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INTELLIGENT SECURITY SYSTEM BASED ON POWER LINE COMMUNICATION

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Abstract. *"Safety and Security" is one of the basic requirements of human life. In general, accidents and disasters are much more occurring at home. How to prevent the happening of accidents and disasters is a very important issue for every family. In this paper, we develop home security technologies to ensure safety and security at home. Because of the reliance of the electrical apparatuses, appliances and devices in our daily life, the power line system has been well established for a long time. Hence, we developed a communication network using the power line as the media and established a security system by using the power line communication (PLC) network. To communicate via power line, the high-frequency signal is transferred over the AC power signal, which is transmitted in 50/60 Hz, with modulation technology. We use the mechanism of multi-carrier modulation to realize the function of automatically dispensing identification number to a connected device. With these designs, the probability of communication collision on the power line will be relatively low. All of the above make the overall system convenient in use and operation. Finally, we use the A* algorithm to find a safe escape path when disaster happened. Hence, an intelligent security system is constituted.*
Keywords: Power line communication (PLC), Multi-carrier modulation, Intelligent security system, A* algorithm

1. **Introduction.** Power line communication (PLC) is a communication technology that enables transmitting data over existing power transmission and distribution lines. The power line network surpasses the phone network in size and coverage. It is very beneficial to the development and promotion of communicating using PLC networks. For power line communication, only plugging the modem into the power-outlet, just like using the appliance in our daily life, can form the communication and no more media or equipment are needed. It is cheap and convenient for use. Unlike wireless communication, it will never be blocked by compartments and no extra electromagnetic wave, which is harmful to human body, will be generated. Thus, PLC is very suitable for small regional information sharing and for the development of digital home automation.

In previous studies, Cortés et al. [1] proposed an analysis of narrowband power line communication channels for advanced metering infrastructure. Dubey et al. [2] proposed performance analysis of a multi-hop power line communication system over log-normal fading in presence of impulsive noise. Son et al. [3] proposed a power management application for a home using power line communication. Rehman et al. [4] proposed a new modulation mode, multiband-orthogonal frequency-division multiplexing (MB-OFDM), to enhance the efficiency of the PLC. Lu et al. [5] proposed an application in wisdom management of smart home using PLC. From these studies, the speed and quality of the power line communication have been the focus of the study. Generally, the data communication amount of a security system is not great. So we developed a 100kbps narrowband PLC modem for a security system. In this PLC modem, in order to ensure the quality of communication, we use the multi-carrier modulation methods. Using this method for finding the frequency in the power line for PLC is of less interference. Carrier detection can reduce the collision during communication. Hence, this method can ensure the efficiency and quality of the PLC modem. In this system, we have designed a variety of sensing modules. Each module can work independently and can be connected to the monitoring computer by PLC. We can see that PLC is very suitable for the application in the home security. So in this paper, PLC is used as the main communications interface for an intelligent security system.

MCS51 series single-chip CPU is used for all modules and PLC modem for the security systems. On each module, it includes an LCD display, Chinese Voice Features, RGB LEDs and an RF communication interface. The wireless communication interface can be used as an auxiliary communication media while PLC being failure, as well as for the module diagnostic use. The security system modules are usually steadily installed, so we use the A* algorithm to design a disaster escape route in this system. When a disaster occurs, the system can provide the shortest and safest escaping route with the location information of each module and the detected signals. Hence, people in the disaster site can escape quickly and safely.

2. **System Architecture.** In this paper, we use PLC to establish a network for home automation and security. The system architecture is shown in Figure 1. All automation and security modules are connected through the power line of the home electrical system. Since no extra power module is needed, the modules can be significantly down-sized. In our security system, an MCS-51 series single-chip (STC 12C5A60S2) is used for the modules. This chip has functions of ADC, PWM and two UARTs. Thus, only one chip can complete the operations of any one module. This is evidently helpful for reducing circuit complexity. The block diagram of the security module is shown in Figure 2.

