Configurable ZigBee-based Control System for People with Multiple Disabilities in Smart Homes

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***Abstract*— Nowadays, home appliances manufacturers are increasingly relying on wireless sensor network and single chip embedded technologies to build smart environment. Many existing systems are already in the market, however, they were designed without envisioning the need of residents with special needs. This work presents a framework that enables the integration and control of devices within a smart home environment for residents with disabilities. The framework supports the integration of multiple control devices for different residents with different disabilities. Moreover, the work addresses the safety of the users by providing warnings and notifications in case of an emergency. A prototype was designed, implemented and tested.**

Keywords—smart home; home area network; wireless sensor network; people with special needs; ZigBee.

I. INTRODUCTION

Smart grid communications are based on wireless and wired networks technologies. Regardless of the technology, these networks can be classified based on their functionality within the smart grid. This classification as reported in the literature are: home area network, neighborhood area network, access network, backhaul network, core and external network [1]. These networks connect many smart grid objects such as home appliances, smart meters, switches, reclosers, capacitors bank, integrated electronic devices (IEDs), transformer, relays, actuators, access points, concentrators, routers, computers, printers, scanners, cameras, field testing devices, and the list can go on to many devices. This work proposes a framework for homes to enable people with different types of disabilities the control of appliances and devices within their home environment. Home Area Networks (HAN) are implemented and operated within houses or other small boundary offices to enable communication between user's peripheral devices to various home appliances. Such appliances are: televisions, air conditioning systems, security systems, and other devices like fax, printers, as well as small network attached storages. Moreover, HAN technology allows the user to control and monitor many digital devices throughout the house. The basic HAN includes devices such as, an access point, the home appliance(s), and a smart meter. The HAN's access point has network switch services that provide users with wired LAN ports or wireless connectivity.

Wireless Sensor Network (WSN) is being implemented to monitor and broadcast information from different applications [2]. It is being developed in various fields such as homes and hospitals. WSN consists of a large number of wireless sensor devices working together to achieve a common objective. A wireless sensor device is a battery-operated device that has the capability of sensing physical quantities [2], provides efficient wireless communication and data storage. Moreover, a WSN has one or more base-stations that gather information all the sensor devices. The base stations provide an interface through which the WSN interacts with the outside world [2]. This work designs and implements a wireless sensor nework inside a house that provide users with special needs essential and basic control within a home environment. The proposed work enables the user to perform his/her daily activities by remotely monitoring and controlling home appliances without depending on others. The input and output are automatically adjusted depending on the user's special needs and environment.

The smart home area network (HAN) technology offers users a wide range of services. Users that integrate HANs into their homes can monitor and/or control their appliances remotely and within the house using smart phones or control panels. However, most of the monitoring and control system in the HAN technology are not feasible to people with disabilities such as visually impaired, deaf, and handicapped.

A blind person cannot see whether the window is open/close, similarly a deaf person cannot hear the fire alarm. A handicapped person (with hand disability) one the other hand cannot use his/her phone to check if the refrigerator door is open or closed. Hence, most of the existing HAN technologies are aimed at healthy people. Other specialized devices are developed; however, the devices operate only based on one specific disability. This work proposes a framework that enables the integration, monitoring, and control of events within a HAN. This work also proposes a device that integrates with HAN that is targeted for people with special needs such as deaf and blind people.

This work is organized as follows, section II presents related work, section III presents the functional requirements, section IV presents the proposed framework for HAN, section V presents the prototype implementation, and section VI presents a brief conclusion.

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II. Literature Review

The work in [3] proposes a wireless sensor network based system consists of three major blocks namely; Intelligent Door Control system, a Gas Detection system and Warning Hearing Impaired people (for the doorbell). Each block has sensor nodes that monitor physical and environmental conditions such as detection of access card, gas level in the kitchen and pressure on the doorbell. A Wireless Smart Home Monitoring systems for assistive independent living is presented in [4]. The system has various functions to help elderly and people with special needs. The system consists of a base station, sensor nodes that contain RFID tags, accelerometer and buzzer. Each node monitors a specific home appliance.

