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Field Programmable Gate Array (FPGA)-based Intelligent Management System for Home Appliances

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Abstract— **This project reviews the implementation of FPGA-based system design on common home appliances in order to achieve energy efficient usage on the appliances. There are many existed method on this subject in the real world. One common method is using the Pulse Width Modulation (PWM) to control the motor speed of the home appliances. In this project, an energy saving home automation was designed using the Quartus II software. The design included a security system, curtain controller, lighting controller and a PWM generator. Security system provides protection to the house. Curtain controller and lighting controller were designed to save electricity and at the same time maintain the house in the bright condition. PWM generator was designed to optimize the air-conditioner and thermostat usage and thus save energy. Not only this system has energy saving feature but it also provide security to the users. At the end of this project, the design has successfully implemented and tested using FLEX10k chip on LP2900 board. The real implementation on hardware has not been done yet but theoretically it is proven that the designed system can save electricity**.

Keywords: PWM, FPGA-based, Energy Saving

I. Introduction

In late 1970's, electronic device had been used widely on household. This is due to the advancement in technology day by day. For example, television set on early 1970's is still using Cathode Ray Tube (CRT) technology. Until 1990's, the technology of Liquid Crystal Display (LCD) was implemented into the television set design. This newly design television set had a clearer display and also much thinner than the CRT in size. With the ease brought by these technologies, it has become a trend where people starting to buy home appliances solely due to the attractive features added-on by the manufacturer. Some even claim just to have a digital life style at home.

However, the countless home appliances in a house appeared to consume a lot of energy. Consumers start to worry about their monthly electricity bills. In order to solve this problem, manufacturers start to add-in energy efficient feature into home appliances.

Until now, various methods had been implemented to improve the electricity efficiency of home appliances such as maintain voltage level, minimize phase imbalance, maintain power factor, maintain good power quality, use adjustable speed drivers or two-speed motors, control temperature and match motor operating speed [1].

Microcontroller (MCU) or Programmable Logic Devices (PLD) were used to control appliance functions such as display panel, temperature sensor and motor. However, PLDs have made steady headway into the home appliance markets due to the rapid decline in PLD cost per function. Until now, there are several types of PLD which are Programmable Array Logics (PAL), Generic Array Logic (GAL), Complex Programmable Logic Device (CPLD) and FPGA. In this paper, a technique of improving home appliances electricity efficiency using the FPGA-based design will be practiced.

II. ENERGY EFFICIENT DESIGN ON HOME APPLIANCES

A. Motor Control using PWM

A motor is operated with a permanent magnet. According to Altera Cooperation, in order to run an AC motor efficiently, the position of the internal permanent magnet must synchronize with the frequency of applied AC voltage. Therefore, sensors are used to detect the location of the magnetic rotor and read out the data for the designer. It is essential for the designer to adjust the frequency of the voltage accordingly to achieve optimal performance of the motor. One of the common methods is using PWM. PWM is widely used in power electronic.

In PWM, the time period of the square wave is constant. However, the time of the signal remaining high (T_{ON}) can be varied or modulated. If the PWM is implemented into the motor system circuitry, duty cycle and average DC value of the signal can thus be varied. Fig. 1 shows an example of the "on" time of a digital pulse.

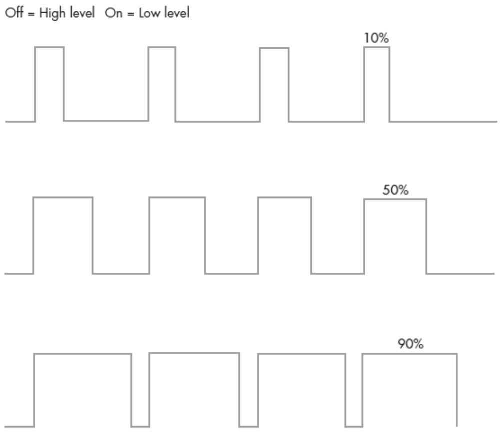

Figure 1 PWM Waveform

B. *Power Advantages of FPGA over MCU in PWM*

An application-specific PWM Intellectual Properties (IP) core in a FPGA has advantage of customizable of the fixed generic hardware in MCUs or DSP blocks. Fig. 2 shows how an optimized PWM in a FPGA can reduce the total harmonic distortion (THD) by nearly 50 percent at a high modulation index, as compared to the standard PWM in MCUs or DSP blocks. In turn, this reduces time-harmonic losses in the motor, reduces audible noise and increases global motor reliability. Experimental validations on Permanent Magnet Synchronous Motor (PMSM) shows that such THD reductions may provide a 50 to 55 percent reduction of motor and power converter losses, thereby providing tremendous gains in global efficiency [3].