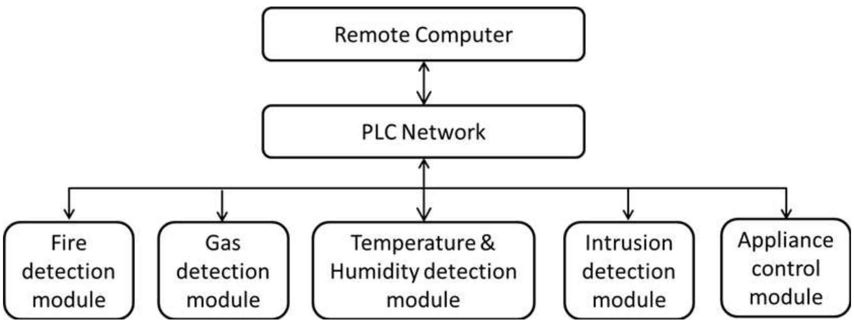


FIGURE 1. Architecture of the security system

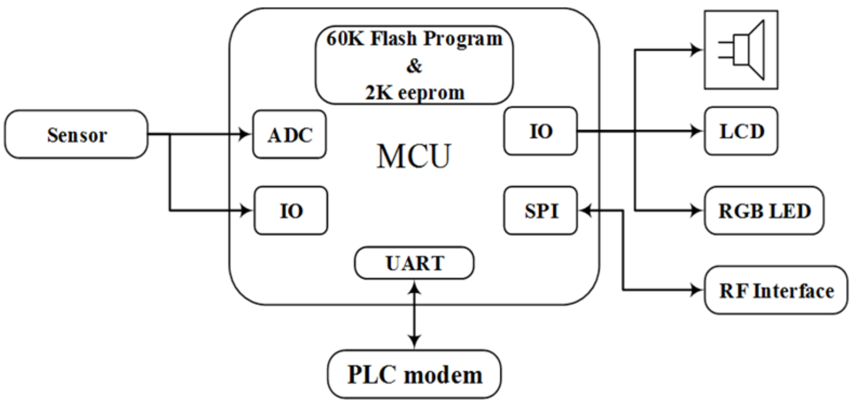


FIGURE 2. Block diagram of the security module

We define a data packet structure for data transmission. There are many advantages for communication with a well-defined data packet structure.

(1) Source of the information can be easily identified and the data can be easily analyzed.
(2) The leading code and the check-sum can ensure the correctness of the information.
(3) The length of the data packet can be estimated, and the receiver can confirm the data integrity.
(4) The required transmission time can be pre-determined, and the communication efficiency will be better.

Table 1 shows the protocol format of our system. Each data followed by 0x35H at Byte 0. The other bytes are illustrated in the following.

(1) ID: This byte defines the type of the sensor and the state of the receiving/transmission. In the ID Byte, Bit 7 indicates the data being received or transmitted, where "0" means requiring information from the host, and "1" means transferring from the module. Bits 5&6 is the type of the sensor module, where "00" means a wired sensor module, "01" means a wireless sensor module, "10" means other systems, and "11" is the system parameter or other system information.
(2) Sensor Kind: This byte is used to define the detail of the sensor or module, called as group number. Table 2 lists several types of sensors. By expanding this table, modules with other functions can be used for the system.
(3) State: For a smart sensor module, it describes the state of the module or the sensor. That is, it can be used for diagnostic. Considering a current-sensing module as an example, since there are algorithms as with the module, after processing the data on the sensor, the malfunctioned sensor can be isolated and marked by this byte.
(4) Module: This byte is used to define the module ID between 0 $\sim$ 255 (00H $\sim$ FFH). So each group can contain maximally 255 identical modules. By combining the bytes of Sensor Kind and Module, there can be at most 65,535 modules or devices on the security network.
(5) Data: Bytes 5 $\sim$ 8 are used for transferring the measured data. It can also be used for setting parameters on the modules for the monitoring software.
(6) Check Sum: This byte is used to check if there is any error on the transmission data. It is simply taking the lowest bytes of the addition of the entire 10 bytes including the starting byte 35H. A reason for this definition is the limited computation power of a single chip.

