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Simulation of Intelligent Fire Detection and Alarm System for a Warship

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ABSTRACT

Fire is one of the major hazards in warships. A warship being a very complex structure, with sophisticated weapons, machinery, fuel and ammunition is always at risk of fire. Restrictions on movement of ship's personnel and equipment requires automation in fire detection and control systems. This paper describes the limitations of conventional fire detection systems, followed by the features of modern fire detection and alarm (the so-called intelligent) systems and the types of fire detectors used in fire detection systems. The experimental set-up used for simulating a simple system having 24 sensors connected to the microcomputer via digital input card is explained in detail with the limitations of the experimental set-up and improvements that can be made by incorporating serial communication in a loop, using fibre optics data links, and intelligent loop/interface units.

1. INTRODUCTION

Fire detection is the first stage of overall fire extinguishing process, and as such the speed at which fire is detected is very important. The faster the fire is detected, the better are the chances of extinguishing it and lowering the cost of damage caused. Another important point for fire detection system is its reliability. Human being is the most perfect fire detector available with his senses of sight, smell and touch and the processing power of brain. He can instantaneously discriminate between an unwanted fire and the needed one. But there are certain limitations in such a fire

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detection system such as efficiency, reliability, economy and speed. With availability of detectors which are capable of assessment of the exent of fire and the prediction of further areas of risks, fixed fire detection systems have been designed. These fire detection systems give more and better information to human observers.

With conventional systems it is very difficult to monitor and control any fire incident on warship and hence, intelligent fire detection systems are necessary. A fire detection system, which will be self-monitoring and which will initiate both audible and visual warning signals in the ship's control station are required on warships. This paper presents the work done by a group of 4 students of Second Electronic Fellowship Course in the Institute.

2. CONVENTIONAL SYSTEMS

In any fire detection system the important functions are (a) detection, (b) transmission, (c) storage, (d) computation, and (e) display.

In a conventional system the detection and monitoring of fire and co-ordination of fire-fighting activities are performed by an 'organisation' which undertakes all damage control and surveillance functions. The damage control and surveillance organisation is still primarily based on manpower. The central point from which detection and monitoring is done is known as the 'headquarter'. There exists a secondary headquarter, which performs the above job when headquarter becomes inoperative. One or more 'Fire and Repair Parties' (FRP) in direct communication with headquarter are present. This forms an 'organisation'.

Information from roundsmen of the FRP is passed verbally via messengers or by telephone to the headquarter. An overall picture of the state of the ship is established and maintained in the headquarter. This picture is updated from verbal reports received from FRPs and suitable actions are taken by the headquarter. A mimic display in the headquarter helps in assessment, priority and containment of fire in the ship.

This conventional system has certain disadvantages as listed below :

a) Damage to installed voice communication system may result in considerable time lapse in transfer of information and thus assessment by the headquarter will be delayed.

b) The effectiveness of this method is extremely dependant on ship's personnel remaining aware of the situation.

c) The very nature of information gathering process creates significant time delays and lacks in rapid response.

d) Probability of false-alarm is high, for example, contamination of a conventional fire detector in use may change the threshold level giving false-alarm.

e) Manual updating methods do not provide easy assessment.

f) Lack of decision making aids in conventional systems require the expertise of the officer at the headquarter and his ability to analyse the displayed information.

In addition to this, continuing reduction in manpower on warships has necessitated for a fire detection system which will have automation and overcome the limitations mentioned above. As a step in this direction intelligent systems are being currently looked into.

3. INTELLIGENT SYSTEMS

These are primarily based on microprocessors. The main reason why microprocessors are becoming popular is that they offer improved and efficient performance for real-time application. By their very nature they can be programmed to replace conventional systems and to perform 'clever' or 'intelligent' functions. The main advantages over conventional systems are : (a) identification of exact location of fire, (b) automatic testing of associated circuitry, (c) ease of maintenance, (d) historical events log, (e) reduction of wiring installation costs, and (f) reduction of false-alarm.

In addition to the above the search for an intelligent system has been mainly to cater for the following factors.

3.1 Limited Manpower

Conventional fire detection methods are based on manpower. To recruit personnel of right calibre who are prepared to stand a watch, checking and observing the operation of machinery weeks after weeks on an ocean passage, is a problem. Today man with such a calibre would not tolerate this type of work. Hence automatic surveillance of the status of the ship has to be incorporated.

3.2 Speed of Fire Detection

An intelligent system will be much faster than the conventional one. This will provide quick access to information, quick updating of information, etc. Hence it will ultimately lower the cost of damage caused.

3.3 Efficient Operation

All monitoring and control will be performed by microprocessor. Software can be developed to make the system react when sensor voltage crosses a fixed or variable threshold. Each detector can be given a unique address code, which can be transmitted by the detector to control panel enabling the detector position and location of fire to be quickly established. System can be programmed to cater for contaminated atmosphere and the software can be used to take correct fire decision. This will reduce the false-alarm considerably. It will perform duty permanently and efficiently at all necessary places. This will improve communication between headquarter and the FRPs.

3.4 The Storage and Presentation of Data

Storage and presentation of data for damage surveillance in conventional system is done manually. Retainment of information is presently limited to peg board, reference document and memory of ship's staff. Intelligent systems with electronic storage techniques to hold information relating to incidents, time and locations will help in this regard. Access time will also be reduced.

