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Sensor Based Home Automation and Security System

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Abstract–**The conventional design of home security systems typically monitors only the property and lacks physical control aspects of the house itself. Also, the term security is not well defined because there is a time delay between the alarm system going on and actual arrival of the security personnel. This paper discusses the development of a home security and monitoring system that works where the traditional security systems that are mainly concerned about curbing burglary and gathering evidence against trespassing fail. The paper presents the design and implementation details of this new home control and security system based on field programmable gate array (FPGA) The user here can interact directly with the system through a web-based interface over the Internet, while home appliances like air conditioners, lights, door locks and gates are remotely controlled through a user-friendly web page. An additional feature that enhances the security aspect of the system is its capability of monitoring entry points such as doors and windows so that in the event any breach, an alerting email message is sent to the home owner instantly.**

Keywords*–*Alarm system; email/short message service (SMS) messages; field programmable gate array (FPGA); motion sensors; web-based interface.

I. Introduction

In recent years, security issues have grown so dramatically that the need to remotely control and secure residential and commercial properties assumed significant importance [1]–[7]. Although there have been many attempts to develop and implement a fully functional and reliable home security system, none of those was really able to penetrate the market. Statistical data reveal that a home without a security system is three times more likely to be broken into compared to those which are equipped with a state-of-the art security system [8]. These facts make it obvious that a good home security system will reduce the chances of intrusion and thus, can protect both life and property. Hence, it is necessary to develop and implement a very dependable home security system that can protect the user and properties.

Increasing advanced home networking infrastructures are giving rise to a multitude of new applications including home automation and home security [7]. According to statistical data of 2007, there were four million household break-ins in the United States, of which 500,000 resulted in bodily injuries and 20,000 resulted in homicides. Home security is thus becoming increasingly important to homeowners. Many companies are now looking to entering the market by providing technology that provides remote home security over a broadband application using Internet. AT&T reports that the U.S. broadband penetration is about 60 percent, while home security penetration is only about 25 percent; these figures suggest a remarkable market opportunity.

Research in the area of home automation and security includes but is not limited to the X10/A10 personal computer (PC) interfaces for lighting and appliance control [10], [11], in which the CM11A computer interface is connected to the PC and sends signals over existing house wiring to control lights and appliances connected to the X10 modules. The interface even works with the PC being switched *off*. Once the interface has been programmed, the PC is no longer needed. Two standard AAA batteries maintain the time, schedule events and macros for up to 500 hours even if the power fails. One can even unplug the interface after programming it and plug it in somewhere else in the home. However, this product has been discontinued for reasons not quite clear. Another product is the Motorola home-sight home monitoring and control system which provides everything that is needed to install a system for security and protection. It is an affordable alternative to expensive custom-installed systems, where one can even monitor activity even being away from home. Real-time notifications are received through cell phones or emails when trouble occurs (over broadband connection). The text message alerts and still images are also received on the cell phone. From the home or office, real-time color video clips and still images could be viewed on the PC. The system will also record events while the user is out, so that color video clips with sound or still images could be viewed later.

The system developed by Motorola is different from the home control and monitoring system developed in the paper. Motorola project focused primarily on monitoring [4] and lacks control aspects of the home. For example, if an incident like someone entering the house during the day and trying to steal certain valuable possessions occurs, the camera captures that person, records it and sends the images to the user and law enforcement authorities. Also, security is not defined because there is a time delay between when the message is sent and when the security people actually arrive. Loss of lives and injuries could happen during this time interval. If we look at these security systems in real depth, it is evident that these are there mainly to curb burglaries and to obtain evidence against trespassers.

The home control and monitoring system as developed herein, on the other hand, being very cost-effective, also provides the user with a much greater control. In the following section, we present an overview of the proposed system.

II. Overview of System and Tools

In this section, we briefly present the details of the proposed system and Nios development board cyclone II edition which provides a hardware platform for developing embedded systems based on Altera® cyclone II devices [8] with the following attributes.

- Remote control over lights and door locks;
- All lights and doors are displayed through a web page that can be accessed through any modern web browser. Lights can be set as *on* or *off* with the page. Doors can be locked or unlocked remotely also;
- Automatic message notification of any breaches in security;
- The system monitoring of the house in real-time;
- If a breach is detected, with the appropriate use of wired and wireless motion sensors, the alarm system will alert the user and security personnel through email/short message service (SMS) messages [5];
- Highly extensible and customizable.

