SoPC based Smart Home Embedded Computer Capable of Caring for the Home Occupants

G. N. Khan and J. B. Chan

Department of Electrical and Computer Engineering
Ryerson University, 350 Victoria St.
Toronto, Ontario Canada M5B 2K3

Abstract—We present a Smart-Home Embedded Computer (SHEC) system with the ability of upgrading the firmware without replacing the hardware platform. Our development and implementation of the SHEC is based on SoPC (System on Programmable Chip) that can accommodate various embedded computer components. SHEC communicates with the home appliances and other devices over wireless or standard Ethernet network. A home simulator software incorporating virtual appliances and devices models the smart home environment. The simulator interacts with the SHEC over the Ethernet network by accepting commands and generating status messages from home appliances and devices. We have developed a home resource management application based on a number of expert rules. The main resources being managed are electricity, gas and water. SHEC can also be used for providing Oxygen therapy to the elderly or patients in a smart home environment.

Keywords: *Real-time Embedded System SoPC, Smart Home Controller, Ubiquitous Computing.*

I. INTRODUCTION

Ubiquitous and pervasive computing is changing the lifestyle. Our living and working environments have become "smart". Traditional home appliances and devices such as refrigerators, washing machines and entertainment systems are becoming intelligent and have various levels of communication [1]. Smart home is a living space that has been augmented with technology to assist the occupants [2]. A smart home should take an active part in providing comfort, care, and safety for the occupants. Home control is leading to safe and environmental friendly living spaces. One aspect of home automation is the direct control of various appliances in a home. A smart-home embedded system makes decisions based on sensory inputs. The system can be allowed to make these decisions autonomously or user can override the system.

Energy savings and other conveniences can now be incorporated into a smart home. Feedback from light sensors can help in adjusting light levels and to automate window blinds. In combination with temperature sensors, it can affect heating and cooling to passively regulate the environment. Smart devices may be placed around the home to provide convenience by giving reminders, displaying information, or alerting about dangerous conditions. A smart door reminder can alert about the weather, or remind us to bring certain items, and attend to appointments.

In this paper, we present the architecture of a smart home embedded computer (SHEC) system. We also provide the implementation details of SHEC, which is based on SoPC (System on Programmable Chip). It incorporates a soft processor core and other system components on a Stratix-II FPGA from Altera. SHEC architecture is upgradeable and the system is flexible that allows new technologies to be integrated into the system. Home resource management and automatic Oxygen therapy applications are executed under a real-time operating system, μ Linux. SHEC regulates the usage of common home resources such as hot and cold water, electricity and gas. Verification of SHEC applications is achieved by employing a home simulator software in the absence of physical home. Ethernet network connects the SHEC with home appliances/devices and the home simulator.

II. SMART HOME EMBEDDED SYSTEM

SHEC can be considered as an information system that logs the home events, and route messages and events to different home devices and appliances. Looking at some smart home projects [3, 4] future of smart home control lies in data services. SHEC design is based on passive interaction, non-intrusive and context awareness. Peer-to-peer and centralized topologies can be considered for SHEC. The physical infrastructure can affect our choice, but Ethernet network support both topologies.

In a peer-to-peer configuration, home appliances and devices are capable of talking to each other, regardless of the presence of a controller. This is costly due to additional interface hardware and software at the device level. Full service oriented architectures involving de-centralized services [3] are difficult to manage and control due to independent services being provided. Moreover, it doesn't have physical infrastructure to connect to all the devices. In a centralized configuration, devices can only talk to the controller and create communication bottleneck at the controller. The controller takes care of interpreting the information and sending messages to other devices. This configuration has lower cost and processing for devices. Resource management and security can be easily implemented and configured from one central device, which all other devices must interact with. Moreover, each device simply needs to understand its own command set, and to update the controller about these commands.

SHEC is a hybrid system, with many “mini-controllers” located to consolidate devices within specific home sections to minimize the physical connectivity. A hybrid topology blends the two approaches where all the appliances, devices, or sensors may not be physically connected to SHEC, but instead they can be connected to a much closer “area node” as depicted in Figure 1. The device/sensor network can be controlled by a low-level system at area node level. An area node acts as a device but it is capable of converting data from analog sensors, or even digital sensors and relays them to SHEC. This simplifies wiring greatly as an area with many devices only requires one connection to SHEC.

Figure 1. Area node configuration

Home control application is developed by using a real-time operating system (RTOS), μ Linux. Various scenarios must be defined and integrated into the system to provide a heuristic way of management without direct user intervention. There are two heuristic behaviors that have been studied and implemented in SHEC. Firstly, SHEC can monitor the user actions and learn. For example, when most of the time, user does x-action followed by a y-action. After SHEC has learned the user’s behavior, it can then automatically do y-action when user does the x-action. In the second case, SHEC will follow a rule that is made by the user e.g., do y-action when a user does x-action. It is easier for the user to tell the SHEC how to behave, rather than a guess by SHEC. This provides absolute feedback because the rules are known, which don’t change unless modified by the user.