The system in [5] introduces a ZigBee-based smart home monitoring system that supports multiple user. The system allows users to monitor their home appliances simultaneously. The work in [6] discussed a system that recognizes and monitors the daily activities of living of elderly people on wheelchairs using triaxial accelerometer.

A study was conducted on a spinal cord injury user who needs to communicate with other people through text-voice conversation and control the home appliances in [7]. An assistive dialog agent was proposed for the case using a dialog agent requirements modeling methodology. The Intelligent Home Environment (IHE) controller provides an interface between hardware and software to gather data from the environment and monitor the home appliances according to the commands from the application senor devices.

Semantic matching framework is proposed in [8] that matches the environment infrastructure and the user's capabilities.

III. Requirements

In a home area network environment, a home with *m* appliances can be denoted by (1).

$$A = \{A_1, A_2, ..., A_m\} \quad (1)$$

An appliance is a physical device that is capable of executing tasks or requests and exchange data. For example, in a smart home environment an appliance can be a television, an air condition, and a washing machine. Each appliance can be defined by a set of capabilities in (2).

$$A_i = \{c_i^1, c_i^2, ..., c_i^{a_j}\} \quad (2)$$

a_j is the number of capabilities that describe A_i. For example, capabilities for a washing machine can be rinse, normal wash, hand wash, water temperature, and spin speed. Each appliance in the smart home environment is placed in a specific home zone. A home zone defines specific areas inside the home. For example, master bedroom can be a zone. A home zone can be presented in (3).

$$Z = \{Z_1, Z_2, ..., Z_q\} \quad (3)$$

Let A_{iq} denote appliance *i* in zone *q*.

A set of *n* tasks for in a home environment, denoted in (4).

$$T = \{T_1, T_2, ..., T_n\} \quad (4)$$

Task $T_j \in T \ \ (j = 1, ..., n)$ is formulated as a set of operations in (5).

$$T_j = \{o_j^1, o_j^2, ..., o_j^{t_\partial}\} \quad (5)$$

t_∂ is the number of operations belonging to T_j. For example, task 1 can be defined as a request to the washer machine, with the operations normal wash and spin speed 800 rpm.

In a home area network environment, there is a need to allocate requests to the capable appliances/devices at specific time. A request may be processed by a single appliance A_i or a group of appliances in A, in which the appliances are capable to process request T_j. For example, a request in a smart home environment can be cooling a specific area in the home to 19 degrees Celsius at 5pm, where the home has three A/C units. The system can allocate the request to the different A/C units at home to achieve this request.

A. Appliances Requirements:

- Appliances in a home shall register its capabilities.
- Appliances shall use a technology standard as a medium of communication within a home environment.
- Appliances shall communicate events within the HAN.
- Appliances shall accept and process events.
- Appliances shall execute requested events.
- Each appliance must have a unique address.

B. Controller Requirements:

Each appliance has off-the-shelf credit card-sized single-board computer with the following built-in resources [9][10]:

- System on chip CPU.
- SDRAM.
- GPIO (General Proposes Digital Input/output ports)
- BaseT Ethernet Socket.
- Two USB Connector and display serial interface analog to digital converter (ADC) adapter board.

The above communications, digital and analog input/outputs ports are utilized in the proposed system as follows:

- The digital inputs are used to enable homeowners to operate the appliance locally.
- The digital outputs are utilized to drive the home appliances through solid states relays to overcome the voltage and current limitation that are provided by the board ports [11].
- The USB port is used to connect the controller to a PC to upload and download developed programs.
- The ADC channels are used to read the analog metrics that home appliances may have such as temperature, humidity, weight, and pressure.

C. Framework Requirements:

- The framework provides a unique identification to homes connected to it.
- The framework shall provide a unique identification to the home appliances and devices within the HAN.
- The framework associates appliances to a home.