3.5 Expert Systems

Intelligent systems can be made 'expert systems' that will recommend the course of action that should be taken following an incident, which will avoid the dependence on the experience of skilled personnel.

4. FIRE DETECTORS

The fire detectors in an automatic fire detection and alarm system are classified in terms of their working principles, comparative functional effectiveness and constructional complexity. But, the primary job for a detector remains the same. Till now, no detector has been designed which can discriminate as to the cause or mediate on the intensity of stimulus. Rather, what an existing detector does is to initiate a signal out of heat, smoke or fire in a form suitable for subsequent processing. It may be mentioned that the detector location (its placing within the fire susceptible zone) is one among the key factors to determine the efficiency, performance and economics of a fire detection system.

4.1 Working Principle

Flame, heat and smoke are the basis of detector classification adopted in the National Fire Protection Association (Boston, 1972) Tentative Standard on Automatic Fire Detectors. The tree structure in Figs. 1 and 2 best describe the basic types of detectors one can have, depending on their working principle.

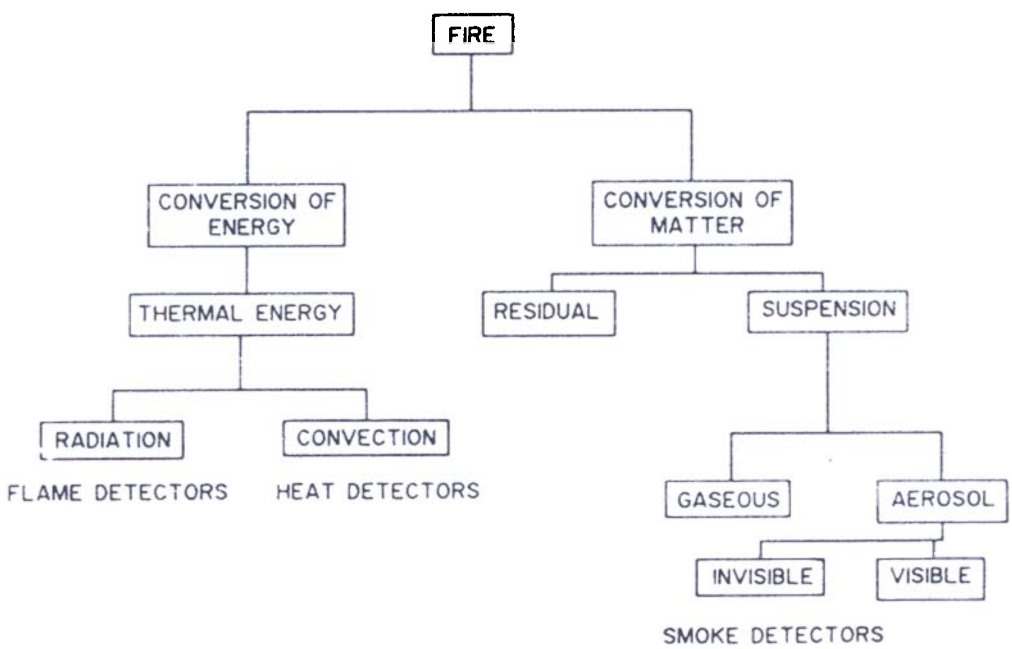


Figure 1. Classification of fire detectors.

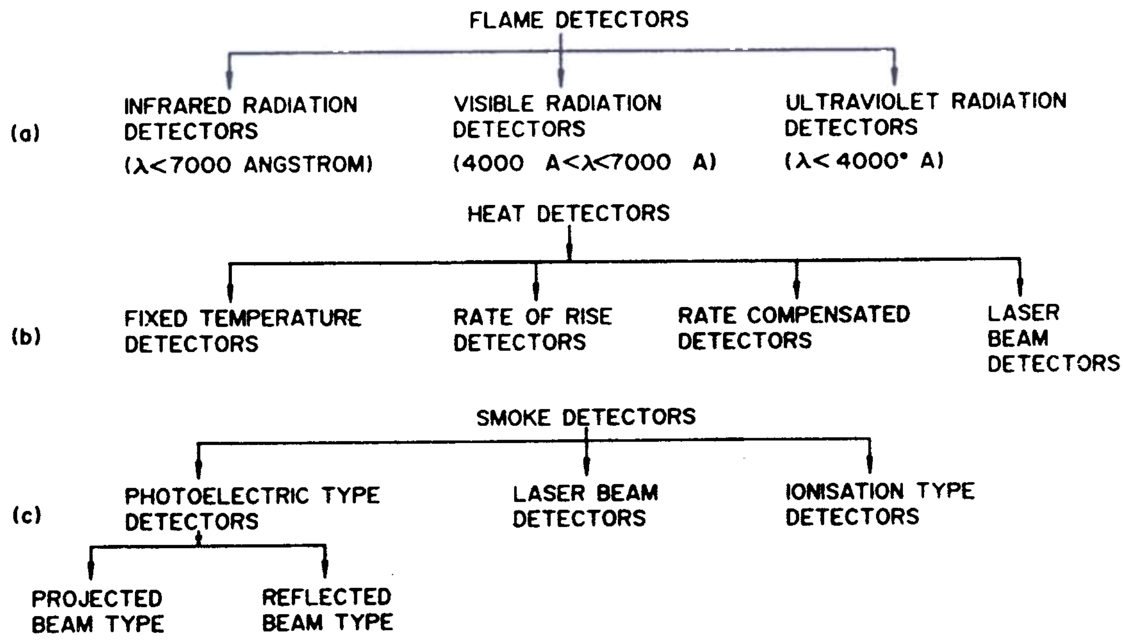


Figure 2. Classification of detectors according to the working principle.