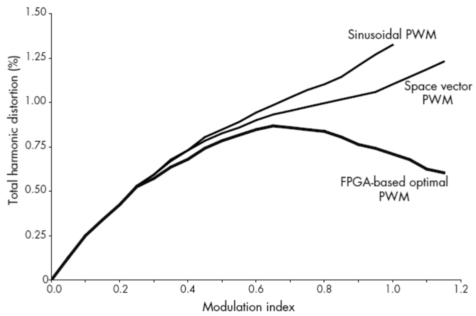

Figure 2 THD Comparison of FPGA-based vs. MCU-based Motor Control

III. Proposed Method

A home automation was designed to control a few appliances including air-conditioner, thermostat and lighting in order to optimize their usage and thus save energy. Besides, there will be a security system acting as a main switch that will close not used appliances once activated. This feature can help saving energy when users are not at home.

A. *Password Checking using State Transition*

The security system requires the correct sequence of password in order to be activated. In this design, the correct sequence of password is set to be 12345. Therefore, the state transition of this design has a total of six states as shown in Fig. 3. When the sequence of input password is correct, the current state will proceed to next state. Otherwise, it will return back to zero state. Output will only change into HIGH state once the program reaches the final state.

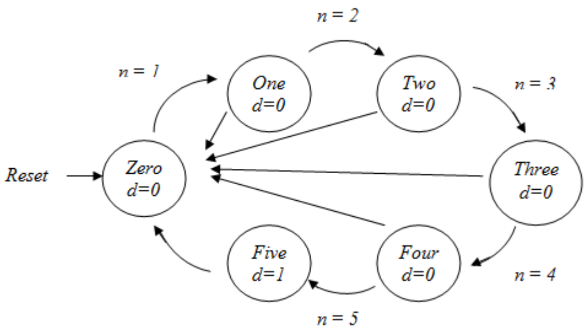

Figure 3 Password State Transition

B. *Security System*

When the users key in the correct sequence of PIN codes, it will either activate or deactivate the security state. Activating the security state will sound the alarm once the door is opened. Deactivating the security state will directly shut down the alarm. The security state is connected to other appliances. If it is activated, all other appliances will be shut down and vice versa. Fig. 4 shows the design flow of security system.

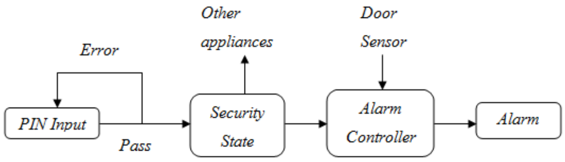

Figure 4 Security System

C. *Motor Control using PWM*

PWM can be created by comparing two signals together which are the carrier signal and modulated signal [4]. Carrier signal can be represented with many types of signal. These signals include sinusoidal signal, triangular signal, and sawtooth/ramp signal. In this project, ramp signal is chosen as the carrier signal. In order to design a ramp signal, a counter is required. The counter counts up for every clock cycle and returns back to zero once it reaches the highest value. The range is varied depend on the designer. Fig. 5 shows the visualization of this technique.

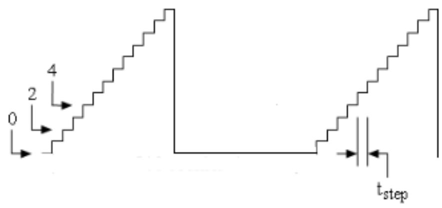

Figure 5 Pattern of Carrier Signal

The modulated signal can also be represented by many types of signal. Some designers use back the same type of signal with the carrier signal and alternate its frequency. Some designers use different types of signal while some simply use different level of pulse signal. Both signals are then compared to generate PWM as shown in Fig. 6 and

Fig. 7. The duty cycle of PWM can be varied depend on the modulated signal.