- The framework manages appliances within a home.
- The framework manages users and roles of users within a home.
- The framework allows users to define roles and accessibility.
- The framework allows users to identify his/her special need.
- The system customizes the inputs of the system based on the user's special need.
  - The system provides the visually impaired and deaf users with voice-recognition and Braille keypad.
  - The system provides the handicapped user with voice-recognition.
- The system transforms the output of the system based on the user's special need.
  - The system provides the visually impaired with voice-outputs and vibrations.
  - The system provides the deaf with lights and vibrations.
  - The system provides the handicapped with voice-outputs, lights and vibrations.
- The framework allows appliances to register with its capabilities.
- The framework allows users to create tasks and operations.
- The framework enables control to the registered devices.
- The framework should provide a monitoring service for specific defined events for the registered devices.

IV. Proposed Approach

This section proposes a home area network framework that transforms input requests and output in a home environment based on user's special needs. The framework as shown in Figure 1 enables the integration, monitoring, and events management within a HAN.

A. The Framework Services

The framework contains the following services:

1) *Registration Service:*

This service enables devices to register with the proposed smart home framework. The registration service receives the following information from a device:

- Device name and identification.
- Device capabilities.
- Device service definition for each capability.
- Event registrations based on the device operation.
- Schema representation if any.

The registration service has the following modules:

- Device registration: The main functionality of this module is to handle registration requests from devices. It takes in the device name, identification, capabilities, and service definition for each capability, and assigns a unique identification to the registered device.
- Schema registration: Each device can produce or consume data based on specific data representation. This module enables a device to register its schema in the smart home framework service.

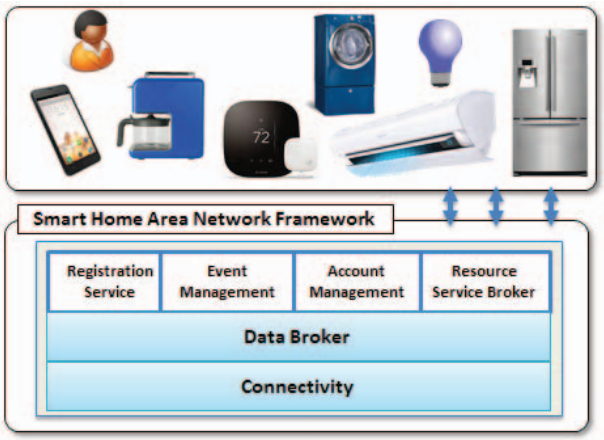

Figure 1. Proposed Home Control Framework Architecture

- Event registration: Based on the device operation, it can produce specific events. Event registration enables a device to register the events that it can produce. Also, it allows users or other devices to register to consumer specific events from a device.
- Register data store: Database repository is registered for the device.
- Unregister: This module enables a device, schemas, data stores, and events to be unregistered from the smart home framework.

2) *Account Management:*

This service deals with the creation of user accounts and enables the framework to customize decisions based on the user special needs attribute. It delivers the following main functionalities:

- Handles the operations to create, update, and delete user accounts. The user's disability is specified in this module
- Verifies and validates the registered devices that belong to the user.
- Links devices to user: associates the created users with the registered appliances/devices. Users can be home resident or verified user that is given access to devices and appliances within a smart home environment.

3) *Event Management Service:*

This service manages the distribution of events produced and consumed. This service has the following modules:

- Event Listing: Provides a listing of events currently available for subscription.
- Retrieve Event Definition: Provides the details required to register for an event.
- Event Trigger: Deals with the set of actions to be executed when an event is triggered.
- Event Monitor: Monitors the occurrence events on a device.
- Event Coordinator: coordinates between event producer and consumer when an event is triggered to execute the set of actions.