Table 1. Protocol format

Byte 0	Byte 1	Byte 2	Byte 3	Byte 4
35H	ID	Sensor Kind	State	Module
Byte 5	Byte 6	Byte 7	Byte 8	Byte 9
Measured Value 1 (Upper byte)	Measured Value 1 (Lower byte)	Measured Value 2 (Upper byte)	Measured Value 2 (Lower byte)	SUM (Bytes 0-8)

The PLC architecture of this paper is shown in Figure 3. After plugging to the power socket, the Power Line Modem (PLC Modem) will detect if there is any interference occurring by scanning other PLC modems on the power line using the frequency table shown in Table 3. We will also test the transmission speed 2400bps $\sim$ 115200bps in the communication quality of each carrier frequency, and record the better communication quality of carrier frequency and speed. A message of requesting an ID will be raised by the newly plugged PLC modem when an undisturbed frequency and communication speed is found. Then the system will assign a new ID and the best communication carrier

TABLE 2. Sensor kind table

bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0	Sensor Kind
0	0	0	0	0	0	0	0	Intrusion ♯ A
0	0	0	0	0	0	1	0	Glass
0	0	0	0	0	1	0	0	Fire
0	0	0	0	0	1	0	1	Human infrared
0	0	0	0	0	1	1	0	Appliances
0	0	0	0	1	0	0	0	Temperature
0	0	0	0	1	0	0	1	Humidity
0	0	0	0	1	0	1	0	Illuminance
0	0	0	0	1	0	1	1	Gas
0	0	0	0	1	1	0	0	Smoke
0	0	0	0	1	1	0	1	CO
0	0	0	0	1	1	1	0	CO_2
0	0	0	0	1	1	1	1	Alcohol
0	0	0	1	0	0	0	0	AC Meter
0	0	0	1	0	0	0	1	DC Meter

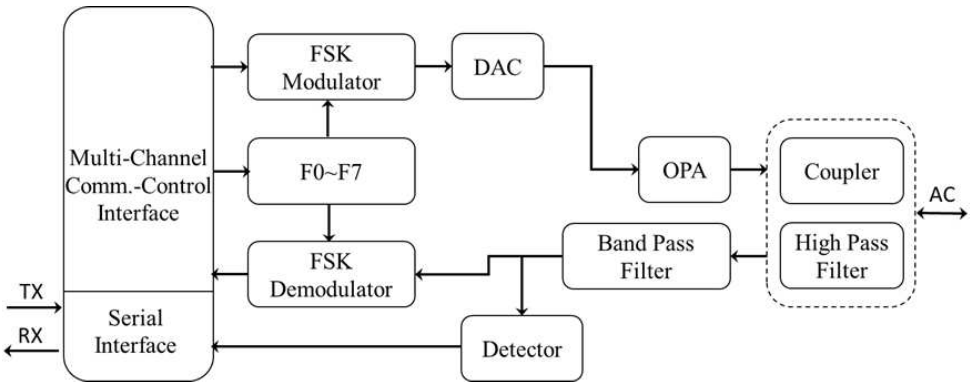


FIGURE 3. PLC architecture

TABLE 3. Carrier frequency

Carrier	F0	F1	F2	F3	F4	F5	F6	F7
Frequency (kHz)	60	66	72	76	82	86	110	132

frequency and speed date to the PLC modem automatically. There is no communication on the network system unless there is any event sensed by a security module. So the communication network is quiet for most time.

3. **Algorithm Analysis.**

3.1. **PLC communication algorithm.** Powerline environment consists of the power lines, power components, electrical characteristics of the load, and user equipment noise caused. Therefore, the entire power line communication environment must be as far as possible to take these effects into account, in order to ensure the quality and efficiency of communications. Because the power line is originally designed for power transmission instead of communication, there may be a lot of devices using electricity in circuit. These devices may have power lines causing some degree of pollution (power harmonics, noise, etc.).

Figure 4 is an ideal case of no load. The power line is a transmission line with uniformly distributed impedance, and power lines above the signal will affect distributed inductance, capacitance and an outer layer of insulating material. This characteristic impedance can be expressed as [6]:

$$Z_L = \sqrt{(R + jwL)/(G + jwC)} \tag{1}$$

Attenuation of the power line signal the frequency will increase as the distance increases. Signal attenuation function can be expressed as [6]:

$$A(f, l) = g_i \cdot e^{-\left(a_0 + a_1 \cdot f^k\right) \cdot l_i} \tag{2}$$

In (1) and (2), f is the carrier frequency, l_i is the transmission distance, a_0, a_1, k are attenuation parameters, g_i is the weighting factor of path i, and $A(f, l)$ represents the frequency and transmission distance attenuation related items.

