Design and Implementation of Uninterruptible Power Line Communication Network for Fire Detection System

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摘要

消防署統計火災資料，台灣地區以住宅火災發生頻率最高。多數的研究者著重在如何判別火災的發生及更正確及快速的偵測出火災，忽略了因火災而導致停電時，該如何繼續維持系統的運作。本研究設計一套不斷電電源線網路，應用在住宅的火災偵測系統上，考慮停電後系統的可用性。利用電源線網路(Power Line Communication, PLC)為傳輸媒介，有別於一般的電源線通訊網路，系統在平時以交流電源為主，當遇到停電時，則轉換為直流電源供電，以達到不斷電的火災偵測系統。系統整體以微處理器為核心，利用基本、簡潔的電路設計原理，構成系統通訊模組。實驗結果確實能改善一般火災偵測系統在停電時候的不足，以應付火災所產生的各種危害。

關鍵詞：電源線通訊、火災偵測、感測網路。

Abstract

According to National Fire Agency statistics residential fires have become the most frequent cause of fire call-outs. Most researchers have focused on how to determine the occurrance of the fires and how to detect them more accurately and correctly. However, they neglect how to maintain the continuous operation of systems to avoid power failures caused by fire. In this study, an uninterruptible power line communication (UPLC) network is designed taking the consideration of its usability after a power failure, and is applied to detection systems of residential fires so as to protect people's lives and property. A Power Line Communication (PLC) network is the main transmission media for the communication and is rather different from the ordinary power line communication network. The system is ordinarily powered by alternating current, and can be switched to direct current if the power fails thus achieving a Fire Detection System with Uninterruptible Power. The system is constructed with a microprocessor as its core to be a system communication module with a basic and concise circuit design principle. In this study, the inadequacy of ordinary fire detection during a power failure can be fixed to control various kinds of damage caused by fire.

Keywords: power line communication, fire detection, sensor network.

1. Introduction

In addition to the convenient and comfort environment provided to residents, residential safety plays an ever more important part in modern intelligent residences. The time people spend in houses is relatively high, hence residence safety becomes considerably more important. According to data regarding the construction type of ordinary residences in Taiwan, 25% consist of apartments that are higher than 6 stories (as shown in Fig. 1) [10]. Once a fire occurs, it can severely threaten the safety of the neighboring residents. According to statistics from the National Fire Agency, there were 5139 fires in 2005. The major cause was, electrical appliances, causing 1533 incidents; the major location of fires was, buildings, being 3053 incidents, among which the number of the residential fires was 2035 [11]. Consequently, in this study, we focus on the usability of residential fire detection systems in a power failure and thus construct a complete and effective fire detection system to protect people's lives and property.

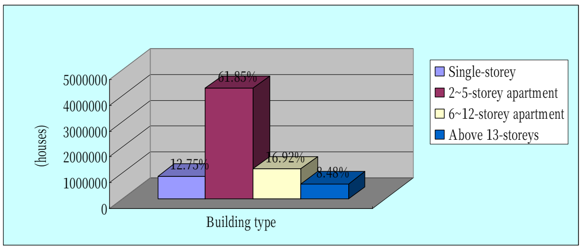


Fig. 1 Ordinary residences in Taiwan by building type

There are two types of existing fire detection systems, the independent type and the network type. The independent type is usually capable of detection and giving the alarm, however it cannot send information about a fire. There are two types of network systems, wired and wireless. The wired systems have the advantages of communication stability and a large coverage area, but the disadvantages of additional wiring cost, unsightliness, and inconvenience in maintenance. When a fire occurs, the additionally laid signal lines can be easily burned and thus most of the fire detection systems fail to operate. Wireless systems have the advantages of ease of construction, ease of use and ease of maintenance, but the disadvantages of being easily subject to interference and to communication dead spots (e.g., basements, or over different floors); when a fire occurs, the thick smoke and high temperature may attenuate the wireless signals. Because the wireless detection nodes are ordinarily powered by internal batteries, they are rarely maintained due to long inactivity, so the systems often fail to operate due to insufficient power.

Nowadays, the electrical infrastructure is nearly complete everywhere, and electricity is used in every residence. Power lines are more prevalent than network lines. While newly constructed buildings are equipped with wired network infrastructure and fireproof building materials, most older buildings have no such equipment. According to data regarding the completion year of ordinary residences, those older than 10 years comprise about 89% (as shown in Fig. 2) [10].

