Simple and Robust Method for Detecting the Electrical Appliances Using Markers and Programmable Logic Devices

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Abstract—**The detection of appliances and their location is important for the efficient management and automatic operation of appliances and their power consumption. In this paper, we describe a simple and robust method of detecting appliances based on their location by using programmable logic devices (PLDs). The results of simulation and implementation are also included.**

*Keywords — **Appliance detection; Location; Location detection; Home Network; Domotics; Power management; Context***

I. INTRODUCTION

We are dependent on electric power to carry out our day-to-day activities. We use electric power to operate various kinds of appliances. A home energy management system (HEMS) [4] manages the power supply at homes in order to reduce power consumption. HEMS can help in reducing power consumption solely by detecting the presence of a human at the location, and therefore, it is not a foolproof system. The identification and location of appliances is required for minimizing power consumption. Information on the location of appliances is used for the integrated control of electric appliances, for providing satisfactory context-aware services, and for the power management of power generators (outdoor power stations and indoor power generators), storage devices (batteries), and consumer appliances so as to minimize power consumption.

There have been several studies on methods for detecting appliances along with their power consumption levels and patterns [1], including the relation between the instantaneous values of current and voltage [3]. Most of the detection methods have employed an actuator to control the power supply to the appliances and a detector with a power outlet [1][3][6]. The systems were designed to manage legacy appliances without any networked communication capacity. Since these systems used the working power consumption data of appliances, they were faced with the limitation of being incapable of detecting an appliance that is operating. In other words, if a user turns off an appliance and plugs it into another power outlet, the system can no longer detect the appliance.

In this paper, we describe a simple, cheap, and robust detection method that uses simple physical markers and programmable logic devices (PLDs) for detecting the locations of power source (power outlet) and electrical appliances without modifying the existing facilities and appliances.

II. DETECTION PROBLEMS OF HOME SERVICE SYSTEM

Sensor technology is one of the bases for ubiquitous services. During the initial stage of the development of Ubiquitous Home services, various kinds of sensors were used to detect context information such as the location and behavior of users, the temperature of the environment, and the relations between objects and users. The use of large number of complex sensors makes the system expensive and difficult to install and maintain. Recently, activity-based computing has been studied in order to extract useful context information from the raw data obtained by simple sensor systems, such as the sound of draining water [2] and the electric noise of power switch [5]. The data of a user's power consumption pattern is a single data from which context information can be obtained. In order to realize a practical sensing system, it is important that the modifications in the existing facilities to accommodate the system should be minimal.

Ever since context-aware computing was introduced, the information on location has been one of the main context information. This information is essential and useful for the construction of a model of the user's behavior from data on power consumption. The user's intention to operate appliances at certain locations can be determined from this model. Each service domain requires unique location information. Generally, a user's concept of location is a region in which similar activities take place [9]. It is possible to extract routine activities from the distribution and operation of home artifacts including electric appliances [11]. The routine consists of the "contextual locations" that describe the sequential pattern of use of the appliances. The information is important because we can obtain not only action and activities but also time, ownership, and awareness from the contextual locations [10].

The ways of detecting the location are by using high-resolution cameras with object recognition [7] or RFID. However, these methods are expensive and not robust. Further, the use of high-resolution cameras for identification has privacy-related issues. The sensor network [8] can also be used

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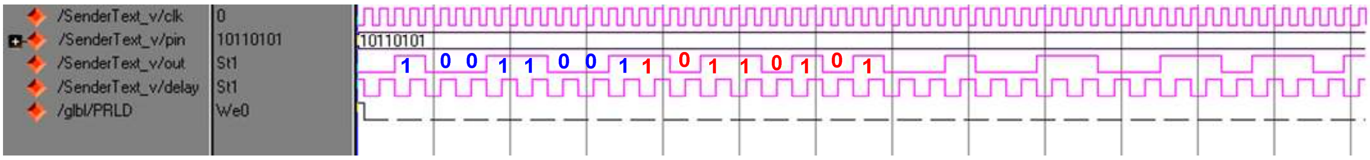
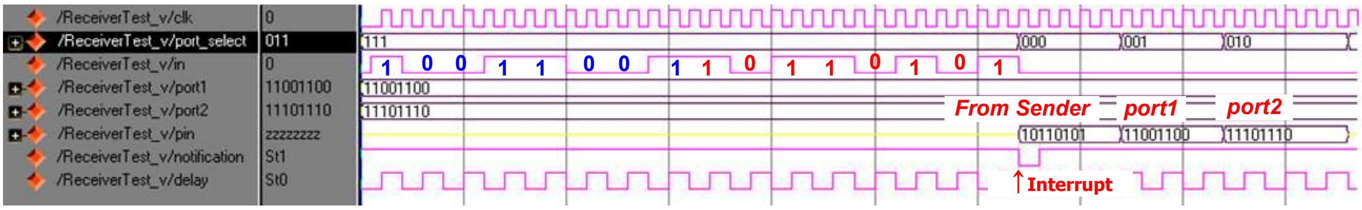