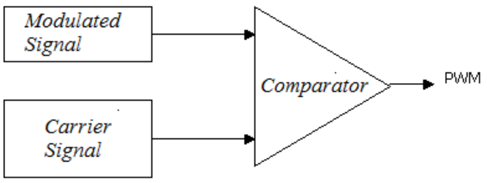

Figure 6 PWM Generator

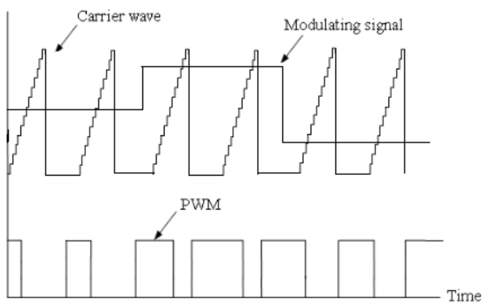

Figure 7 Pulse Generation Technique

D. *Intelligent PWM Generator*

Fig. 8 shows Intelligent PWM generator. PWM generated will be used to control the motor speed of air-conditioner and thermostat. By connecting to a temperature sensor, the generator is able to generate different duty cycle of PWM automatically according to the temperature desired by the users. As an additional feature, the generator is able to choose either air-conditioner or thermostat to operate by adding an appliances selector. When the current temperature is below 18°C, the generator will operate thermostat and close air-conditioner. When the current temperature is above 18°C, the generator will operate air-conditioner instead and close thermostat. This feature can save energy by turning off the appliances that are not used.

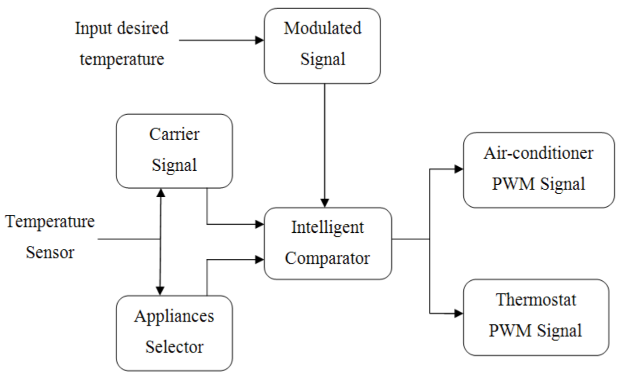

Figure 8 Intelligent PWM Generator

E. *Curtain Controller*

The curtain controller is connected with a sunlight sensor and television switch. This controller cooperates with lighting controller to ensure the house is in bright condition. When the sensor perceives sunlight, the controller will pull up the curtain. When the sensor does not perceive any sunlight, the curtain controller will pull down the curtain and send a signal to light controller to switch it on. At testing stage, Hamamatsu S8369 [5] will be used as the proposed sun sensor. When the television is switched on, the controller will pull down the curtain. When the television is switched off, the controller will pull up back the curtain if the sunlight sensor perceives any sunlight. Users are no longer frustrating pulling up and down the curtain anymore. Fig. 9 shows how curtain controller works.

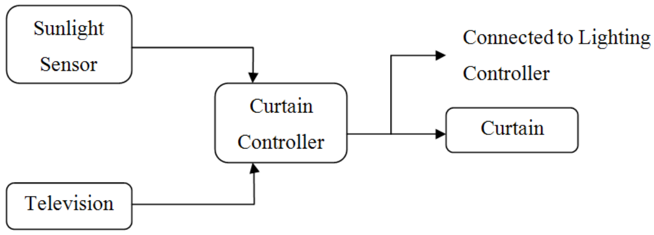

Figure 9 Curtain Controller

F. *Lighting Controller*

A lighting controller is used to ensure the usage of the main lamps and side lamps is optimum and thus save more energy. The controller is connected to human sensor, television and pause switch as shown in Fig. 10. At testing stage, the LED Human Sensor Night Light will be used as the human sensor. When the human sensor senses any movement, the controller will switch on the main lamp only. If the sensor does not perceive any people's movement, both lamps will be switched off. The lighting controller is cooperating with the curtain controller. When the sun sets, the sunlight sensor perceives no light. The curtain controller will send a signal to the lighting controller to switch on the lamps. This step helps to maintain the house in bright condition.

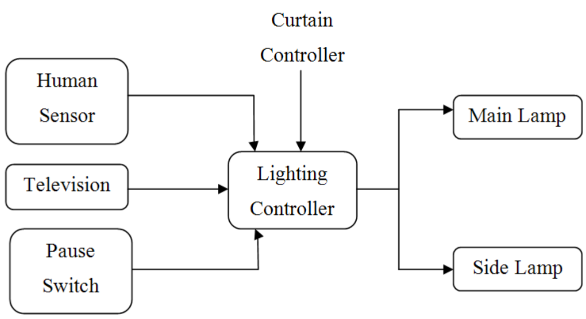

Figure 10 Lighting Controller

G. *Simulation and Implementation Scenario*

All the separated modules as mentioned earlier will be simulated using Functional and Timing Simulation in Quartus II. LP 2900 board is chosen for implementing the program. LP 2900 Board contains the FLEX 10K chip and many other input and output devices that can be used to test the design. These devices include LED bulbs, 7 segment display, switchable clock speed, data input switches, pulse switches, keyboard, A/D converter, D/A converter, 8 x 8 dot matrix display, electronic dice, buzzer and LCD display.