The object of this study is to solve the above mentioned problems of wire-laying and power failure. By using the PLC as the main communication media for the transmission, it has the advantages of not requiring the laying of additional lines, getting rid of the transmission lines between various pieces of equipment, savings on consumable parts and the time required for wire-laying, and avoiding the problems that can be caused by the transmission lines, thus allowing the equipment to have the advantages of a wireless (no-line) system only with power line connections. Because power lines are mainly buried inside buildings, when a fire occurs they are safer than the exposed signal lines in ordinary wired systems, and the transmission is more stable than in wireless systems. When the power fails, it can be powered by the mechanism that we propose, that convert the power into a DC power supply mode to maintain a stand-alone system.

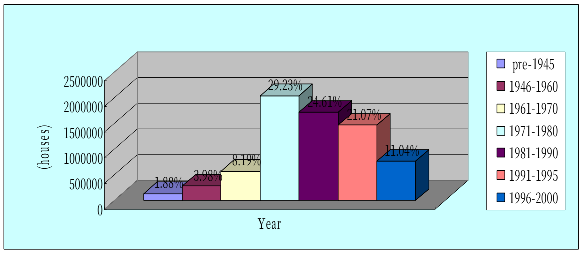


Fig. 2 Ordinary residences in Taiwan by completion year

2. Related Work

2.1 Power Line Communication Network

Power Line Communication (PLC), also called Broadband over Power Line (BPL), is a communication technology that uses the existing power lines as a communication media to provide communication services. There are many PLC alliances in the world, and many standards have been proposed. HPA (HomePlug Powerline Alliance), an organization for setting up international standards for power line communication in residences [9], proposed HomePlug 1.0 in June 2001 in which the transmission speed is set at 14Mbps by using the OFDM (Orthogonal Frequency Division Multiplexing) technique. A new version of the standard HomePlug AV has been proposed, in which the transmission speed can be up to 200Mbps by using the OFDM technique.

Power line carrier communication technologies can be divided into two categories according to the data transmission speed: the control system and the high speed system. The high speed system is mainly used for the integrated high speed transmission used by personal computers and digital appliances. It is suitable for home network applications. The control system is used for the connections of traditional home appliances such as refrigerators, washing machines, etc., where only simple control functions are required and the transmission speed does not need to be high, thus it is suitable for home automation system applications.

2.2 DC Power Line Network

Usually, a PLC is mostly constructed based on AC power lines. There are some researchers who run a PLC using Direct Current, called a Direct Current Power Line Communication (DC PLC). Maryanka applied DC PLC technology to the communications between parts of a car, i.e., the DC power lines from the car battery are used as the communication media. It has the benefits of controlling all the equipment without the trouble and cost of additional cabling. In addition, he emphasized that the DC power line communication may be influenced by the car's operation, so it is necessary to overcome the interference [6]. Other researchers also use DC PLC for the control applications in cars. The power line and signal line are integrated as one, and unnecessary control lines are neglected in addition to the power lines such as the power lines and control lines required for the traditional servo motors [2,8].

Wade proposed a warble DC PLC network, for detection of body's health. Various sensors are placed on a human body, and a DC power line can not only be used for supplying power for each node but also as the signal lines between nodes, then the data is collected and collated by the central node [7].

2.3 Fire Detection System

In fire detection systems, smoke detectors and temperature sensors are traditionally used. Some researchers have suggested that if only one detector is used for detection, false detection and false alarms may easily arise. In a detection mechanism that uses several integrated detectors (smoke, flame and temperature) because the three detection situations usually do not occur simultaneously, it can be used to correctly determine occurrence of fires, reduce occurrence of false alarms and improve usability and accuracy [3,4,5].

Lee proposed a detection system that uses a Controller Area Network (CAN) to construct a fire detection system. In order to avoid the disadvantages of traditional fire detection systems, digital communication approaches are used to not only directly determine the location of the fire, but to also reduce false alarms due to the failure of some detectors. A PC is used as the core receiver, thus it is more easily constructed and maintained than conditional receivers [1].

3. System Architecture and Design Approach

3.1 System Architecture

In this study, the fire detection system is based on the uninterruptible power line communication module (UPLCM). Its hardware architecture is shown in Fig. 3. To lower the cost and improve the performance, an AVR AT90S series (AT90S2313) microprocessor from Atmel is used as the core. It has RISC (Reduced Instruction Set CPU) architecture, and the advantages of low cost, low power consumption (μA) and high speed (50nS). It can be coded in assembly language.