(a) Sender (preceding bits stream for start of stream indication: 10011001 / actual bits stream: 1011010)



(b) Receiver (bits stream from sender: 10110101 / port1: 11001100 / port2: 11101110)

Fig. 1 Simulation results of PLD implementations

in order to detect the location information and appliance. However, setting up such network requires high system installation costs and maintenance. These problems obstruct the popularization of automatic home services including home energy management services.

In order to provide home energy management services with the contextual locations the high resolution location detection systems are not necessary but the information on contextual locations that are related to the routine activities (e.g. preparing food in the kitchen, and washing in the bathroom) of appliances are sufficient. From the power consumption pattern detecting the location is impossible without a pre-defined location of the power outlet or the appliance. The classification and detection of multiple appliances that are same are also impossible.

Some domotic service systems are equipped with user interfaces and actuators that provide the options of controlling the appliances automatically or manually. However, when a user changes the location of an appliance, i.e., from one power outlet to another, or uses a new appliance, the user has to first turn on the appliance and then register the location of the power outlet by manually entering the exact outlet port number.

We propose a method for detecting the physical markers on the power outlets and power plugs of appliances. We used an array of plastic rods to activate bit arrays in the PLDs (Fig.2). A smart multi-power tap detects the marker for determining the location of the power outlet on the wall and identifies the appliance by aligning the array of rods along the power plug of the appliance. The operation of the marker detection is basically a switch operation. Only the replacement of a power tap to a smart power tap is required in order to use the system.

