Design and Implementation of an Intelligent and Scalable Gateway with an integrated IVR, for transforming ordinary homes to Smart Homes/SOHOs

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Abstract— *With the emergence of Internet of Things (IoT), more and more devices are getting connected to the Internet, apart from computers and mobile phones. However, due to the lack of affordable data services in many parts of our country and since majority of the appliances in the market doesn't have any sort of data connectivity currently, there is a need to manage such a system from any type of phone over any type of telecommunication network. Users of such a system should at a minimum be able to remotely control designated power sockets to which appliances like geysers, air conditioners, water pumps, washing machines, rice cookers, porch lights etc. are connected. The users should also be able to monitor their home for critical conditions like gas leaks, smoke, fire, open doors, suspicious activities, medical condition of households, especially our aged ones etc. The proposed Gateway will have a Hub which connects to the telecommunication network through a GSM interface and/or a PSTN interface. The Hub connects to the local actuator nodes inside the power socket panels and sensor nodes using a secure ZigBee wireless interface. When the user is at home, the management can be done quickly using a ZigBee based remote from any room. When the user is away, the gateway number can be dialed and the Interactive Voice Response (IVR) module in the Gateway provides voice prompts to help the user navigate a set of menu options using DTMF key presses. A low power ARM Cortex M0+ MCU at the Hub and an ATtiny MCU at the local actuator/sensor nodes provide a flexible and low cost platform for the implementation. An open source RTOS is used to make this platform more scalable and flexible to cater to different sizes of home/SOHOs. Other enhancements like "Smart Metering" of power sockets are also being explored on this platform.*

Keywords – IoT, IVR, Metering, RTOS, Scalable, Secure, Smart, SOHO (Small Office Home Office), ZigBee

I. INTRODUCTION

Home automation may be briefly described as the automation of the home itself or housework/house hold activities. This may include controlling various aspects of a house such as security locks of a gate /doors, lighting, air condition, home appliances etc. Home automation has a more profound effect when the users are the elderly or the disabled as home automation provides increased quality of life.

The existing home automation system in the market today are platform dependent implying they require the use of smart phones running a particular application in order to interact with the home automation system. These systems are not only relatively expensive but also require the user to own a smart phone and have the technical 'know how' to use it. Hence for a country like India where major section of population are unaware of smartphones, these complex and expensive systems may not be feasible.

The proposed gateway is intended to target such markets as its operation is not confined to a smart phone. The gateway consist of a HUB with an ARM Cortex M0+ core running an RTOS which acts as a central access point for all communications to/from the user allowing them to indirectly interact with the subsystems. The subsystems are paired with the HUB over the 2.4 GHz ZigBee wireless platform. Users can access the HUB either remotely or locally. Local access is facilitated by the ZigBee remote which will be used by the user when he is at his residence. The user can access the HUB by placing a call to it via cellular or PSTN channel where he will be prompted through different menus/options via an IVR system linked to a GSM module in the HUB.

The subsystems linked with the HUB are:-

(1) Wireless Switch- Two versions of the wireless switch has been proposed, one for pluggable appliances like rice cookers, grinders, geysers etc. and another for appliances which are directly wired into the home wiring like Fans, lights , water pumps etc.
(2) Integrated Sensor Module- This module consists of a smoke and a gas sensor interfaced with a microcontroller and a ZigBee transceiver and is wirelessly tethered to the HUB and constantly monitors the gas and smoke levels within its vicinity and if triggered, the HUB places the call and prompts the user about the emergency.
(3) RFID Door locking system- This system allows the user to open and close his/her door lock by flashing an RFID tag. The emergency override feature allows the

user to call the HUB and after the passcode authentication phase it unlocks the door in case of an emergency like losing the RF tag. This locking system can also be accessed via ZigBee remote.

(4) ZigBee Remote- The remote allows the user to interact with the above subsystems while within the home.

Any number of the above subsystems may be paired with the HUB as per the users' requirement making for a scalable system tailored for the individual users' needs. All the above subsystems have backup power supply provision making the system more reliable.

II. SYSTEM ARCHITECTURE

HUB: The HUB comprises of an ARM Cortex M0+ core running an RTOS. The core communicates with the wireless subsystems using the interfaced ZigBee cc2500 transceiver. The voice feedback system consists of a voice playback chip to provide the user with vocal queues, navigating them through the system using DTMF keypad which decodes users' key strokes and this system is connected to the 2G/PSTN networks via SIM 900A GSM module. The basic block diagram of HUB is shown in figure 1.