III. SHEC IMPLEMENTATION DETAILS

SHEC prototype is implemented by using a readily available Stratix-II FPGA based development board from Altera. The development board facilitates Ethernet, JTAG and serial I/O and parallel interface for LCD/LED modules. The serial interface is used SHEC console messages. SHEC has a dedicated embedded architecture given in Figure 2. Stratix FPGA accommodates the main SoPC modules of SHEC including the NIOS-II processor, Avalon bus, and glue logic for timers, memory, Ethernet, serial and parallel interfaces. The μ Linux and smart home application modules are stored in the flash memory and at power up they are loaded to random access memory for execution. SHEC is connected to various devices in the home through an Ethernet network. Wireless communication can provide the Ethernet medium without any cabling. Quartus-II CAD tools facilitate the construction of SHEC and its memory address mapping can be adjusted [5].

Figure 2. SoPC blocks of SHEC architecture

We have introduced a handshaking protocol “banter” for communication among SHEC and home devices or appliances. It is a simple communication protocol implemented on top of the basic TCP/IP protocol as illustrated in Figure 3. Table 1 lists the possible data types that SHEC uses to establish the purpose of information contained in a packet received from the device/appliance. The status-change message is issued by the device to update its status to SHEC. The acknowledgement (ACK) type is a generic acknowledgement message used either for simple receive confirmation or as a positive action. Negative acknowledge (NACK) is also used similarly. The Data type indicates an arbitrary data is being sent. During resource management, devices send request messages to the SHEC, and in turn SHEC sends the grant or deny messages. The initiation message signifies the beginning of handshaking. When a home device enters its initialization, it attempts to find the SHEC and send data under this type. SHEC will then proceed with its device initialization processes. The banter protocol allows for an arbitrary data length, although fitting it in a single packet is preferred.

Figure 3. Banter handshake and data transfer protocol

Table 1: Banter Datatypes

Type	Description
01	Status Change or Request
02	Set Informational Message
03	Banter initiation Message
04	Acknowledgement
05	Negative Acknowledgement
06	Data
07	Resource Change or Request
08	Device initialization

Ethernet interface is the main communications medium for connecting SHEC with the home devices and appliances. During the system development process, the prototyping platform is connected to both the workstation hosting the

hardware-software codesign CAD tools and the system executing the home simulator as depicted in Figure 4. The configuring of SoPC is enabled via a JTAG interface and another serial connection provides a console to display various messages. Providing a web interface from SHEC can be better due to the dynamic nature of the system and devices to be configured. The visual feedback can also accompany the web interface.

Figure 4. SHEC system development and testing

The heart of smart home controller is a software system running on μ CLinux. Upon startup, SHEC performs the initialization including the resource tables, and appliance or device status tables. SHEC system is event driven and aside from timer interrupts, data arriving over the network is another key event indicating an appliance or device is trying to communicate. MacOS-X hosts the home simulator software, which is illustrated in Figure 5. Home simulator, home devices/appliances and SHEC itself are inter-connected via the Ethernet network. Home simulator mimics all the devices and appliances and provides feedback to the user and SHEC. Home sensors, devices and appliances data are either numerical calculated or it is based on expert rules. The simulator software has two primary windows of status and control. The status window depicted in Figure 5 shows the current state of SHEC, and can be used to bring any situation to the attention of the user. The control window is equivalent to the smart home. The status of a simulation run shown in Figure 5 is the output of SHEC console after power-up.

IV. SMART HOME APPLICATIONS AND SERVICES

A. Smart Home Resource Control and Management

Home resource management is an important data service. While most day-to-day activities are self or user-regulated, resource control may still be useful for the uncommon situations that arise and can cause a heavy shift in resource usage. Resource tables are initialized and modified as devices use the resources including electricity, gas, and hot and cold water. As appliances perform their service tasks, they use and produce different resources. They request a resource and the

controller will grant or deny their requests based on the existing resource usage. Most resources start at a finite level and decrease as device and appliances use them, however, it is possible that one starts at zero, and increases as an appliance creates that resource (e.g. water heater creates the hot water).

Figure 5: Simulator status window.

One of the SHEC application limits the use of resources. Devices and appliances have to sign out resources from the system before using them, and check-in the resources when they are done with them. An appliance will request and return resources as necessary until it is done. SHEC also periodically polls the appliances that it sees in its usage list, to make sure that they are still operational and using the assigned resources. The real-time data may also be taken to correlate with its resource list, to check for large discrepancies. The resource management can be illustrated with a scenario of hot water resource required by multiple devices and appliances. A shower can consume around 800 liters per hour, while a dishwasher and washing machine consume around 500 liters per hour each when operating. SHEC is set to allow up to 1500 liters of hot water per hour. Consider a situation where a person is taking shower and the washing machine is filling at the same time. We have a total of 1300 liters of hot water consumed per hour. The hot water resource is only 200 below the limit. At this point, if the dishwasher is activated, SHEC will deny the resource request from dishwasher. A partial simulation of this situation is shown in Figure 6. When washing machine is done, it checks in the hot water back, releasing it to be used by the dishwasher.