4.1.1 Flame Detectors

Flame detectors operating in visible wavelength range are rarely used, since in this range, the detectors cannot effectively distinguish between fire induced radiation and the normally present background radiation (the non-fire radiation produced by natural or artificial illumination, for example, solar radiation). Rather the detectors operating in IR and UV regions are popular.

i) IR detectors : A fire flame emits radiation which is rich in IR and UV energy. In addition, the flicker produced by a flame (1 to 30 Hz) modulates the IR frequencies which can also be detected by suitable photoelectric cells, for example, silicon photocell. The wavelength of operation for the cell is chosen such that the solar radiation does not affect its performance.

ii) UV detectors : Since, appreciable amount of optical energy in the UV band is radiated by primarily higher intensity flames, they can be detected from long distances by photoelectric, or photoconductive cells. Majority of UV detectors operate below 2700 A wavelength (solar radiation below 2900 A is absorbed appreciably by air). Gas discharge tubes, silicon carbide diodes and molybdenum crystal detectors have been used for the detection.

4.1.2 Heat Detectors

i) Fixed temperature type : Two principles are generally made use of here

When a bimetal (a laminated material consisting of two metals of differing thermal coefficients of expansion) is heated, one metal expands more than the other and the bimetal takes up a curvature in an attempt to allow this defferential expansion. This bending can be used to close an electrical circuit which will give indication of a fixed amount of heat through current flow.

Yet in another form of detector, a thermally sensitive eutectic salt compound is packed in-between two electrodes. A potential difference between the electrodes maintains a steady flow in the circuit whose magnitude depends alongwith other factors, on the resistance of the salt compound. When the salt compound experiences a fixed amount of heat, its resistance reduces causing an increase in the current flow in the circuit which can be detected.

ii) Rate of rise type : In a closed chamber, when the air is heated up by a fire plume, above ambient level, the volume of air increases by an amount that depends on the rate of rise of heat, and presses a flexible diaphragm to make contact to a metallic screw. This principle can be used to indicate the rate of rise of heat, when the metallic screw forms a part of an electric circuit. To respond to varying rate of heat rise, the spacing between the metallic screw and the diaphragm is made adjustable.

iii) Rate compensated type : This type is sensitive to both fixed temperature levels and the rate of rise of heat, eliminating the major problems of both types, i.e., the thermal lag found in the fixed temperature detectors and the insensitivity of the rising rate.

Two curved struts of low thermal coefficient of expansion are kept under compression within a stainless steel tube, whose coefficient of thermal expansion is more than that of the struts. On the curved struts there are two silver contact points, which are thermally insulated from the respective struts, and are physically separated from each other in normal condition. Upon receiving a fixed amount of heat or a rate of rise of heat, the steel tube heats up quickly (its coefficient of thermal expansion being more) and expands thereby applying tension to the curved struts. Thus the contact points touch each other. When these points are within an electric circuit, a current flow through the circuit in excess heat condition can be detected.

iv) Laser beam detector : The hot air emerging from a fire plume may cause deflection of a highly directional laser beam. This is used as the working principle in a laser beam detector. In construction, a photodetector is kept face to face with a laser source. Normally the photodetector will be receiving a constant illumination from a laser beam, with its current output remaining steady. When the space between the source and the receiver is exposed to heated air, the laser beam is deflected and the signal output from the photodetector fluctuates. This fluctuation can be used as an indication of heat.

4.1.3 Smoke Detectors

i) Photoelectric type : In this type of smoke detectors, a light source (normally an LED–light emitting diode) and an optical sensor (photo cell, phototransistor, etc.) are always common.

In *projected beam type*, the light source and the detector are facing each other with a steady signal output from the detector under normal conditions. The smoke particles in the space in-between, produce scattering and/or absorption of light beam, thus, reducing the intensity of light input to the detector. The consequent fluctuation in its signal output can be recorded.

In a *reflected beam type* of detector, the arrangement of source and the photodetector is such that in normal condition, the light falling on detector is zero and it increases due to scattering from the smoke particles, if they are present. Thus the signal output of the photodetector increases.

ii) Ionisation type : This type of detectors work using the heavy mass (compared to electrons and ions) of the smoke particles.

A chamber, open to the atmosphere, is formed in-between two electrodes. The inter-electrode space is ionised by a radioactive source. Upon applying a potential difference between the electrodes, ions and electrons are attracted to opposite poles. On the way, random collision between these particles results in a certain extent of re-combination. However, a steady current flows through the chamber. As heavy smoke particles enter the chamber, they get attached to the ions, their mobility is reduced. In effect, the electrical current in the electrical circuit, of which the detector forms a part, is reduced, which can be recorded.

iii) Laser beam type : A laser source can be used in place of the normal light source (LED) in the photoelectric type of smoke detector and a photodetector working in the same frequency range as the laser, to have a considerable improvement in the performance of the detector.