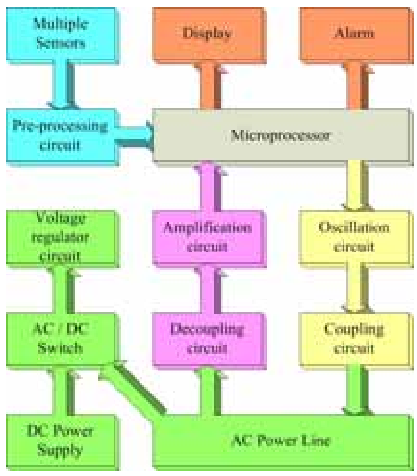


Fig. 3 System hardware architecture

For the transmission part of the UPLCM, the signal is generated by the microprocessor, and carried onto the power line by the coupling circuits after being processed by the oscillator and modulation circuits. For the receiver part, the small signal is extracted from the power line by the decoupling circuits, and sent to the microprocessor for analysis after being processed by the amplifier and the demodulation circuits. The sensor signal detected is processed by the pre-processing circuits and also sent to the microprocessor for analysis, and the microprocessor will make related display operations, alarm operations, etc. according to the analyzed results. Finally, for the AC/DC converter part, the electricity is ordinarily AC for supplying the power required for the whole system after being transformed and stabilized. In a power failure, the electricity is converted to DC power operation mode and supplied to the UPLCM after being stabilized.

For the UPLCM operation algorithm, as shown in Fig. 4, the initial I/O state is configured. The module will take the input signal repeatedly for a given time period, to determine whether a fire has broken-out. There are two determination mechanisms for the fires: one is the common method, when the detection value exceeds a certain threshold the alarm is activated; the other is a quite important mechanism proposed in this study. Even if the detection value does not exceed the threshold, however, the data can change drastically in a very short period. At this time, a suitable warning may be activated to achieve a pre-alarm effect to gain more time for evacuation.

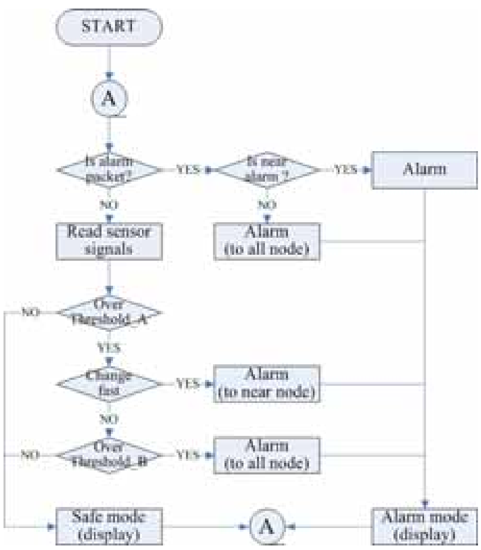


Fig. 4 Operation algorithm flowchart

3.2 System Design

The design of the UPLCM in this study can be equipped with various detectors required for a range of situations. Each detector is comprised of sensors and an UPLCM. It can be further connected to actuators, for example, to activate a sprinkler system for an instantaneous response, as shown in Fig. 5.

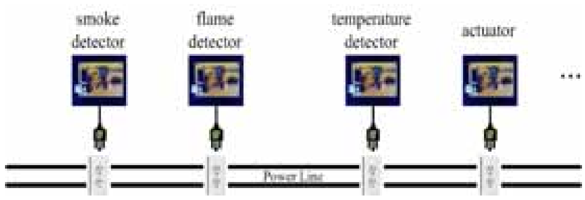


Fig. 5 System configuration for the test

An ordinary network type fire detection system consists of several detectors and one (or more) central monitoring unit(s). The main operation of the distributed detection nodes is to transmit the detected data to the central monitoring unit for determination. If the value exceeds the standard value, the alarm is immediately sent out and the related operation is performed. However, it takes some time for the detector to detect the situation and then send the data to the central monitoring unit. In this study, the system has the feature of each node being independent, i.e., each detection node itself is a monitoring unit, so it can determine the situation immediately after the data is detected. This feature relies on the effort of the microprocessor.

To overcome the problem of power failure, the Uninterruptible Power Supply (UPS) or the generator is used. UPS can be used only for supplying the power for some important equipment (such as computers). It is easily installed, easily accessed. However, the supply area is smaller. A generator can supply the power required for a larger area. However, the cost is high, installation is difficult, and it is impossible for every house to have its own generator. Because an UPLCM operates in a power failure, it doesn’t need power from the power line (network), only from the UPLCM itself. The electricity on the power line is simply used for the communication signals, thus the total power consumption is not large. Consequently, in this study, the most conveniently available resource, the backup power in the emergency lighting equipment or evacuation signs equipment, or the UPLCM can be equipped with a rechargeable battery as their power supply. In a power failure, it can switch into DC power operation Mode, as shown in Fig. 6.