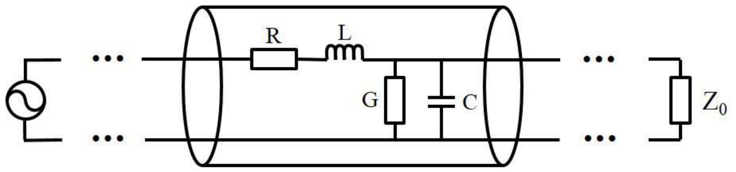


FIGURE 4. The characteristic impedance of the power line [6]

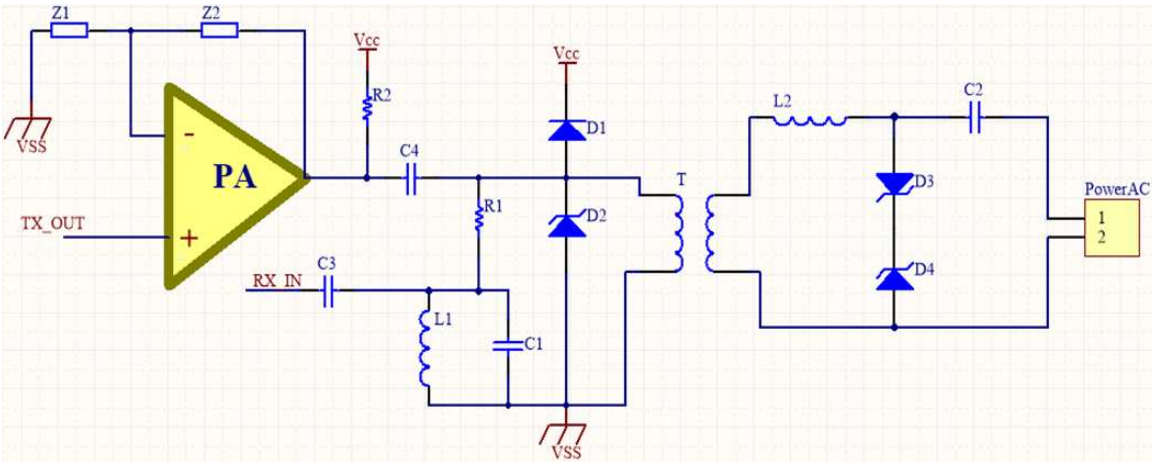


FIGURE 5. HPF&BPF circuit

Figure 5 is an equivalent circuit of the core of the PLC modem of this paper. $D_1 \sim D_4$ form the protection circuit to ensure the amplitude of high frequency signal in the range of $V_{cc} \sim V_{ss}$. T is a coupling transformer. C_3 and C_4 are cross-connected capacitors. C_2 and L_2 are high-pass filters (HPF) with

$$f_c = \frac{1}{2\pi\sqrt{L_2 C_2}} \tag{3}$$

R_1, C_1, and L_1 are band-pass filters (BPF) with

$$f_c = \frac{1}{2\pi} \cdot \omega_c = \frac{1}{2\pi\sqrt{\frac{R_1 + R_L}{R_1 L_1 C_1}}} \cong \frac{1}{2\pi\sqrt{L_1 C_1}} \tag{4}$$

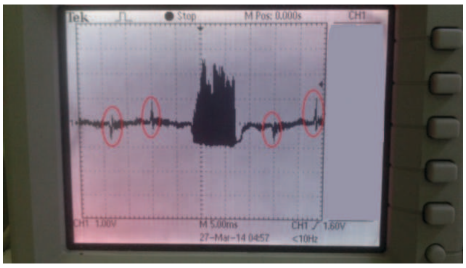
R_L is the equivalent DC resistance of L_1. Since $R_1 >> R_L$, R_L can be ignored. The designed pass band of the BPF is $60 \sim 140$ kHz.