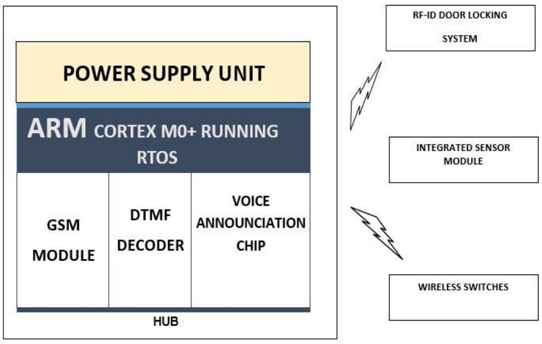

Figure 1: Basic block diagram of Gateway

RFID Door Locking System: The locking system shown in figure 2 consists of an ATtiny microcontroller connected to a ZigBee transceiver to be wirelessly linked to the HUB. A relay circuit is implemented to commutate the electronic lock's actuator. The locking system can be accessed via the remote or an RFID reader. An emergency override feature allows the user to unlock the door by placing a call to the HUB and completing authentication.

The backup power supply is also provided which maintains continuous power supply to the door locking system.

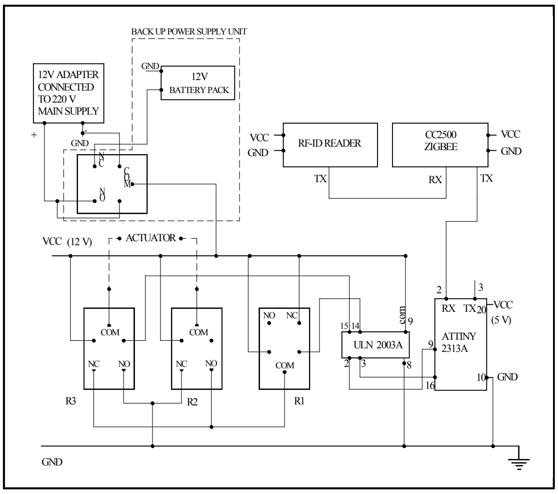

Figure 2: Schematic of RFID Door Locking System

Integrated Sensor Module: This module comprises of a ZigBee interfaced ATtiny microcontroller paired with MQ2 and MQ6 smoke and gas sensors respectively as shown in figure 3. On detecting the threat the sensor module intimates the HUB about the emergency and in turn alerts the user to take action. The MQ6 sensor senses both gas as well as smoke but since there is no way to decipher the cause of the trigger, so a separate MQ2 Gas sensor has been interfaced with the ATtiny MCU. The MCU is programmed to constantly pole the digital outputs of these two sensors that have been calibrated to give an output 'high' when the

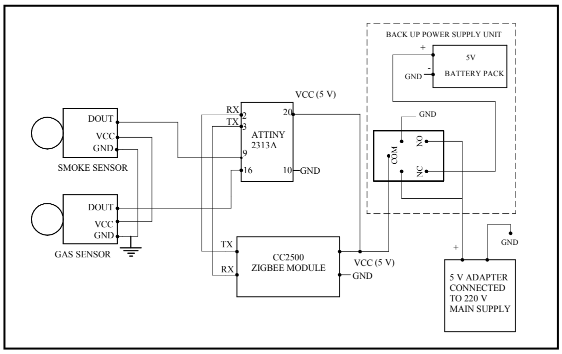

Figure 3: Schematic of Integrated Sensor Module

gas/smoke levels reach beyond acceptable thresholds. When this happens the MCU sends a control frame to the hub indicating it of the nature of the threat. The hub makes a timed log of this and places a call to the users registered number and alerts him of the threat using the voice playback chip.

Wireless Switch: The wireless switch network is made of a coil relay controlled by an ATtiny microcontroller on receiving encrypted commands from the HUB via a ZigBee transceiver interfaced to the HUB as shown in figure 4. The HUB sends unique control frames for energizing/de-energizing

the relays within switches resulting in power control
to the appliance. The incoming command is intercepted by the ZigBee transceiver in the wireless switch and the MCU within the switch first identifies if the frame is meant for it and then decides on the action it must perform. Two versions of the switch have been implemented. Both versions of the switch have identical circuitry except for the fact that the switch version for pluggable appliances can have multiple relays in order to individually control multiple appliances whereas the switch meant for directly wired appliances only has a single relay to control a single appliance due to the spatial separation between these appliances being considerable.