Furthermore, ordinary emergency lighting equipment is usually turned on during a power failure and turned off otherwise. However, in the initial period when a fire occurs, the power may not fail but smoke might be everywhere, and the emergency lighting will not be activated. Hence, we integrate the UPLCM and the emergency lighting equipment so that when a fire is detected and the alarm given, the emergency lighting is immediately activated to provide more sufficient light for evacuation from the fire scene on the one hand, and to warn people of the occurrence of a fire on the other hand.

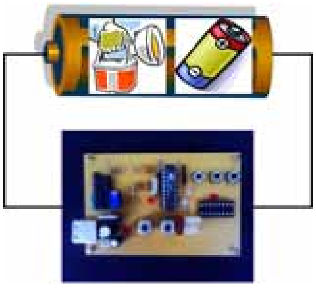


Fig. 6 The DC power source for UPLCM

When an UPLCM operates in AC/DC modes, do not worry that the AC signal may flow into the circuits, because the coupling circuits will isolate the internal power from the external power, as shown in Fig. 7. A fire can cause a short circuit or circuit break to the wired network, thus the network may fail under those two situations. However, we can determine the fire starting point according to the communication failure between the pieces of equipment.

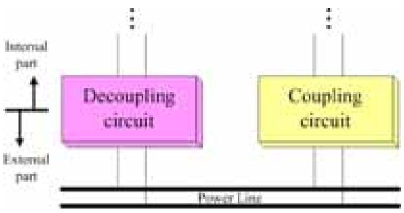
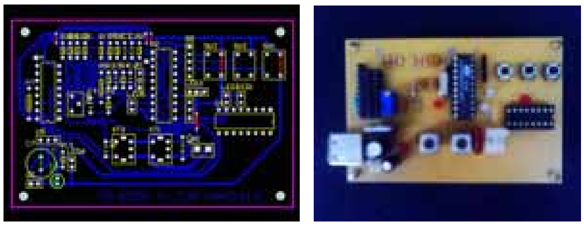


Fig. 7 Coupling circuits block diagram

4. System Implementation

In this study, devices and circuits are used for the actual test. After the test is complete, the Printed Circuit Board (PCB) is fabricated, and the circuit layout of the UPLCM is shown in Fig 8(a), and the actual implemented circuit board is shown in Fig. 8(b).

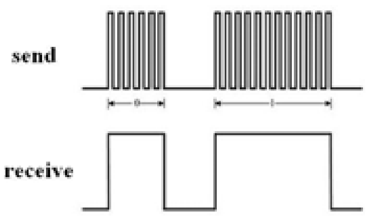
For the system communication part, in order to simplify the complexity of the hardware, the modulation signal is generated by the microprocessor in the transmission part. The actual waveform of the transmitted signal “0” is shown in Fig. 9(a). The receiver demodulates the received signal. The waveform of the actual received signal “0” is shown in Fig. 9(a). In the same manner, Fig. 9(b) shows the waveform for the transmitted and received signal “1”. Then the microprocessor at the receiver end determines the signal to be 0 or 1. The signal is determined as 0 or 1 according to the principle shown in Fig. 9(c). The period of “1” is twice of that of “0”.



(a) Circuit layout **(b) Hardware implementation**

Fig. 8 Fire detection system module

(a) The waveform of signal “0” **(b) The waveform of signal “1”**



(c) The modulation and demodulation of signals

Fig. 9 Modulation and demodulation

Finally, the UPLCM is connected with temperature sensors to perform the test. The temperature sensor used is a Dallas DS-1821. There is no need for additional conversion circuits. Only one pin is used for the digital writing and reading of temperature. An oscilloscope is used for the test. The actual signal measured in the house is shown in Fig. 10. The data transfer rate of the power line is about 160 KHz. The period of the transmission end is about 6.2us and the latency of the receiver end is about 25us. Thus, the transmission delay is very short.

When facing power failure under a normal power supply situation, the system can really maintain the operation in DC power supply mode.

Fig. 10 Transmission delay measurement

5. Conclusion

In this study, to solve the problem where an ordinary fire detection system can not operate normally in a power failure, a fire detection system based on an uninterruptible power line communication network is proposed. This system can maintain the detection with uninterrupted power to ensure that a timely fire alarm can be activated even in a power failure; for example, a fire caused by a candle or the circuit breaker not switched off immediately on power failure. For the design and the implementation, low cost microprocessors and parts are used to construct the UPLCM with the connection of various detectors according to the actual situations. The implemented results show that the system can really resolve the inadequacy of an ordinary fire detection system, especially the mechanism for maintaining the normal detection operation in a power failure. The UPLCM designed in this study can act as a communication platform. In the future, it can be used in the study of other fields, such as the indicators for evacuation, emergency rescue systems, and so on.

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