4) *Resource Service Broker:*

The resource service broker enables the capability based integration of devices and appliances with specific capability requests. The resource service broker has the following modules:

- Discovery: This module discovers specific service based on its identifications and capabilities.
- Retrieve capability definition: Gets the service definition provided by an appliance/device.
- Associate event to device/appliance: Links specific event to a defined device/appliance.
- Associate device to another device: Links a specific defined device/appliance with another device/appliance. This enables specific dependencies of requests to be executed within a single device or multiple devices.
- Invoke appliance/device operation: Determines the address to connect to the device. This component connects and invokes the operation on the home appliance/device. This also provides an orchestration between operations, if they are associated with the dependency relationship.

5) *Data Broker:*

The data broker enables devices in the HAN to persist its data. The following components enable persisting the device data within the HAN infrastructure, as well as with data accessibility, extraction, loading, and transformation.

- Data Access: This module enables data accessibility for device. It provides the insert, delete, and update operations to devices and other components within the HAN framework.
- Data Extraction: Determines the source and extracts the data for the device within the HAN.
- Data Loading: Sends the data to the appropriate destination.
- Data Transformation: Transforms the data format from the stored data source to the data consumer destination format.
- Data Monitoring: Monitors specific data for changes. This component is consumed by the event to monitor specific data changes related to a device/appliance within the HAN.

B. *Technology Approach*

This work proposes the design of the home network by utilizing wireless sensor network (WSN) as it offers greater coverage, accuracy and reliability at a possibly lower cost than conventional methods. To design an adequate HAN geared towards users with special needs, three main criterions:

1) Minimal delay between an event that happens within a device/appliance and letting the user know about this event. For example, the delay between sensing fire and notifying the user should be minimized.

2) Low power consumption

3) Range and expandability: The protocol should ensure coverage of the entire house and it should be easy and flexible to add new nodes.

This work utilizes ZigBee protocol as it achieves the aforementioned criterias. ZigBee is used to establish the wireless communication between the devices and appliances with the master ndoe that contains the proposed framework in section III.

The WSN consists of wireless sensor nodes. Each node consists of a microcontroller connected to sensors and home appliance. Every node in the network is connected to a master controller to integrate, control, and monitor the dervices/appliances within the HAN. The wireless sensor node communicate with the master controller node using Zigbee.

V. IMPLEMENTATION

For the purpose of validation, a prototype was developed to mimic the proposed framework. Figure 2 shows the prototype setup that is implemented for testing and validation purpose. The implemented system consists of four functional wireless sensor nodes: light, fire alarm, door and doorbell, refrigerator and the master controller.

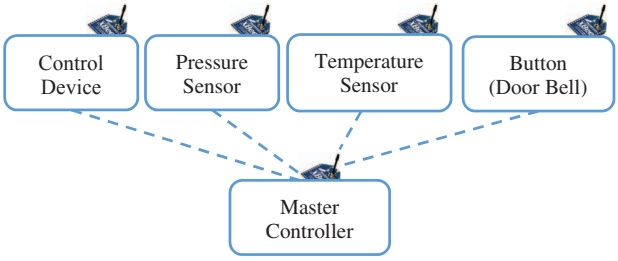

Figure 2. High-level view of the Prototype Implementation

The master controller communicates to the nodes wirelessly using ZigBee. ZigBee is enabled through the XBee boards connected to the master controller and the wireless nodes. The master controller contains the proposed framework discussed. The appliances and devices within the house register with the master controller. Events and activities are coordinated by the master controller.

Once the appliance is turned on, it registers its address, capabilities, and the events that can be consumed with the master node through the registration module.

Figure 3 shows the prototype system setup. The control device consists of a Mega microcontroller connected to several I/O. Inputs include Braille keypad, microphone and switches. Outputs are LEDs, LCD display, buzzer and speaker. The control device is also connected to XBee chip which connectes to the master controller.

The user can control the home lights by turning it ON by presssing the '1' button on the keypad. This triggers an event to consume the light device opeariton in the smart HAN framework. Similarly, when the user presses '2', the light turns OFF. If the user wants to acquire the status of the light, he/she presses '3' on the keypad. To acquire the status of refrigerator door, the user presses '0'. Each event generated by the control device generates a request to consume specific event registered within the master controller nodel.