The proposed system can be connected to home appliances and devices such as refrigerators, air conditioners, fans, lights, motion detectors, smoke detectors and so on. The system is highly extensible; it can be tailored to fit the user's needs at a low cost. The system was developed as a custom-designed processor in field programmable gate array (FPGA) and implemented on a Nios development board cyclone II edition components and interfaces. C programming language was used for interaction between the main processor and external components, *viz.* sensors, appliances and devices. Socket programming, hypertext markup language (HTML), cascading style sheet (CSS), Javascript and personal home page (PHP) are used to develop the user interface. Figure 1 describes the details of the system.

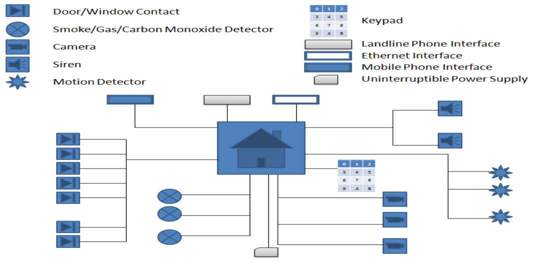


Figure 1. Overall system.

The Nios development board is preprogrammed with a Nios II processor reference design [8]. This reference design can be used as an example of how to build systems using the Nios II processor and to gain familiarity with the features included. The preprogrammed Nios II processor design on the board can be used to begin prototyping immediately. The Nios II board is factory programmed with a reference design that implements a web server [8]. A host computer can be connected to the board's Ethernet port, assigning an internet protocol (IP) address to the board and helping with browsing the web server from the host computer. In order to function on a network like local area network (LAN) or from point-to-point, the board must have an IP address. Once the Ethernet is connected to the board, the board will either obtain a dynamic IP address using dynamic host configuration protocol (DHCP) or a static IP address stored in flash memory.

The Nios II development flow is comprised of three categories.

- Hardware design steps;
- Software design steps;
- System design steps (involving both hardware and software).

For simpler Nios II systems, all the steps may be performed, while for more complex systems, separate hardware and software designers might be responsible for different steps. The system design steps involve both the hardware and software and might require input from both sides. In the case of separate hardware and software teams, it is important to know exactly what files and information must be passed between the teams at the points of intersection in the design flow.

The present work combines FPGA hardware design, low level software design and web programming to prove the concept of hardware and software co-design and web integration. A prototype of the proposed home control and monitoring system has been designed, implemented and tested in a real-time environment. In the following section, we describe the system design aspects.

III. System Design

The overall design concept of the proposed home security system can be summarized in the following.

The user must be able to communicate directly with the board through an Internet web browser; the board communicates with the user using the browser and email/SMS messages [3], [6]. This allows for two-way communication and therefore, the user is always in control over the system [2]. Although the concept seems relatively straightforward, there are many issues that need to be resolved in order to have a high quality system. The following sections will describe the major approaches in hardware and software that were chosen so that a proper system could be implemented. Figure 2 presents the system design diagram.

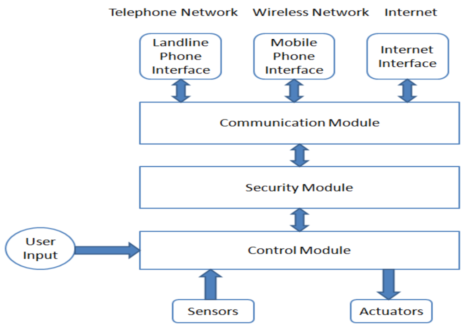


Figure 2. System design.

A. Hardware Design

- *Real-time operating system:* In a case such as home security, the system must be able to react instantly to any stimuli that signal a breach into the system. Also, commands to the system must be immediately resolved as latency in such a system is unacceptable since it compromises security.
- *Networking capable system:* Networking allows this system to be accessed remotely [1]. A remotely accessible system gives the user power to control home from anywhere in the world (through the Internet). It also allows the security system to not only communicate with the user but also with the emergency authorities.
- *Hardware input-output (IO):* This system relies on sensors and actuators to operate. In most cases, the sensor outputs just need to be digital signals, 0 (0 volts) and 1 (+5 volts). This means that the system must be able to output signals and read input signals directly from the hardware.

The Nios II system allows a user to write a customized real-time operating system (RTOS) for applications [8]. This represents the first hardware component that is important as the board has to do many things simultaneously. For instance, the system serves the user with web pages which reflect the state of the house. If there is a breach, the system needs to do the following things.

- Detect where the breach occurred;
- Alert the user through the web page that a breach has occurred;
- Send an email alert to the user;
- Continue monitoring other areas of the house for breaches.

This is done through the use of hardware interrupts. Thus, the system reacts to external changes and updates itself in a timely manner.