3.2. **Escape path algorithm.** In the motion planning, we use A* searching algorithm to program the safety escaping path according to the relative risk values of each cross point. The formula of A* searching algorithm is:

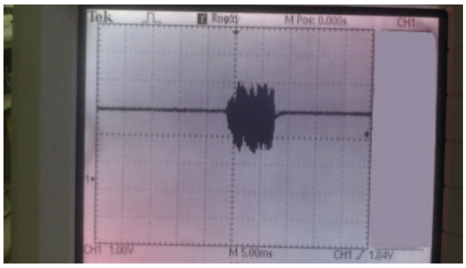
$$F(n) = G(n) + H(n) \tag{5}$$

The core part of a searching algorithm is the definition of a proper heuristic function $F(n)$. $G(n)$ is the exact cost at sample time n from start point to the target point. $H(n)$ is the minimum cost from the start point to the target point.

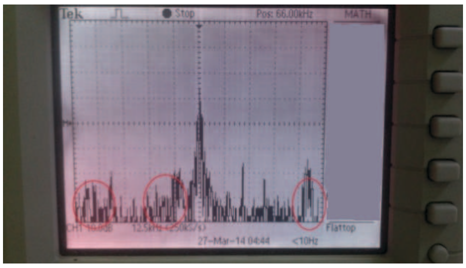
4. **Experimental Results.** We use multi-carrier modulation (MCM) in this paper to conquer the impedance variation of the power line. Figure 6 shows the actual test results for comparison. Left figures are under the circumstances of multi-carrier modulation



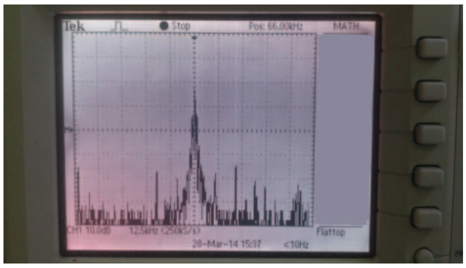
(a) Without MCM (time domain)



(b) With MCM (time domain)

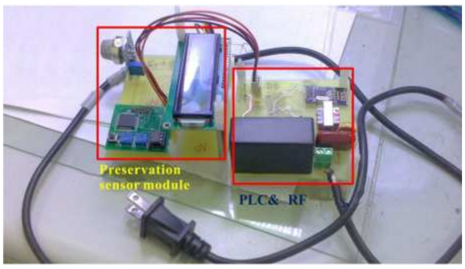


(c) Without MCM (freq. domain)



(d) With MCM (freq. domain)