4.2 Functional Effectiveness

The detectors used for an automatic fire detection and alarm system can be classified in terms of their functional effectiveness. The following are considered as the critical parameters for the selection of a detector for its optimum performance :

i) Sensitivity : Sensitivity of a fire detector relates to its ability to detect the smallest amount of stimulus (flame, heat or fire).

ii) Reliability : Reliability of a detector relates to its ability to be in proper working condition at all times to perform its intended function.

iii) Maintainability : This is defined qualitatively as the ability of the detector to be in proper working order after specified periodic inspection and servicing.

iv) Stability : Stability or repeatability of a fire detector relates to its ability to sense fires over extended periods of time work without any change of sensitivity.

Table 1 summarises the performance of various detector types. The classification done above is general. The actual performance of a detector will strongly depend on the sophistication built into its design and precision of manufacturing process, quality and reliability control procedures and other factors.

Table 1. Performance of various detectors

Detector type*	Sensitivity	Reliability	Maintainability	Stability
IR flame	Medium		Medium	Low
UV flame	High		Medium	Medium
Fixed temperature	Low		High	High
Rate of rise	Medium		High	High
Rate compensated	Medium		High	High
Photoelectric	Medium		Medium	Medium
Ionisation	High		Medium	Medium

*The laser beam detectors have not been graded since they are not available commercially

4.3 Constructional Complexity

The last classification among detectors is through their constructional complexity, that is, the extent to which the detector has been made intelligent such that in addition to providing the basic fire status information, it does some other functions to be suitable for use in a microprocessor-controlled fire control system. According to this classification the fire detectors are differentiated as either conventional or intelligent.

Conventional fire detectors involve a minimum of electronics so that they can give only an analogue signal fluctuation at the output corresponding to their exposure to flame, heat or smoke. Most of the older detectors are of this type.

Intelligent fire detectors are those involving a fair amount of electronics in itself. (This is the type of detector planned to be used in the proposed intelligent fire detection and alarm system). The detector may have a sophisticated logic circuit which provides the detector with a 'name' (a unique address within a group of detectors). When the central monitoring unit sends an address along the transmission line, this logic circuit matches with that of its detector, and if they match, the analogue signal output of the detector is dumped into the transmission line. The logic circuit may also provide an 'acknowledge' signal (output, indicating that the address sent by the central monitoring unit was for it), a 'status' signal (whether the analogue voltage output is zero or non-zero) and a 'warning' signal (output to indicate the presence of any contamination in the detector), etc. Because a microprocessor handles the data for the purpose of fire detection and alarm, the data has to be converted Analogue-to-Digital (A/D) before inputting to the microprocessor. Some sophisticated fire detectors include A/D converters in their construction to facilitate this operation.

The constructional complexity in the fire detectors has been increased to make them compatible to the digital computer for optimum performance, faster detection of fire and pin-pointing the location of fire. Of course, they are not realised without corresponding increase in their cost.

5. EXPERIMENTAL SET-UP

In order to establish how an actual intelligent system will function as a first step, a simulation of such a system has been tried out.

The experimental set-up consists of (a) mimic board, (b) digital Input/Output (I/O) card, and (c) microcomputer. A schematic of the experimental set-up is shown in Fig. 3.

There are different types of sensors as indicated in earlier section which would provide varying analogue voltage output. Since only digital I/O card was available, it was assumed that there are only two states in which the sensors operate, that is, either these states are active or non-active, or in other words the value is 1 or 0. 1 represents 5V and 0 represents 0 volts. In actual environment analogue signals for varying voltage will have to be considered.

The mimic board gives the pictorial representation of ship showing plan of each deck. The visual indication of the type of sensor activated in a particular compartment is shown with the help of different coloured LEDs. Thus from mimic board, the location of fire and type of sensor can be known.

The digital I/O card is an interfacing unit between microcomputer and sensors. It is an addressable unit and works in accordance with control signals from microcomputer. It has twenty four signal lines divided into two groups, each with twelve signal lines. These can be programmed either as input ports or as output ports, or 12 as input and 12 as output ports. In the experimental set-up, all 24 lines have been used as input ports.

When power is switched on, all signal and data lines of the I/O card get reset. To initialise them, a control word 9B (Hex.) is sent by the simulation program. The I/O card sends the status of the 8 channels at a time to the processor which processes the information about the 24 sensors (received as 6 bytes) sequentially and takes suitable action according to the software.

An IBM compatible PC/AT microcomputer has been used as the main monitoring unit in the set-up. It executes the simulation program and stores the information regarding the activated sensors in the memory. There is a real-time clock which aids in recording the time of occurence of the incident.

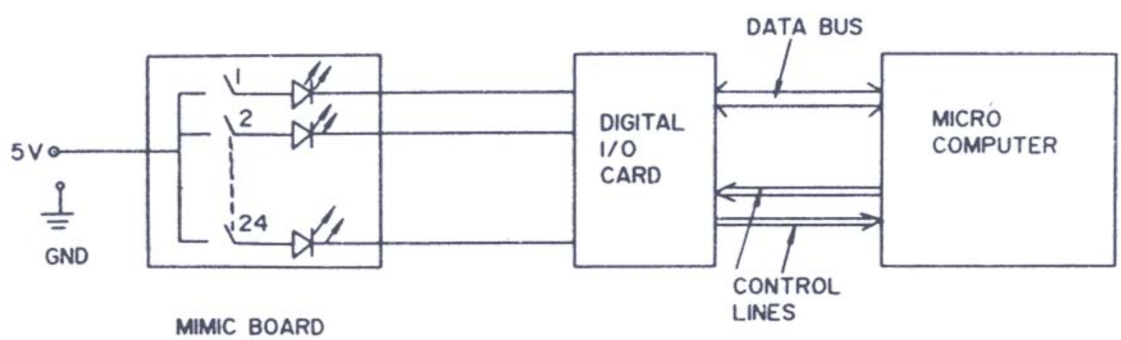


Figure 3. Schematic diagram of experimental set-up.