The next hardware component is the networking controller [7]. The Ethernet interface is built into the Nios II system. This gives the board the portal to the Internet. This hardware allows for one to easily create an HTTP server and helps the user to log into the web pages that are served from the board in order to get real-time information about the house.

The final hardware capability is IO ports. The binary logic 0s and 1s are used to represent an *open* and *closed* switch. A light bulb is either *on* or *off*. A window can also be *open* or *closed*, which can be looked at as *on* or *off*. With IO ports, the system is able to control all the lights in the house and even can detect any changes. If a light bulb is to be turned *on*, the user tells the system and the system simply sends a high signal to an external circuit that switches on the light. If a door is to be opened, a switch can be put to *open* or *closed* position based on the state of the door. The board will just read that pin for a high or low voltage and thus, would know the current state of that door.

B. Software Design

The system has two main soft components as given below.

- *HTTP web server*;
- *Input-output*.

The web server is placed at home and it is designed as the backbone of the entire system. It can only be controlled manually and the user can just remotely access well-defined functions of the system. The web server is where the user and system can directly communicate. The user can see in real-time changes to the home and interact with it. The other section is the IO section. The board detects any changes in the system or any user requests and responds to them. However, unlike a traditional system, the approach used has to be non-blocking such as hardware interrupts. This will become clear in the implementation section, but for now, if a system continuously listens to one IO port, it will block all other operations. This would leave the HTTP server unable to serve pages and board will be severely handicapped.

Now that the system's backbone is fully designed, the next step is to go to the actual webpages. This is the user's portal to the entire system and it must be designed with high efficiency and must maintain ease of use. To design the web pages, the technologies used were HTML, CSS, PHP and Javascript. HTML was used for the actual markup on the page, while CSS was used for the layout and style of the page. PHP was used to communicate with a server in order to send emails to the user. Finally, Javascript was used for the more advanced parts of the code that makes the page dynamic.

To design the HTTP server, several things need to be considered. First and foremost is security; a secure website is essential as the website gives the user almost total control over the home with the ability to lock and unlock doors, turn lights *on* and *off*, etc. The next thing was performance; the server should be able to instantly update itself based on any changes in real-time and alert the user accordingly.

IV. Implementation

This section outlines the actual implementation of the proposed system. The entire system was broken down into smaller blocks in order to simplify the process.

A. External Stimuli

i) Input: Responds to high and low signals driven into input pins.

ii) Output: Signals an output pin to high or low.

B. HTTP Web Server

- Create a web server that can provide web pages to a browser;
- Design and implement the web pages for the browser
- Add capability to control output pins from the web pages;
- When the inputs are triggered, automatically update web pages.

The process was broken down into two main areas and these have many other subareas that need to be completed as well.

The HTTP server consists of several parts in order to make the code organized. The *http.c* file hosted all the functions that served the webpages and also responded to *post* and *get* requests from the browser.

The most important functions in *http.c* file are

```
int http_handle_accept(int listen_socket, http_conn* conn)
```

If a user tries to connect to the system, the function connects to the socket. This establishes the connection and allows for the web pages to be served.

```
int http_find_file(http_conn* conn)
```

The above function is where the web pages are actually served. If a user requests a page such as *index.html*, this function looks for that page in its database and if the file is there, it is served to the browser. If it is not there, then, the user is informed with a *No page found* error message.

```
void sweep(http_conn* conn)
```

Whenever the web browser sends a request through *post*, a function is created to react to whatever the request is. For instance, let the lights be turned *on* or *off*. In the above, the function detects which light the user has requested to be toggled based on its ID from the HTML code. The code then forwards the request to a function within *webserver.c*.

The other functions within the code maintain connection and deal with requests from the browser and they are all helper functions. They also do error checking and recovery such as maintaining a connection.

The *webserver.c* file does most of the important jobs in the program by controlling the lights and responding to button presses through interrupts.

```
void board_control_task(void *pdata)
```

The above function is what is called from the *sweep*() function described earlier. To control the lights, a task management process was employed. It is similar to spawning a thread on an operating system (OS). The task works independent to that of the normal operation of the code and is therefore non-blocking. To elaborate, light No. 1 can continue to remain *on* with just one call. Once that call is made, the light stays *on* without any interruption from the user. It may seem unnecessary but when multiple lights are involved, each time a user switches a light *on* or *off* requires the board to set all the lights into that particular mode. With the task system, each light is independent of one another and therefore, very efficient. So, to turn *on* a light or to turn it *off*, it is as simple as running a task or suspending it.