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© SOPC Builder 3.0.0
pqPeek: Packet found
[CFD(): checkForData found PQ_ONE data.
CFD(): Packet decoded, going to banter.
<Banter>
Banter state for tag 16 is 3
Banter[c3]
[decode]: sendr:raw: [ 16]
[decode]: rcvtr:raw: [ 1]
[decode]: data: [USECOLD:250;USEHOT:250

]
Datatype for tag 16 is 7
[Processdata]
USECOLD:250
USEHOT:250
Device 0 found, removing...
[tk]: USECOLD, 250Device 1 found, removing...
[tk]: USEHOT, 250water usage:
Hot water: 250 / 1000
Cold water: 250 / 1000
Total: 1300 / 1500
pqAdd()
pqAdd - Add link
Device 16 found, removing...

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Figure 6. Simulation for hot water resource usage

Resource management system also has two more resources, “risk” and “attention” that helps to determine if a device or appliance can safely be used. The “risk” resource identifies a

risk level associated with the operation of device. The “attention” represents the attention level required of a particular user. This applies to running the appliances or leaving them and the living spaces unattended. If a threshold is reached, or the attention level is not sufficient, the system warns the occupants and may shut down the relevant appliance. These resources are managed in identical fashion as the basic resources.

B. Oxygen Therapy to the Elderly in a Smart Home

SHEC can also serve as a point of intelligence that can monitor the elderly at home as well as provide assistance in their daily life. People with asthma, emphysema chronic bronchitis, occupational lung disease, or lung cancer may need oxygen therapy at home [6]. Pulse oximetry is one of the most widely used tools to determine a patient’s cardio respiratory stability. It provides a rapid and noninvasive way to measure blood oxygen saturation levels. Wrist wearable pulse oximeters with wireless connections are widely used to determine a patient’s arterial oxygen saturation and heart rate. Baseline oxygen saturation levels vary depending on the patient’s cardiopulmonary status, but in general, the normal saturation for a patient at sea level is 95% SpO₂ or above. The level at which a person starts to become noticeably impaired is approximately 90% SpO₂ [6]. Domiciliary oxygen improves neuropsychological function, and other conditions likely to benefit from oxygen therapy include cyanotic congenital heart disease, severe congestive cardiac failure, lung diseases, bronchiectasis or any illness with chronic hypoxemia [7].

Oxygen cylinders, concentrators and liquid oxygen are the main types oxygen delivery systems. Oxygen concentrators are stationary electrical units, which takes in regular air and provides a streaming flow of oxygen that is 87-95% pure. We have developed another application (SmartLife) for SHEC to automate the oxygen therapy in a smart home. SHEC interact with oxygen concentrators and pulse oximeters put on by the elderly or patients requiring oxygen therapy. The SHEC setup providing oxygen therapy in a home is depicted in Figure 7.

Figure 7. Providing oxygen therapy in a Smart Home

A typical oxygen concentrator interacts with SHEC as any other home device with an Ethernet connection. SHEC identifies the oxygen concentrator and register its ID, which is then used for all subsequent messages. Sampling of the output from concentrator sensor then begins, and transmissions occur as a ‘burst’ with 20ms intervals. The concentrator begins to watch for a ‘resource request’ message sent by the SHEC and respond with an acknowledgement. Pulse oximeter is put on by the patient also establishes a similar connection with SHEC. The system acts as a server for both the oximeter and

concentrator and waits for the incoming data. Sampling of the data is done continuously, and receiving occur in a ‘burst’ every 20ms. If this data is received from oximeter and it’s reading is less than 90% then SHEC sets the concentrator to deliver oxygen at the rate of 3lpm. If a data packet is received from oxygen concentrator and it’s reading is less than 85% then SHEC turns on the alarm to indicate a malfunctioning. SHEC screen shot of the application running on μ CLinux shows messages to/from pulse oximeter and oxygen concentrator in Figure 8.

Figure 8. SHEC simulation for oxygen therapy

V. CONCLUSIONS

SHEC is a standalone embedded system that enables home devices and appliances to communicate over a standard Ethernet network. One of the main features implemented by the SHEC include resource management in terms of usage, tracking and control for greater quality of service. SHEC also supports Oxygen therapy for the elderly in a home environment. SHEC system is implemented on Stratix-II SoPC. The main benefit of an SoPC based system is its programming capabilities. If a hardware change or upgrade is required, it can be achieved by reconfiguring the SoPC rather than replacing the hardware platform.

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