6. SOFTWARE DEVELOPMENT

The software constitutes the major part of the system. This is extremely important since ultimate performance of the microcomputer based system depends on the strength of the software. The various features of the software developed for this simulation are discussed briefly in the following paras.

6.1 High Level Language

A high level language, TURBO-PASCAL, has been used to develop software as it is more powerful and much easier to use than assembly language program from the design and documentation point of view, especially for large projects (like fire detection and alarm system) which involve large programs.

6.2 Modularity

The high level language used is highly structured and as such, the program is modular so that it is easy to add new modules and debug the software.

6.3 User Friendliness

The software developed has been made highly interactive for the use of common attending personnel of the warship.

The flow chart for the fire detection and alarm program is shown in Fig. 4.

The functioning of the fire detection and alarm software can be discussed under the following headings :

6.4 Detection

The detection is done logically. A fire occurrence is sent to the I/O card as a logical 1 (+5 volts) and a logical 0, for safe condition.

6.5 Transmission

Information regarding the channels is passed on to the processor via 8 bit data lines.

6.6 Storage and Retrieval

The detailed information about type and location of each detector is stored in tabular form. By doing mathematical manipulations on the received data, the processor determines the channel showing fire and retrieves all previously stored information about it. Automatic maintenance and updating of a log book about the sensors, as and when they are activated has also been provided in the software. A typical historical record printout is shown in Table 2.

6.7 Display

Graphical representation has been provided to indicate the location of a place in fire with respect to its surroundings. Appropriate text informations also appear in

Table 2. Historical record of activated sensors

Today is – 27/11/1987						You started at – 9:12:13
Date	Time	Ch. No.	Sensor type	Compart. name	Deck. No.	Remarks
8/10/87	10:47:10	19	Smoke	Naval store number 3	41	
10/10/87	8:45:50	11	Smoke	OPS room	22	
10/10/87	8:45:59	12	Heat	Electrical store	23	
10/10/87	9:55:36	24	Fire	Boiler room	51	
10/10/87	10:40:23	22	Fire	Aux. switch BD	42	
12/10/87	12: 1:31	9	Fire	Main switch BD R	22	
14/10/87	14:52:44	24	Fire	Boiler room	51	
14/10/87	14:53:56	21	Smoke	Conv. M/C RM	42	
14/10/87	14:55: 3	21	Smoke	Conv. M/C RM	42	
27/11/87	9: 8:19	18	Smoke	Naval store 1	33	
27/11/87	9: 9: 9	7	Heat	Dining hall	21	
27/11/87	9: 9:24	8	Fire	Sick bay	21	
27/11/87	9: 9:40	11	Smoke	OPS room	22	

the display which inform the attending personnel about what is going to happen. Typical graphical display for 'no fire' in a compartment is shown in Fig. 5.

6.8 Alarm

Depending on the type of sensor activation, alarm of a particular frequency is sounded. As and when the sensor gets activated, the clock time freezes. The alarm sound can be stopped only by the operator by acknowledging with the help of one and only one key. After the alarm has been acknowledged, the clock starts again.

7. LIMITATIONS OF THE SET-UP

7.1 Use of High Level Language

A high level language, though offers ease of program development and documentation, has the disadvantage of occupying more memory space than that written in assembly language or machine language. The speed of execution is also typically lower. This limitation is a significant one in view of the fact that in actual ship environment, there may be more than a thousand sensors which will have to be scanned in real-time. Slower response in a real-time system results in poor performance.