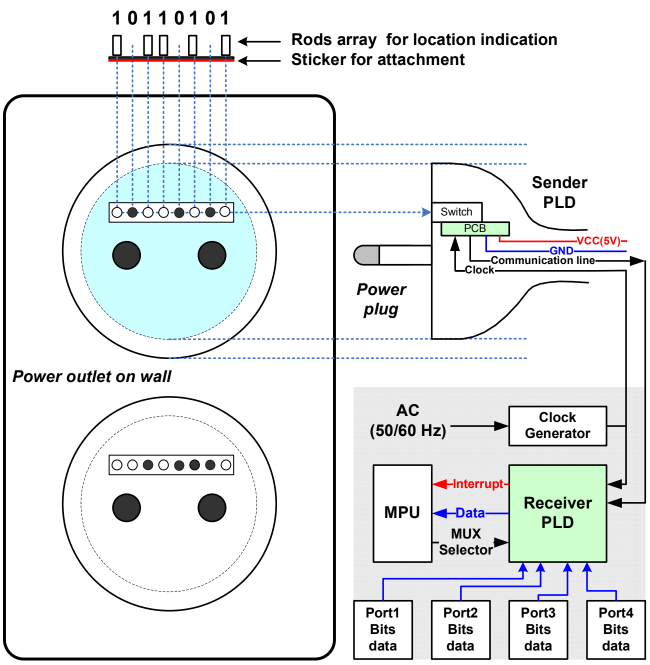


Fig. 2 Mechanical structure of the plug and system configuration

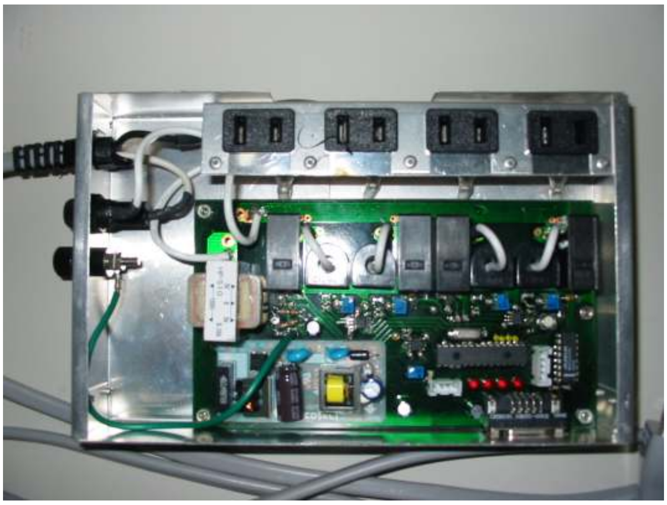


Fig. 3 SmartTap

Thus, there is no high cost installation and technical problem for using the system. In addition, if appliance providers attach the arrays to their appliances during manufacture or before sale, and home providers attach the coded array to pre-defined locations such as bed room, living room, bathroom, and kitchen, then the users have no additional work while using the system. As a practical system, we developed "SmartTap" that measures and controls the power consumption of four independent power ports.

III. IMPLEMENTATION

For retaining the multi-tap functionalities, the system requires a power line between the power outlet on the wall and SmartTap. The sender reads the bit data from the fixed power outlet and sends them to the receiver through the lines. In order to reduce the number of transmission lines and errors from the disturbance, we applied serial communication. The receiver receives this data, changes it into a bit array, and generates an interrupt signal to a micro controller of SmartTap. The receiver is equipped with a smart power outlet. Fig. 2 shows the mechanical structure and wiring of the proposed system. When a user plugs the SmartTap to a fixed power outlet on the wall, the array of rods on the surface of the power outlet operates the switches array of the sender. The sender converts the bit data obtained from the switches to a serial bit stream and sends the data to the receiver. The receiver provides the sender with power and a clock for synchronization. The sender sends the data at every rising edge of the clock signal. The receiver receives the data at every falling edge.

We developed a PLD prototype by using Verilog. Fig. 1 shows the results of a simulation of the PLD implementation. The receiver also reads bit arrays that are activated by the plugs of the appliances plugged into the SmartTap and sends the measured data to a micro controller in the SmartTap. The sender and receiver operations are synchronized with the AC power supply (60 Hz or 50 Hz). We used full-wave-rectified AC voltage and a Schmitt trigger to double the clock frequency (120 Hz from 60 Hz) for the synchronization.

The micro controller in the SmartTap reads the bit data from outlet ports or a sender selected by three selection bits of a multiplexer (MUX). In the present study, we used three bytes for identifying of the company, category, and model number of the appliances. As shown in Fig. 1, the number of ports and bytes for each port were reduced to two and one, respectively, because of the space constraints in this document. Because of a low operation frequency and a short distance, the interference for data transfer and clock had no problem in the actual operation.

IV. RESULTS

In order to evaluate the feasibility and performance of the system, we conducted two experiments: data transmission only and data transmission with actual appliance operating under several conditions of transmission line. The common power condition of the experiments is 220V AC with 60 Hz. We used AWG of 30, i.e., wires with diameter of 0.25 mm as transmission lines.

A. Data transmission test without appliance operation

We have evaluated the data transfer for three distances (1, 2, and 3m) and shapes (straight, single folding, and winding) of the transmission line. The diameter of the winding was 55 mm. Fig. 5 and table 1 shows the results. The MAX and MIN values of edge in the table indicate the sizes of the overshoot. Fig 6 lists the values. The MIN value is important because the value can makes over-clock if it exceeds more than 1.5~2 V.