The following snippet of code shows how the bedroom lights are toggled.

```
  if(board_control_mbox_contents->bedroom_ON) {
     OSTaskResume(bedroom_PRIO);
    }
    else {
     OSTaskSuspend(bedroom_PRIO);
     led = led & 0x7;              //led = led &0x7;
     IOWR_ALTERA_AVALON_PIO_DATA(      LED_PIO_BASE,
led);
    }
```

Note that while the above discussion refers only to lights, this is obviously extensible to other gadgets such as locks.

The other section is the buttons (breach detection). As explained above, for a real-time board, external stimuli cannot be constantly monitored with an infinite *while ()* loop, for example. That is why hardware interrupts are used. The hardware interrupts allow the board to continue fulfilling its other tasks; if someone hits a switch, the board is alerted through an interrupt system. Based on this logic, the board employs an interrupt service routine that checks which button was pressed and responds to it when it happens.

```
static void handle_button_interrupts(void* context, alt_u32
id)
```

Once the above function finds the button that caused the interrupt, an email is sent through PHP by using the HTTP web server. The following snippet shows how the button is identified when the board raises an interrupt.

```
switch (edge_capture)
    {
    case 0x1:
       button1 = true;
       break;
    case 0x2:
         button2 = true;
       break;
    case 0x4:
      button3 = true;
      break;
    case 0x8:
      button4 = true;
       break;
    default:
       break;
    }
```

This code allows the board to work with high performance in real-time.

The actual web pages were designed using HTML and CSS. The layout and text on the page allow for the user to view and control different aspects of the system. The following sections will again emphasize important parts of the code.

For a user to log into the website, it is only needed to provide a username and password to the system. This is critical from the security viewpoint [9]. The system looks at the username and password supplied and compares them to the information saved in the database. As the system gets larger, My structured query language (MySQL) server could be implemented that would hold all the usernames and passwords; however, the concept of comparing the usernames and passwords will be basically the same.

Once the user has logged into the website, control is given through another webpage. This page is completely dynamic and reflects the state of the house at any given time.

```
<form method =”post” action=”/SWEEP” name=”sweep”>
        <td><input type=”IMAGE” src=”../Images/
        topView_04.png” id=”bathroom” width=”74”
        height=”119” alt=” ”
        onclick=”toggleBathroomLights()”;
        name=”seven_seg_sweep” value=”Seven Segment
        Sweep” /></td>
</form>
```

The above code snippet shows how the lights are toggled from the webpage.

V. Results

Figure 3 is a snapshot of the layout of the house and lights. The house is represented by an image that shows its different areas. The images are partitioned in such a way that clicking on a particular area would activate or deactivate the relevant light. In the above code, the bathroom lights are toggled whenever the image area that represents the bathroom is clicked. This is done using a *post* from the web page. The *post* data are interpreted by the *http.c* file. The board then controls the lights. The other part of the code is the user feedback. This is done by simulating yellow tint over the area of the house that was lit. The *onclick* action is called whenever the image is clicked. This leads to a *javascript* function being activated that changes the opacity of a yellow tint using CSS. The following code snippet shows the Javascript code being set.

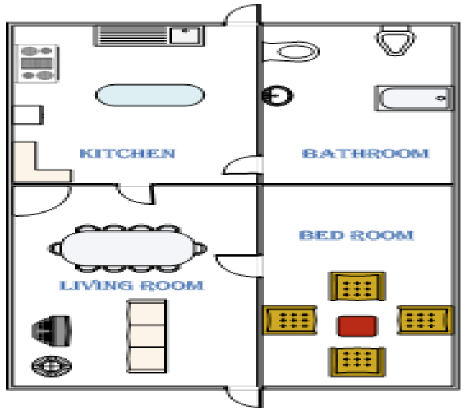


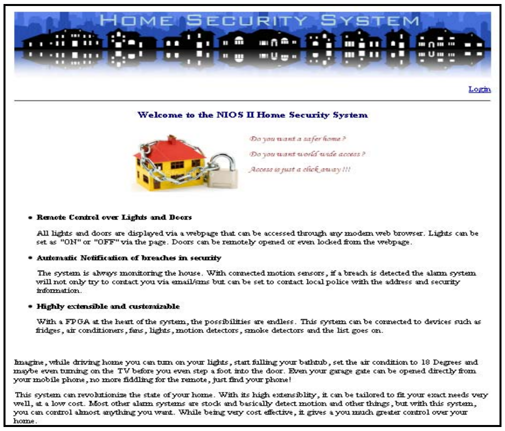
Figure 3. Layout of house and lights.

```
function toggleKitchenLights(){
        if(kitchenLgt){
                alert(‘Turn off’);
                kitchenLgt = false;
                document.getElementById(“kitchen”).style.op
        acity = 1.0;
        }
        else {
                alert(‘Turn on’);
                kitchenLgt = true;
                document.getElementById(“kitchen”).style.op
        acity = 0.3;
            }
}
```

It is clear from the code that just the opacity of a layer above the tint (the image of the house) is changed. If the light is *on*, the opacity is *off* and therefore, the image looks normal. If the lights are turned *on*, the image becomes transparent and allows a yellow background to become visible.