IV. Result and Discussion

The design was separated into several modules for the ease of designing and debugging. The core of each module was programmed using VHDL codes and converted into block symbol. After that, the modules were linked together using the Block Diagram Technique.

A. Converting VHDL design into Block Symbol

Fig. 11 shows the symbol for the security password module after converting VHDL codes into Block Diagram. From the diagram, it has 3 inputs which are pin, reset, and clock.

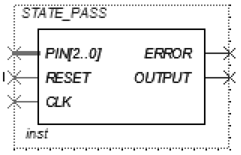

Figure 11 Block Symbol for security password

B. Home Automation

Fig. 12 shows the Block Diagram Design of the Home Automation and the connection between all the modules designed.

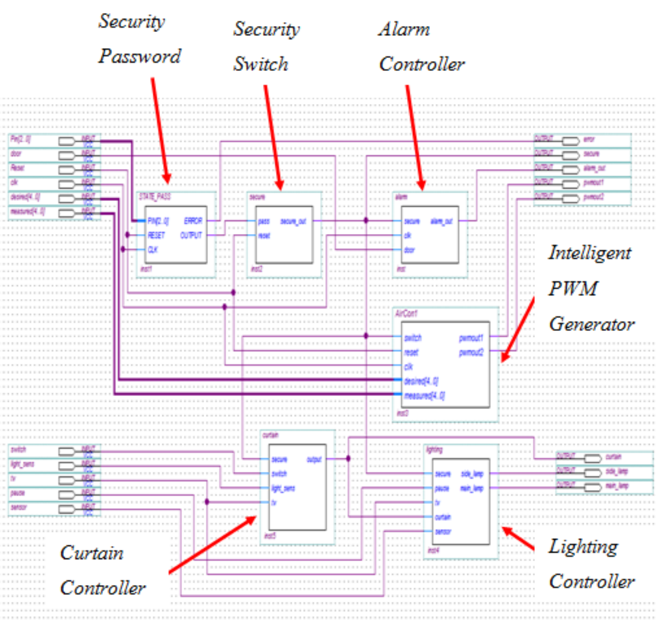

Figure 12 Block Diagram of Home Automation

C. Simulation using Quartus II

Fig.13 shows the waveform simulation of overall Home Automation. The result shows that all the output was operating as expected. The security state was reacting with the pin codes. The PWMOUT1 signal was reacting with the temperature reader. The PWMOUT2 signal was off all the time because the measured temperature was below 18°C. The curtain was reacting with the light sensor.

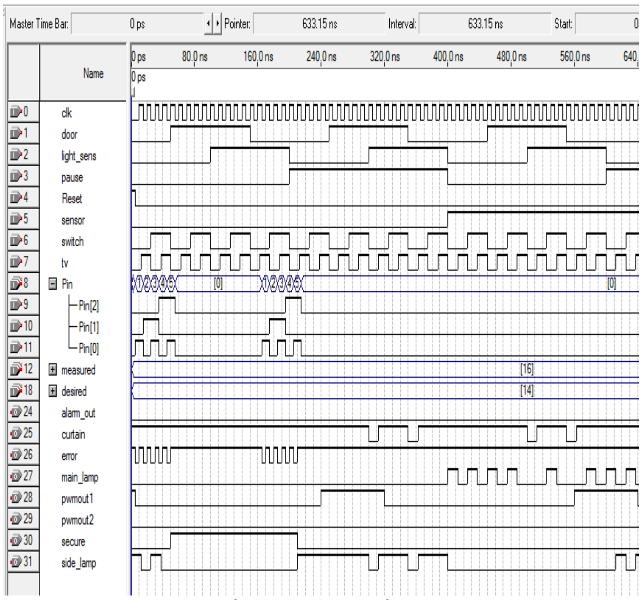

Figure 13 Waveform Simulation of Home Automation

D. Implemention on Testing Board

The LP2900 testing board has many devices that can be used to test run the system. Before the system was run, pin assignment of input and output ports of the system must first be made. Pin assignments of this system can be shown in Fig. 14. This step is very important since each device in the testing board had its own pre-assigned pin location. In order to utilize the devices, correct pin assignments were required. After assigning all the pins, the system was tested.