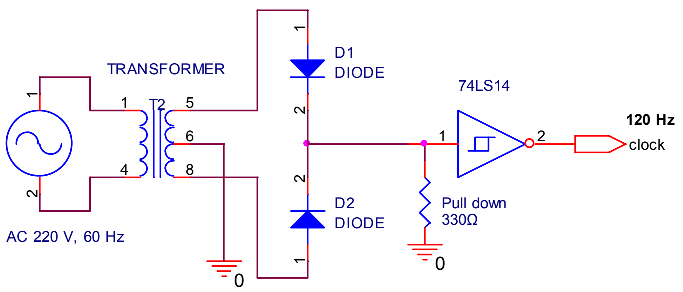
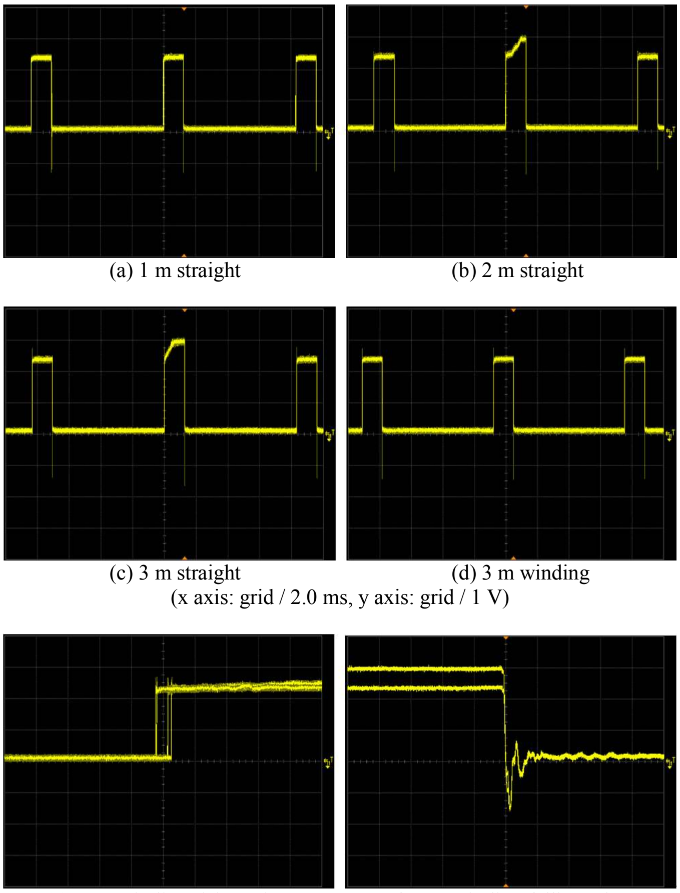


Fig. 4 Clock generation module



(a) 1 m straight (b) 2 m straight

(c) 3 m straight (d) 3 m winding
(x axis: grid / 2.0 ms, y axis: grid / 1 V)

(e) 3 m winding rising edge
(x axis: grid / 10.0 µs)

(f) 3 m winding falling edge
(x axis: grid / 200.0 ns)

Fig. 5 Pulse transmission without appliance operation

However, the values were less than 1 V in our experiments and did not cause such problem. The rising edge had longer settling time than the falling edge; however, the longest settling time was less than 5 µs.

TABLE I. DATA TRASMISSION WITHOUT APPLIANCE OPERATION

Length (m)	Transmission line	Rising edge overshoot		Falling edge overshoot	
		MAX5(V)	*MIN5(V)*	*MAX0(V)*	*MIN0(V)*
1	Straight	4.9	4.5	-2.5	0.75
	Single folding	4.9	4.5	-2.5	0.75
	Winding	4.9	4.5	-2.0	0.6
2	Straight	5.25	4.5	-2.75	0.75
	Single folding	5.25	4.5	-2.75	0.75
	Winding	5.25	4.5	-2.75	0.6
3	Straight	6	4.5	-4.0	1.0
	Single folding	5.5	4.5	-3.75	1.0
	Winding	5.5	4.5	-3.0	1.0

Appliance operation condition: 2.2A, 220V AC

In addition, fig. 5 (e) shows a small amount of jittering at the rising edge. However, the maximum variation was less than 10 µs. Since the minimum width of the clock pulse (logical "1") is more than 1 ms, the jittering do not violate the data transmission. The results also show that the longer transmission line makes bigger the overshoot. We restricted the maximum length of the transmission line to three meters because if the length is more than three meters, the coverage of the appliances of the SmartTap is very wide to estimate its contextual location. The results show that the maximum and minimum variations of overshoot are no problem for the system operation.