VI. Evaluation

When choosing the user interface, a webpage was preferred over a customized graphical user interface (GUI). One of the main reasons for this is accessibility. A webpage can be accessed from anywhere anytime in the world provided that there is Internet connection available. It also eliminates the hassle and inconvenience created by having to install a program in order to access the user's property. It is also quicker, easier and more cost-effective to update and to make changes to. A website at the scull of the prototype makes it marketable and allows competition with other companies in the same arena. Figure 4 is a snapshot of the proposed running graphical home control and security system.



Welcome to the NIOS II Home Security System

Do you want a safer home ?

Do you want world wide access ?

Access is just a click away !!!

- **Remote Control over Lights and Doors**

  All lights and doors are displayed via a webpage that can be accessed through any modern web browser. Lights can be set as "ON" or "OFF" via the page. Doors can be remotely opened or even locked from the webpage.

- **Automatic Notification of breaches in security**

  The system is always monitoring the house. With connected motion sensors, if a breach is detected the alarm system will not only try to contact you via email/sms but can be set to contact local police with the address and security information.

- **Highly extensible and customizable**

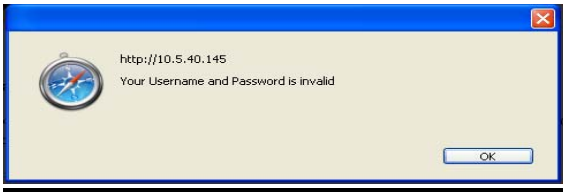
  With a FPGA at the heart of the system, the possibilities are endless. This system can be connected to devices such as fridges, air conditioners, fans, lights, motion detectors, smoke detectors and the list goes on.

Imagine, while driving home you can turn on your lights, start filling your bathtub, set the air condition to 18 Degrees and maybe even turning on the TV before you even step a foot into the door. Even your garage gate can be opened directly from your mobile phone, no more fiddling for the remote, just find your phone!

This system can revolutionize the state of your home. With its high extensiblity, it can be tailored to fit your exact needs very well, at a low cost. Most other alarm systems are stock and basically detect motion and other things, but with this system, you can control almost anything you want. While being very cost effective, it gives a you much greater control over your home.

Figure 4. Home control homepage.

The figure above shows the home page for the system. It is simple and load quickly when the user accesses it. The concept of the page is to market and advertise the project. It describes certain features on the board. On the top right hand side of it is a login button; when this is pressed, a user login page appears that asks for username and password. If either the password or username is incorrect, the message below is shown (Figure 5).



http://10.5.40.145

Your Username and Password is invalid

Figure 5. Login error message.

Once the correct password and username are entered, the system navigates to the home control page which is shown below in Figure 6.

On this page, the lights and doors can be controlled. There is also a bar below that monitors that sets the alarm. This page refreshes every 10 seconds so that if there is a breach, there will be a delay of 10 seconds before a notification is sent out through email messages. Lights can be turned *on* in any order or as many as possible.

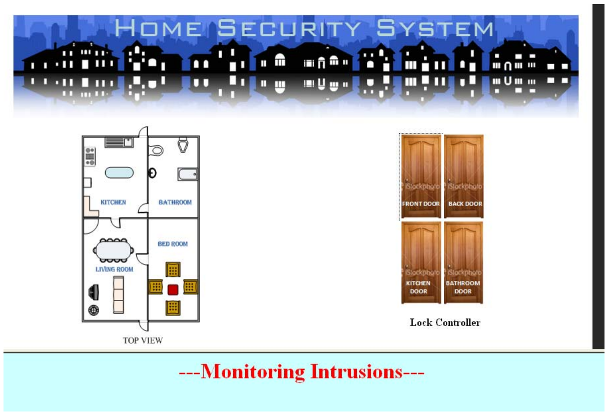


Figure 6. Control interface.

VII. CONCLUSIONS

In this paper, we introduced the development of a home control and security system based on the use of FPGA and Internet web-based technology. The system is suitable for real-time home security monitoring and for remotely controlling the home appliances and others. The system is designed and implemented on a Nios cyclone II FPGA development board as a custom designed processor. The user interacts with the system to send control commands and receive feedback from different devices and peripherals over the Internet or through SMS messages. The design was simulated and tested, a prototype was implemented and the correctness and working of the system were verified.

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