FIGURE 6. Comparison of using multi-carrier modulation or not



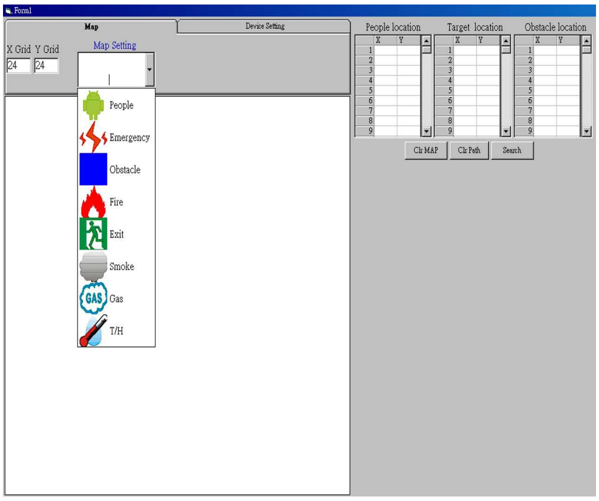
(a) Circuit of gas module

(b) Gas module

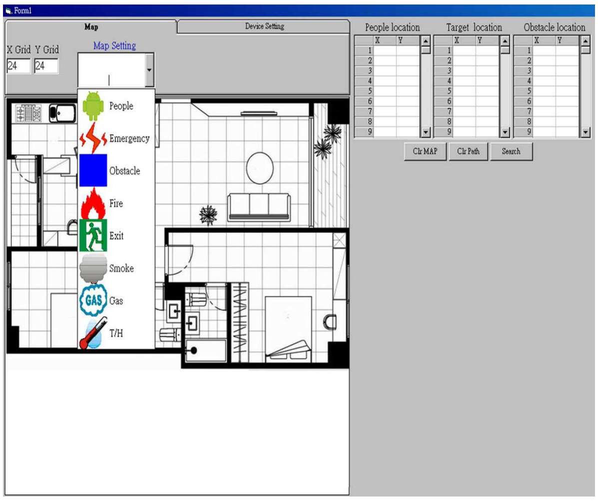
(c) Fire module

(d) T/H module

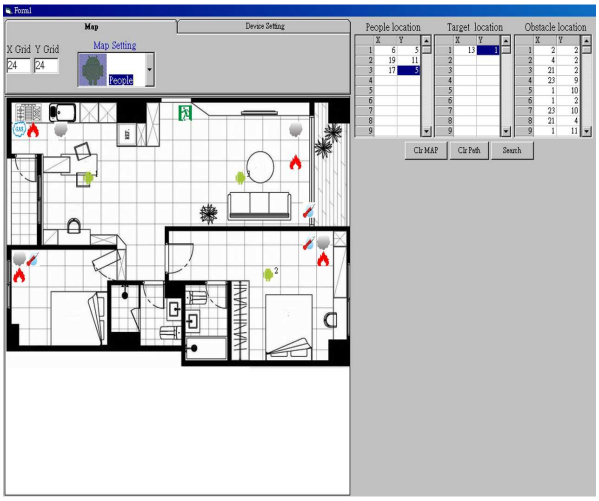
FIGURE 7. Security module



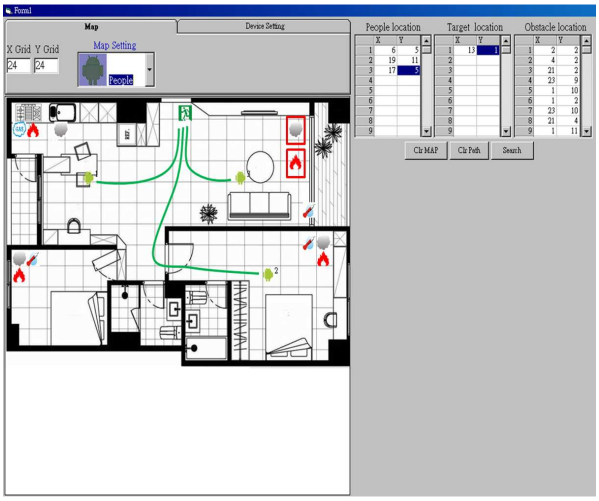
(a) Module selects



(b) Environment setting



(c) Environment setting result



(d) Event warn and shortest path result

FIGURE 8. User interface system result

unused. It is evident that there are interferences at frequency outside the pass band on the power line. Right figures are the results of using multi-carrier modulation method. The results are obviously better than the unused cases in signal quality.

We have designed a number of security modules to cope with different needs. Each module works independently and displays on the LCD the sensed data in the surroundings. Figure 7 shows some of the designed module. Once any one module detects any danger, it will warn by sound and broadcasts the alert message to other security modules and the monitoring system. We have designed a user interface system. Users can set environmental plan and define each sensing module installation location. So the user interface system is closer to the real environment and friendlier use, the actual screen shown in Figures 8(a) and 8(b). When a disaster event in the environment is detected by a module, the relative icon will be marked with a red outline. Then the system will calculate the shortest escape path according to the environment situation using the A* algorithm for everyone in the environment, as shown in Figures 8(c) and 8(d).

5. **Conclusion.** This paper presented an intelligent security system based on PLC. Because of the wide coverage of the power line which is unmatched by any network, without any extra cable laid, and without any communication dead zone, the power line is very suitable for a security system.

Since the power line is originally designed for power transmission, many problems, such as noise, interference, and signal attenuation, have to be faced for transmitting high frequency signals on the power line. It has been verified in this paper that the proposed functions of multi-carrier modulation can really conquer the frequency selective fading and reduce the impact of the power line signal interference. It is evident that the proposed intelligent security system using the existing power lines can be applied in smart home automation. Thus, the smart home can be easily set up and we can live more safely.

In the future we will continue to improve the speed and PLC quality. Also we will develop more modules for the designed system for the applications in more fields. Finally, we hope to develop modules with automatic positioning technology, so that the system is more convenient and intelligent.

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