B. Data transmission test with appliance operation

In actual situation, users use a SmartTap in order to provide electric power to appliances and the system operates with actual operation of electric appliances. Thus it is

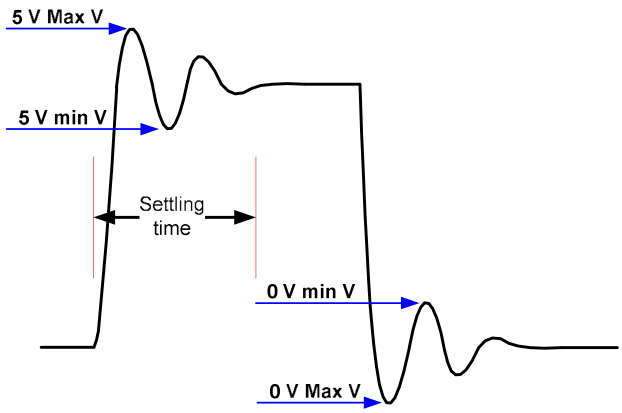
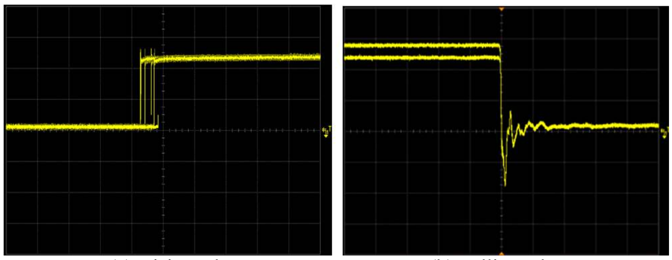


Fig. 6 Clock data reference position



(a) Rising edge (x axis: grid / 20.0 µs)   (b) Falling edge (x axis: grid / 200.0 ns)

Fig. 7 Pulse of transmission line with appliance operation (3m winding with hair dryer - current: 2.2 A)

necessary to check the interference of the operation of the appliances. We conducted the experiments with a hair dryer because it consumes significant amount of electric power and generates a lot of electric noises. Fig. 7 and table 2 show the results. In the experiment a hair dryer consumed approximately 500 W and 2.2 A with 220 V AC. In this case, the variation of jittering was more than the former experiment but less than 20 µs. The results show that there was also no problem during the data transmission.

TABLE II. DATA TRASMISSION WITH APPLIANCE OPERATION

Length (m)	Transmission line	Rising edge overshoot		Falling edge overshoot	
		MAX5(V)	*MIN5(V)*	*MAX0(V)*	*MIN0(V)*
1	Straight	4.8	4.5	-2.5	0.6
	Single folding	4.8	4.5	-2.6	0.9
	Winding	4.8	4.5	-2.4	0.7
2	Straight	5.3	4.5	-2.4	0.6
	Single folding	5.1	4.5	-2.3	0.7
	Winding	5.2	4.5	-1.7	0.5
3	Straight	5.5	4.5	-3.8	1.2
	Single folding	5.3	4.5	-3.8	1.3
	Winding	5.3	4.5	-3.5	1.4

Appliance operation condition: 2.2A, 220V AC

V. CONCLUSION

In this paper, we described a simple, cheap, and robust method by using PLDs for domotic service systems and HEMS so as to detect appliances and their approximate location before the appliances begin their operations. The additional installation cost of the sensor system has been one of the main barriers for the popularization and development of automatic electric appliance control and monitoring services although the services are essential for the energy management system. This method can easily be applied to conventional facilities without the modification and cost. Users can easily install and use this system both as conventional power-taps as well as advanced domotic service systems with network

Fig. 8 Bit-Watt network system in the Ubiquitous Home

capacity. A domotic service system can detect the appliance even if the appliance is not in a power-on state with the proposed system. The system can conduct routine services anytime and anyplace if the appliances are plugged in SmartTaps with the PLD and marker detector.

Smart meters that measure power consumption data and send the data to remote sites are one of the core components that provide home energy management services such as the measurement of power consumption patterns of users and the generation of effective feedback and guide for saving electric power. However, most of the current home energy management systems cannot obtain detail power consumption data of all of individual appliances but only measure the total home power consumption or several selected appliances that have a special measurement device. Our solution provides a simple and robust way to measure the power consumption of the appliances in order to realize the home management services.

We have developed PLD prototypes with a micro controller and continued actual test to get the location and device information. There are many kinds of appliances that have unique electric operational characteristics at home and the combinations of the appliances are more than the number of appliances. More experiments are required to confirm the stability under various conditions. However, the experiment results show the optimistic potentiality of the proposed system. We have a plan to evaluate the performance with our home energy management system; i.e., the Bit-Watt network system (Fig. 8).

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