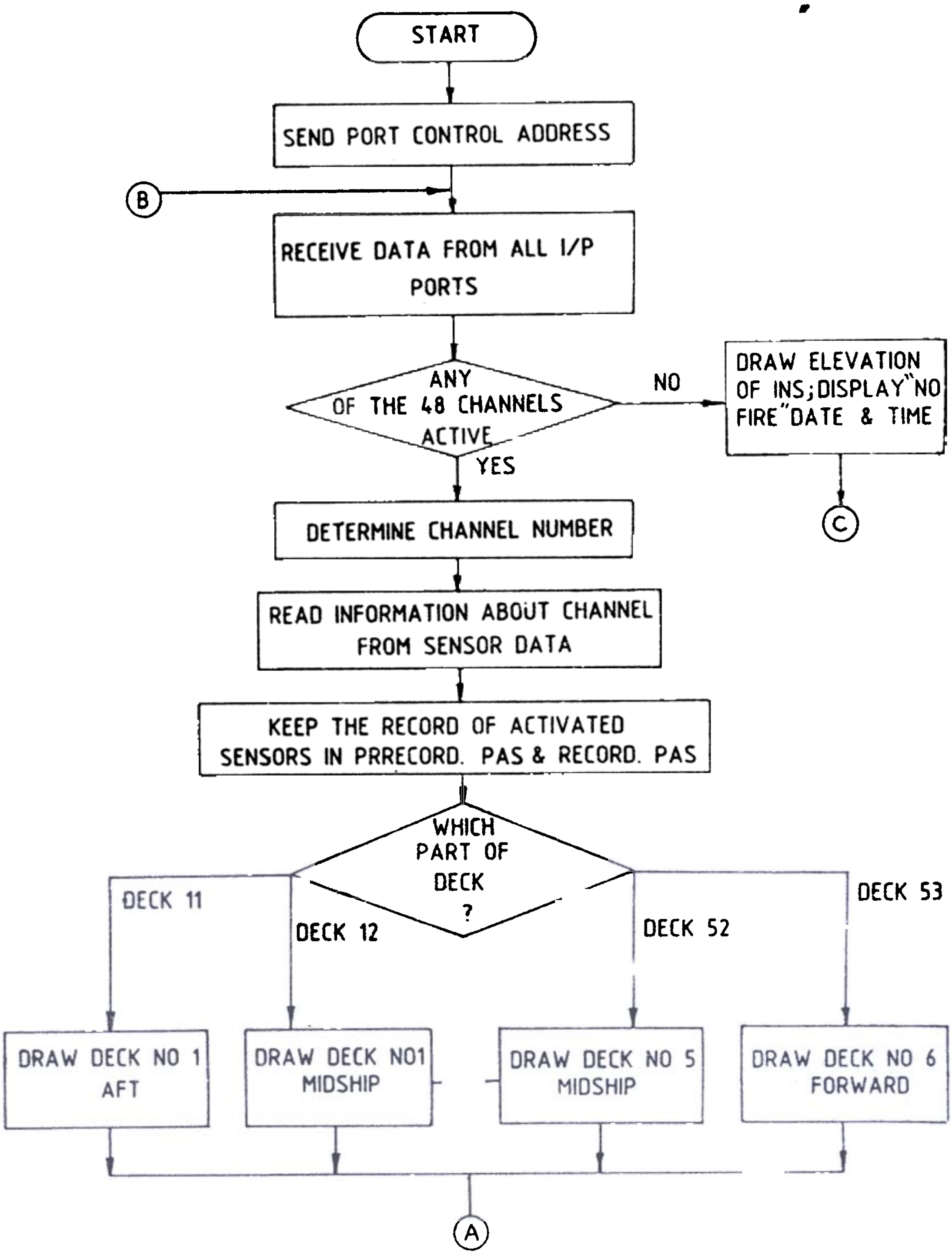
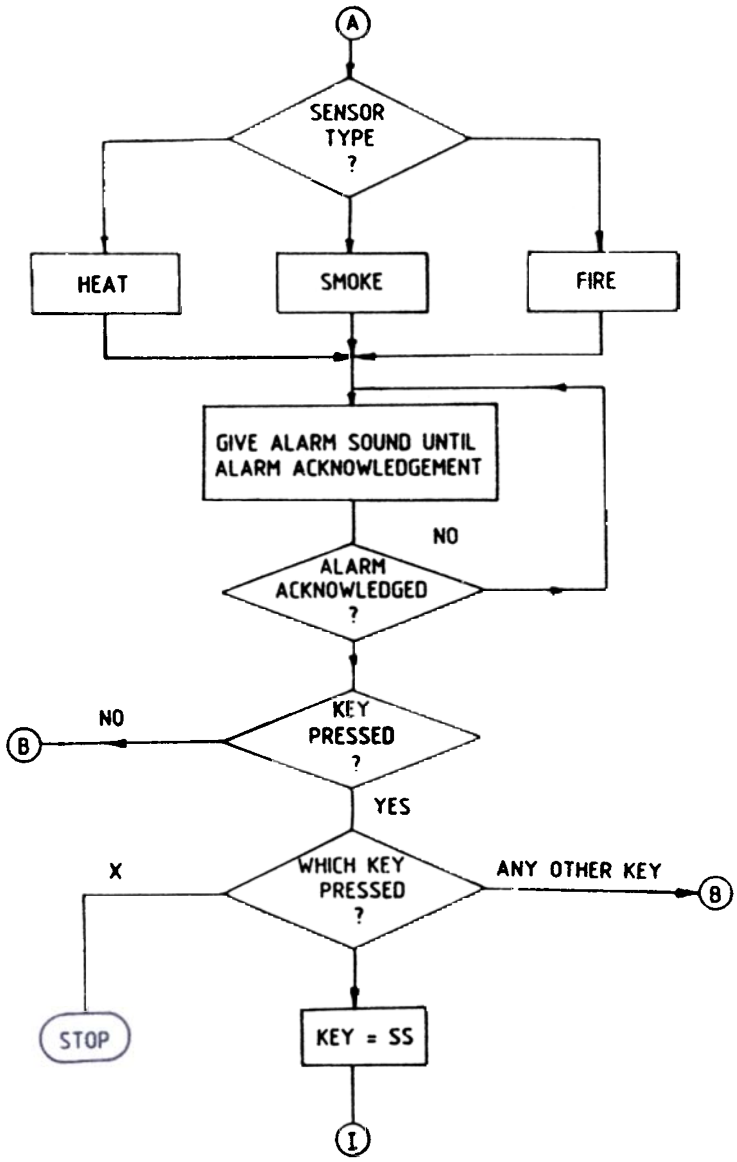


