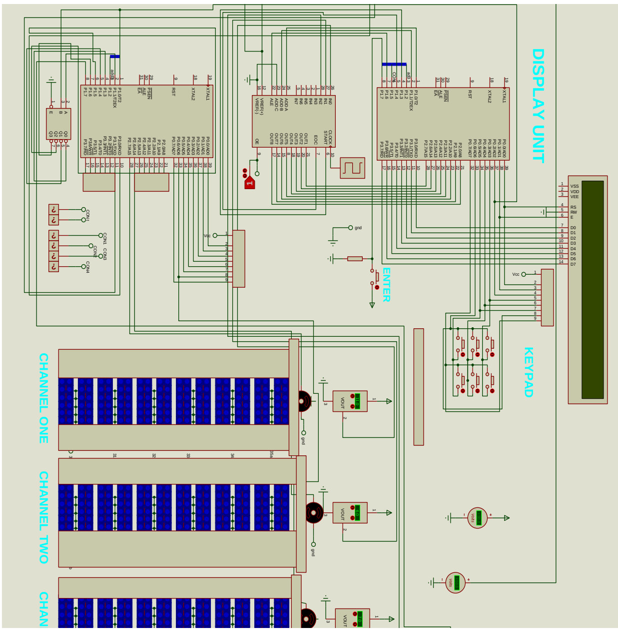


Figure 7: Scope of the unit step response of the system for test 3.

Using Matlab/Simulink toolbox, various parameters were tested and the best parameters were used for PID tuning for optimization of the microcontroller.
For the purpose of this simulation in MATLAB SIMULINK to characterize the tuning of the processor using PID control, certain values of Kp, Ti and Td where assumed.
For the first simulation Proportional gain, Kp= 0.29, Integral time, Ti = 0.11, Derivative time, Td = 0.36.
For the second simulation Proportional gain, Kp= 7.95, Integral time, Ti = 0.12, Derivative time, Td = 1.57
For the third simulation Proportional gain, Kp= 16.37, Integral time, Ti = 0.13, Derivative time, Td = 3.33

The results showed the system responses to a step input. It can be inferred from the results that the optimal set of parameters that give a more desirable transient response in terms of short rise time(rise time is the time taken by a signal to change from a specified low value to a specified high value.), low overshoot(overshoot refers to an output exceeding its final, steady-state value), short settling time(is the time elapsed from the application of an ideal instantaneous step input to the time at which the output has entered and remains within a specified error band,), low steady state error(is defined as the difference between the input and output of a system in the limit as time goes to infinity i.e. when the response has reached the steady state)are got from the results of test 3 where:
Proportional gain, Kp = 16.37,
Integral time, Ti = 0.13,
Derivative time, Td = 3.33.
Hence, a PID algorithm used to tune a microcontroller, simulated and fine-tuned using the set of parameters obtained from test 3 will exhibit a better control performance to changing temperature conditions in the proposed system.



Snapshot capture of the system on Proteus 7.6 after initialization

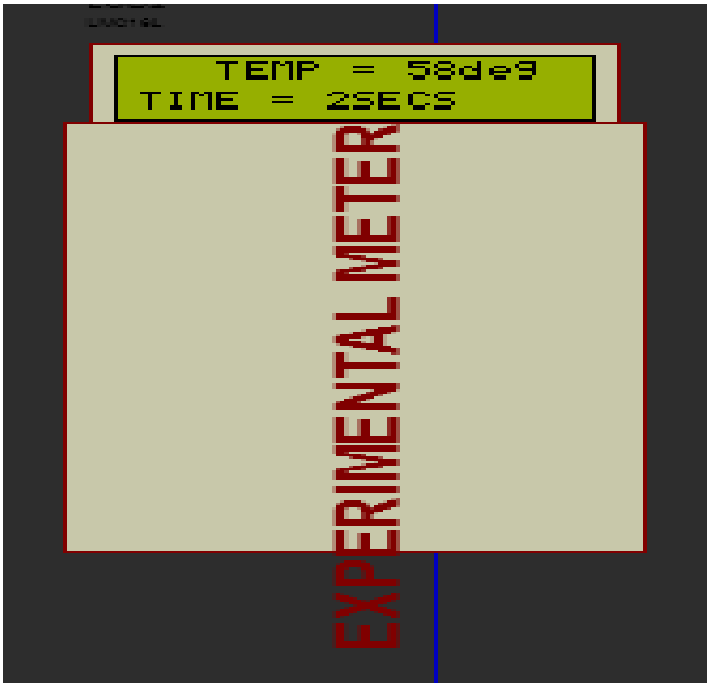
4.1 Performance Evaluation

For the purpose of performance evaluation in this research work, analysis is done on the response time of the proposed fire detection and suppression model.

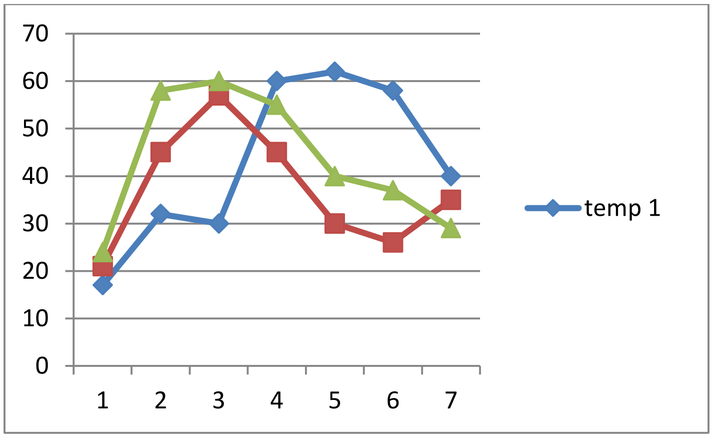
As a modelling assumption, we configure the activation temperature of fire response systems at 57^0C and as such the basis for the evaluation would be the system that would attain this activation temperature in the shortest time after fire goes off.

This research performs a performance evaluation by comparing the response time of fire suppression systems done by (Cadwallader, 1995) & (Raia *et al.*, 2014).

The proposed system makes use of the simple experiment meter to evaluate the systems' readings of temperature vs. time (this meter is equally used to evaluate the LPM). Fig 4.12, 4.13 and 4.14 clearly indicates real time response values gotten from the proposed system at 0.5sec, 1sec and 2secs respectively with the various response temperatures. This would now form the basis of evaluation



Snapshot capture of the systems' meter showing the corresponding time response at two second!



Temperature vs. time for different fire response system.

CONCLUSION

This work has developed and simulated the proposed system which integrates many strategies for improving the overall efficiency and *response time* of fire management systems by leveraging signal filters, energy release algorithms and tuning of microcontroller with PID control mechanism. One of the aims of the proposed controller is to speed up and regulate the response time of the system to a fire outbreak with minimum or no overshoot, short rise time, small peak time and short settling time

The system also has the ability to function as a standalone temperature data logging system. We have developed a system that has a real time temperature monitoring and control based on information acquired.

This proposed simulation model would be able to minimize the vulnerabilities associated with the conventional fire detection, alarm and suppression system like false alarms and false triggers, over flooding/water damage caused by uncontrolled sprinkling of the area under fire. The existing fire management systems do not handle these faults comprehensively.

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