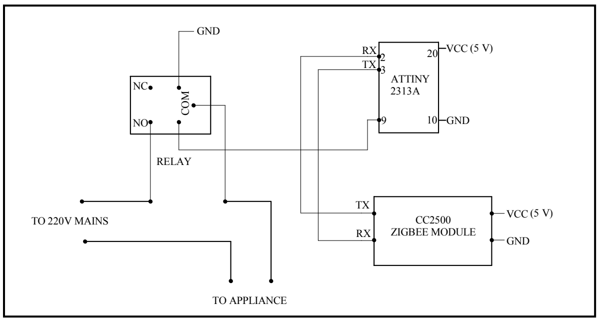

Figure 4: Schematic of Wireless Switch

Appropriate delays have been introduced in the MCU code so as to prevent high frequency switching of the relays resulting in damage to the appliance.

Remote: The remote consists of appropriately labeled push buttons connected to an ATtiny microcontroller that sends an encrypted frame to

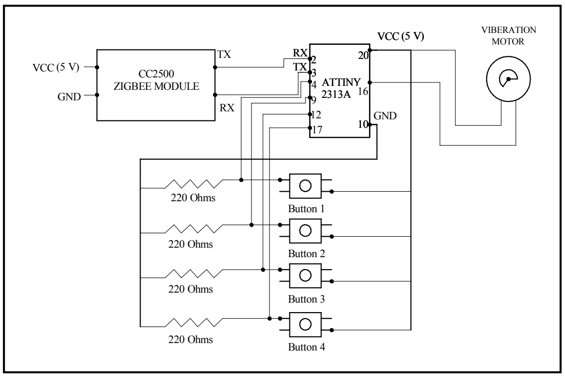

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Figure 5: Schematic of ZigBee Remote

HUB via a ZigBee transceiver when the user presses a button to perform various actions. The remote consists of a motor with an asymmetric chuck as shown in figure 5 that is intended to vibrate the remote for half a second when any button is pressed indicating that the action is recognized by the MCU. On pressing a button the remote control frames are routed via the HUB to the subsystems associated with the buttons where specific actions take place. The HUB logs all the actions made using remote.

III. IMPLEMENTATION

Software Architecture

The RTOS has been chosen to be the core software architecture in the hub as it provides several advantages that make the home automation gateway efficient and also extends its capabilities. A wide range of wireless peripheral subsystems are interfaced to the hub and need to be handled concurrently, the RTOS simplifies this by having dedicated tasks that can be prioritized as per requirement. The RTOS chosen for the HUB is CoOS by the developers of the CooCox INTEGRATED ENVIRONMENT as it provides us with all the functionality of completely configurable RTOS while remaining light on the systems memory [4kB Flash usage].

The RTOS running in the HUB is organized such that the lowest priority tasks are those that monitor both the ZigBee transceiver as well as the sim900A GSM module. Since these low priority tasks have equal priority with respect to each other, they have been round robin time sliced in order to monitor both these peripherals virtually simultaneously.

The highest priority task is the time keeping task which on initialization fetches the time from the GSM module via AT commands and then proceeds to maintain time and date by incrementing minute wise hence preempting all other tasks once every minute. The time thus maintained is used in the production of logs on the user's request. Individual Tasks have been dedicated to each of the switches which are initially in the blocked state and are unblocked only when certain events happen at either the ZigBee transceiver or the GSM module.
The ARM Cortex M0+ core has to deal with several peripherals each using a different interface .The ZigBee and GSM modules are interfaced to the ARM core using separate UARTs (Universal Asynchronous Receive Transmit).

LOGS on Demand:

With such versatile control over the home environment it quickly becomes apparent that there must be a way of logging the different activities taking place locally as well as remotely such as Door lock/unlock, sensor triggering/switch toggling etc. Thus a logging system is developed within the RTOS that consists of a size 180 character array into which LOGS of different events are appended/rewritten as they occur and on the users demand this character array is sent to them via SMS so they have an account of the events that have transpired. Currently this system offers the users provisions to receive the timed logs of the last five events. Figure 6 shows the screenshot of received logs from HUB.

Figure 6: Screenshot of received logs from HUB

IV. RESULTS

The HUB as well as all the subsystems have been developed, tested and the following results are obtained.

1. The maximum effective range between any two wireless nodes should be less than 10 meters. Frames not meant for a wireless node is re-transmitted, resulting in an extension of range as long as there is at least one wireless node within stipulated distance.
2. The ARM Cortex M0+ running the RTOS comfortably handles up to 20 subsystems of any type to be paired with it.
3. The APR33A3 voice playback chip gives reasonable quality voice feedback at a very low cost.
4. Sensitivity of the integrated sensor module has been calibrated to trigger only above a particular threshold that signifies a gas leak or a fire. This reduces the chance of false triggering.
5. The Door can be locked or unlocked via remote or RF tag. The emergency override feature over GSM allows the user to unlock the door in case of emergency (e.g. Loss of tag).
6. Multi language support for over 10 languages can been implemented for the IVR system. Currently 4 languages have been implemented and tested.
7. The subsystems merely need to be paired with the HUB in order for it to become active/controllable.