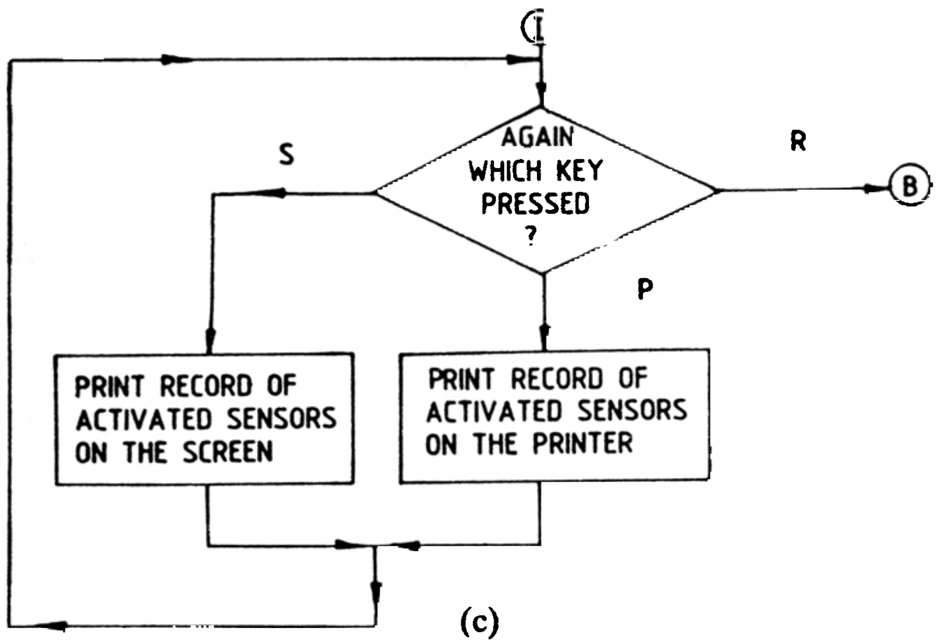
Figure 4(a). Flow chart of the fire detection and alarm system.

7.2 System Configuration

The experimental set-up is a parallel one, i.e., each detector is assumed to be connected to a single channel of the I/O card. In an actual system, the number of detectors will be much larger (may be a thousand). In that case, going for parallel connection will amount to a heavy wiring cost with associated problems relating to increase in weight, system expandability and reliability. Each detector has to have its unique address, i.e., they are to be intelligent. In addition, the scanning time of the monitoring processor will be large. Besides, the fault detection takes a long time in a parallel system. The problems of electromagnetic interference and radio frequency interference will increase.



(b)



(c)

Figure 4(b,c). Flow chart of the fire detection and alarm system *(contd).*

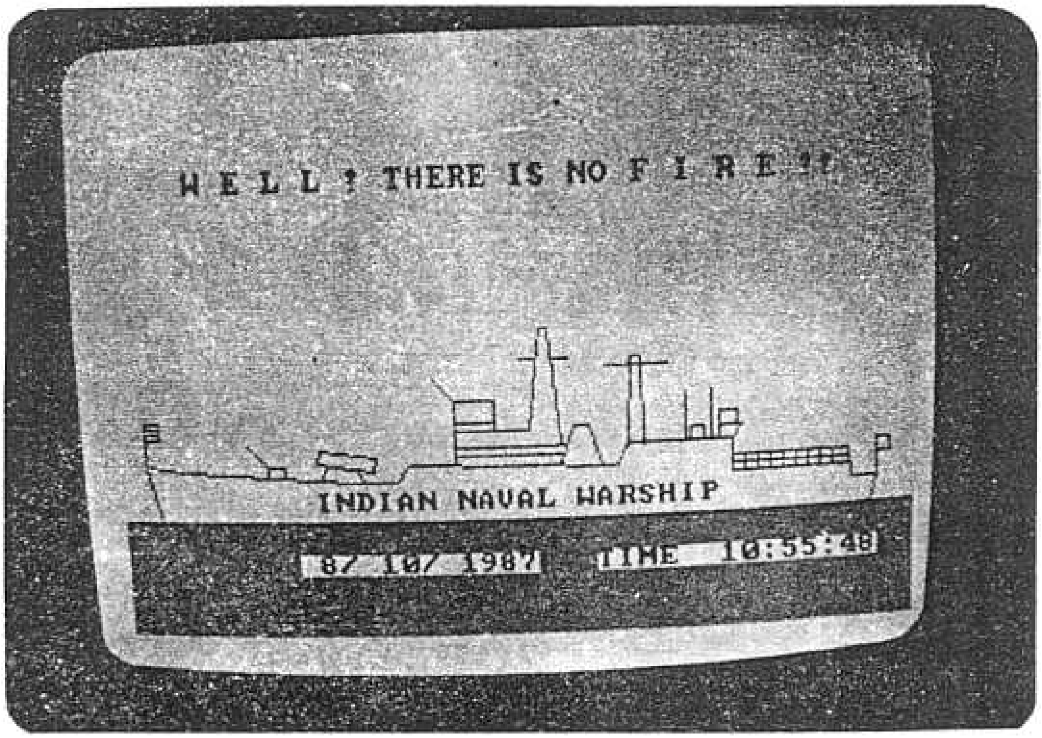


Figure 5. Graphic display of 'no fire'.