	To	Location	General Function	Special Function	Reserved	Enabled
1	alarm_out	PIN_46	Column I/O			Yes
2	clk	PIN_55	Dedicated Clock	Global_CLK,CKLK		Yes
3	curtain	PIN_11	Row I/O	RDYnBSY		Yes
4	desired[0]	PIN_87	Row I/O			Yes
5	desired[1]	PIN_86	Row I/O			Yes
6	desired[2]	PIN_83	Row I/O			Yes
7	desired[3]	PIN_82	Row I/O			Yes
8	desired[4]	PIN_81	Row I/O			Yes
9	door	PIN_51	Column I/O			Yes
10	error	PIN_7	Row I/O	CLKUSR		Yes
11	light_sens	PIN_59	Column I/O			Yes
12	main_lamp	PIN_12	Row I/O			Yes
13	measured[0]	PIN_73	Column I/O			Yes
14	measured[1]	PIN_72	Column I/O			Yes
15	measured[2]	PIN_70	Column I/O			Yes
16	measured[3]	PIN_69	Column I/O			Yes
17	measured[4]	PIN_68	Column I/O			Yes
18	pause	PIN_62	Column I/O			Yes
19	Pin[0]	PIN_42	Column I/O	LOCK		Yes
20	Pin[1]	PIN_43	Column I/O			Yes
21	Pin[2]	PIN_44	Column I/O			Yes
22	pwmout1	PIN_9	Row I/O			Yes
23	pwmout2	PIN_10	Row I/O			Yes
24	Reset	PIN_124	Dedicated Input	.		Yes
25	secure	PIN_8	Row I/O			Yes
26	sensor	PIN_60	Column I/O			Yes
27	side_lamp	PIN_13	Row I/O			Yes
28	switch	PIN_63	Column I/O			Yes
29	tv	PIN_78	Row I/O			Yes

Figure 14 Pin Assignments on FPGA

The system was successfully tested and showed correct results. Some of snapshots during system testing is shown in Fig. 15 and Fig. 16.

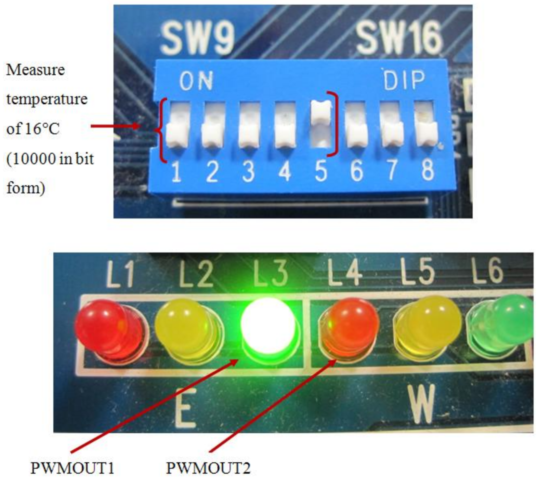

Figure 15 LED PWMOUT1 on when data input switch was below 18°C

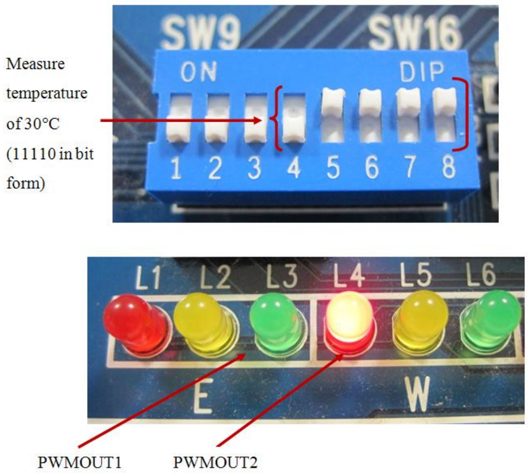

Figure 16 LED PWMOUT2 beeping when data input switch was above 18°C

V. CONCLUSION

The project designing FPGA-based system on home appliances has been successfully developed. All the subsystems (security system, intelligent PWM generator, curtain controller, and lighting controller) have been designed using VHDL codes and successfully linked together with Block Diagram Design. It is observed from the timing simulation results that the program runs as expected.

Although the home automation system designed is completed, it still cannot be used in the real world. The system is only simulated and analyzed using Quartus II software and tested and verified using LP 2900 board. Real hardware implementation needs to be done in order to prove all the findings are correct. Yet, there are still many problems that need to be solved before entering the real world market including the real time constraint of the system operation, circuit connection, interfacing between appliances and FPGA system and system developing cost.

ACKNOWLEDGMENT

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