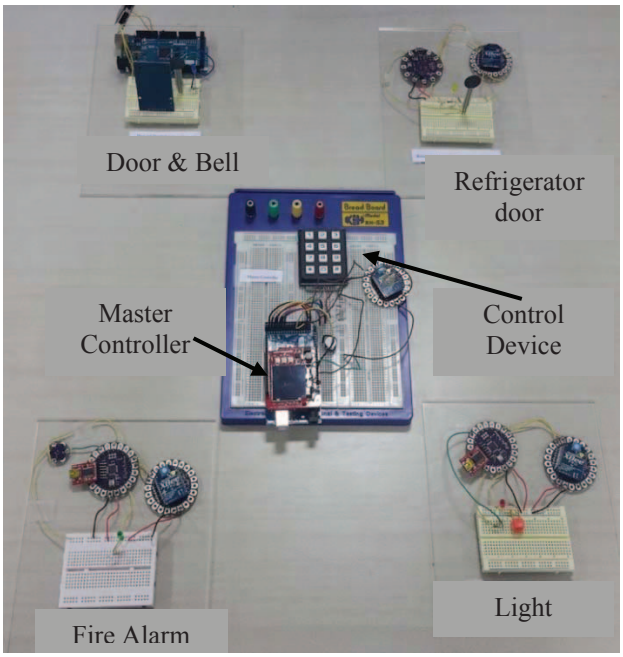

Figure 3: Prototype System Setup

The master registers the capabilities of the control device such as LCD screen, and a buzzer. The master controller allocates the request to the control device capbility based on the user special need. For example, if the user is visually impaired, then all notifications from the master controller will be sound based. Different notifications will sound differently. For example, if there's fire, the buzzer will keep running until the temperature goes back to normal. On the other hand, to notify that a light or refrigerator door is open, the buzzer will beep with a delay. Similarly, if the user is deaf, all alerts and notifications will be displayed on the LCD.

The fire alarm node is connected to a temperature sensor, LED and Xbee board. The node keeps monitoring the temperature of the surrounding. If the temperature reaches beyond a certain limit, the node alerts the master controller and turn ON the LED connected to the node. The Door and Doorbell node are connected to an RFID tag reader and a pressure senor which allows the node to perform two operations. First, when the user swipes the RFID card that matches that connected to node, the door opens for a specific amount of time then automatically closes. Secondly, when a person (visitor) presses the pressure sensor (demoed as doorbell), the node will notify the master controller of this event and the master controller will transform into an output action based on the user special need through the control device. The refrigerator monitoring node has a pressure sensor connected to it. When the pressure is below a certain value, it means that the fridge-door is closed. When the pressure is above a certain limit, it means that the door is open and the LED is lite. This node notifies the master controller of the status of the refrigerator's door (opened/closed) and automatically close the door if the user forgot to do so. The node waits untill it receives the appropriate command from the master controller, check the status of the door, and send the status back to the master controller. For auto closing the door, the system will start a timer when the refrigerator's door is open, the timer checks every 10 seconds if the door is closed or still open. If, after a certain time has passed and the door is still open, the node will automatically close.

VI. Conclusion

Most of the existing smart home monitoring and control systems do not accommodate special needy users to manage their home appliances. A wireless sensor network based system for smart home automation was designed, built and tested to address such missing functionality. The implemented system's major contribution is that it is customized to provide the special need residents with tools and services to monitor and operate home appliances remotely. The implemented system provides home residents with disabilities to take advantage of the advancement in technology. It enables them to perform their daily activities by remotely monitoring and controlling their home appliances without having to depend on others. The system is programmed so that it can be configured to adjust to the customer's disability providing them with better and convenient lifestyle. It is worth mentioning that the system is scalable and can be extended to include more and different services and tools. The system is portable, compact, affordable and easy to use.

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