7.3 Limitations on Sensors

The type and number of sensors required for each compartment of the ship has not been decided. The number will depend on the size of the compartment, its internal arrangement and the type of the sensor. The type will be decided by the role of the compartment : what it normally stores or what it is used for.

7.4 No Control Action

The program developed can detect fire intelligently, but it does not provide any decision aid or control action that can be taken automatically if fire condition prevails.

8. WAY AHEAD

In view of the limitations of the experimental set-up listed above, a system as shown in Fig. 6 is proposed. This intelligent fire detection and alarm system has the following features :

i) In an actual environment, the detection algorithm will handle the 'real' detectors. Depending on the detector characteristics, its signal output will replicate the fire phenomenon and depending on its fabrication complexity, it will output its type, status signals and the voltage level in analog or digital form. The central processor will recognise these and take appropriate decision depending on the implemented algorithm of fire.

ii) To avoid excessive wiring in a parallel system, the system proposed will support serial communication between the main processor (microcomputer) and the detector. But, then again, to save the scanning time of the main processor, one or more

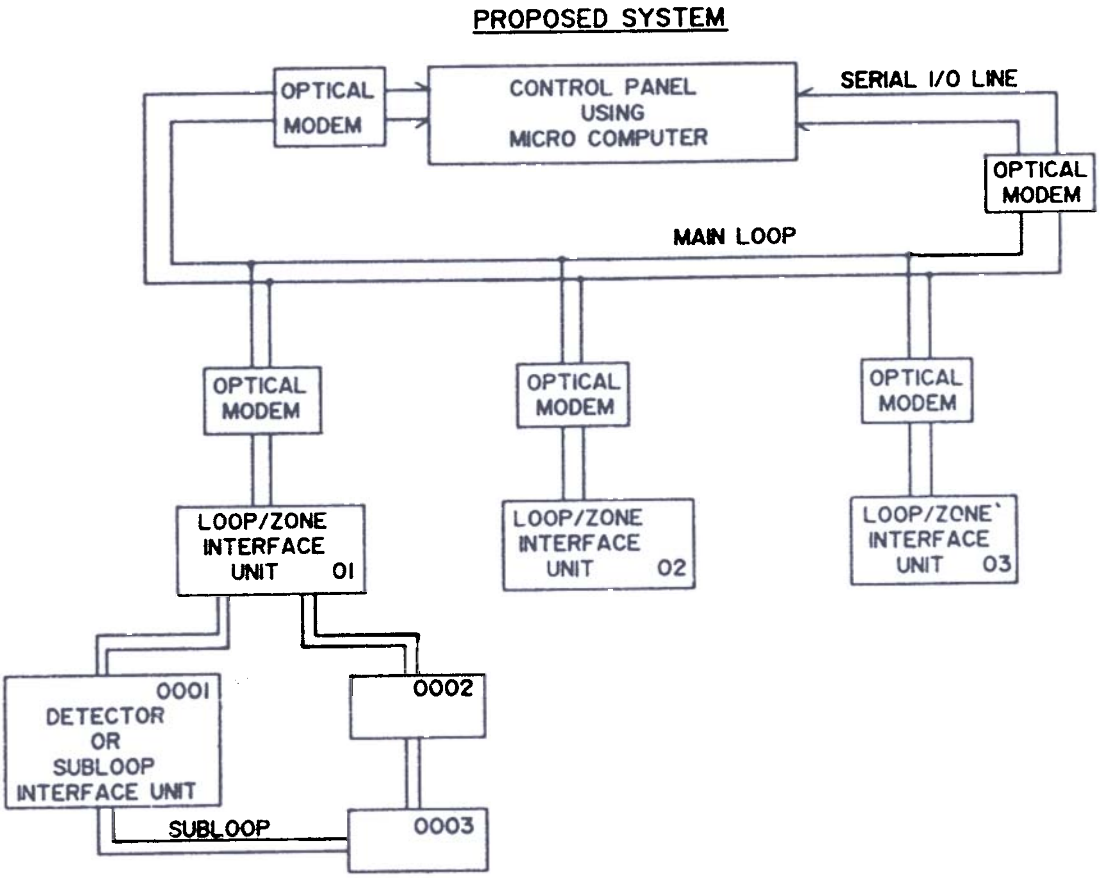


Figure 6. Schematic diagram of the proposed fire detection and alarm system.

addressable interface units between the main processor and the sensors, as shown in Fig. 6, are required. In case the sensors are intelligent, fault localisation is easy and quick. Otherwise, a group of detectors connected to an interface unit can be collectively monitored for fire or fault. When the interface unit(s) and detectors are in a loop configuration, the system can be made resistant to a single-wire break by suitable modification of the port configurations.

In the proposed system, the use of optical signal transmission utilising fibre optics cable is recommended since a commonly used data bus is always susceptible to the noise and electromagnetic and radio frequency interferences in a shipboard environment.

9. CONCLUSION

Use of intelligent techniques for fire detection are presently being examined and will be implemented in near future. As a first step towards building up such a system, simulation of fire detection and alarm system to a limited extent has been successfully completed. Additional modules incorporating advanced features can be added as and when increase in sophistication is required. With slight modifications in the software this system can be adopted for various places other than a warship such as large housing complexes, laboratories, factories, places of public gathering, storehouses or godowns, schools, hospitals and nursing homes, etc.

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