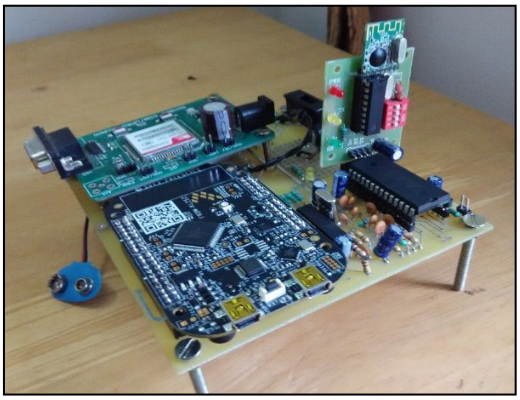

Figure 7: HUB

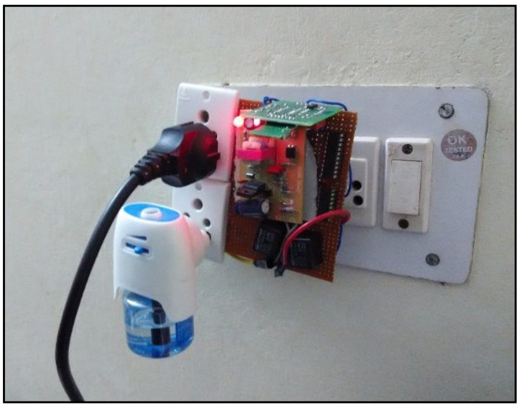

Figure 8: Switch version 1

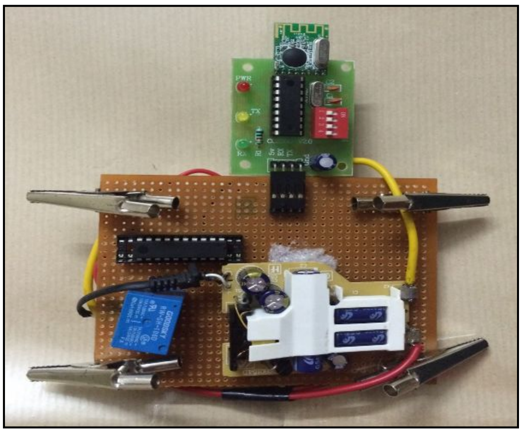

Figure 9: Switch version 2

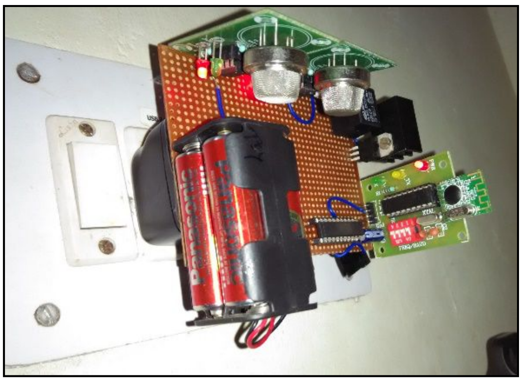

Figure 10: Integrated Sensor Module

Figure 11: Door Locking System

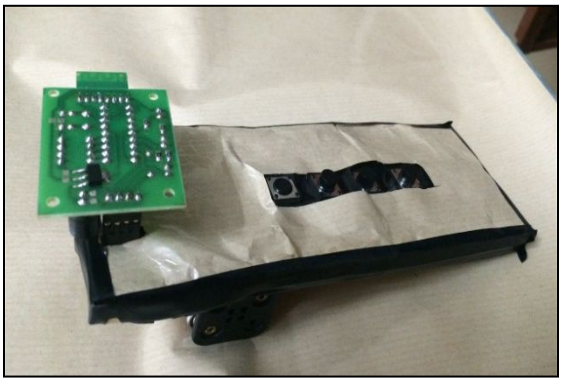

Figure 12: ZigBee Remote

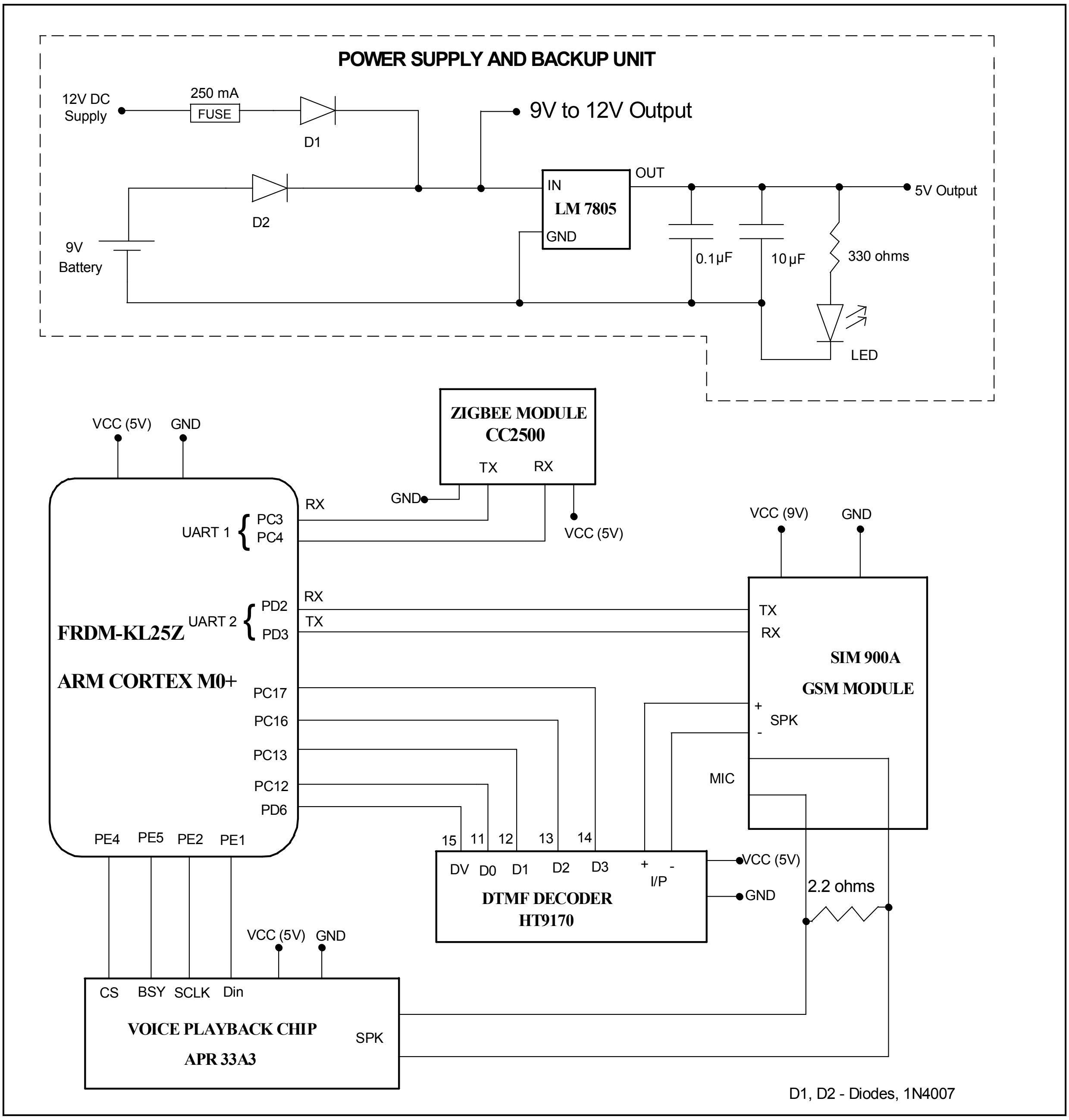

Figure 13: Complete schematic of HUB

V. CONCLUSION

The proposed gateway can have a huge impact because of its scalability and versatility and will have increased acceptance because of its simplicity and ease of use. The low cost design ensures affordability as the user only has to purchase the subsystem he desires and pair it with the HUB. The HUB is equipped to meet the automation needs of the elderly and reduces the need for institutional care/caretakers. This gateway increase the users' independence giving him greater control of his home environment while enhancing his personal safety.

The gateway is easy to use by members of any age group and does not require understanding of complex devices like smartphones etc. The fact that the gateway is not reliant on mobile data/data services makes it all the more reliable in country where cellular data services have not penetrated a lot of areas or is unreliable. The installation of the subsystems into households/offices has been made very convenient because of their user friendly design.

The multiple regional language support makes the system more acceptable for a country like India with a wide linguistic diversity.

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