Cross-Domain Integration of home automation, entertainment, and e-Health using Wireless Sensor Network

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Cross-Domain Integration of home automation, entertainment, and e-Health using Wireless Sensor and Actuator Network

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Abstract

Recent advances in wireless sensor and actuator network (WSAN) and other emerging technologies are promoting a paradigm shift in the way that traditional domains like home automation, home based entertainment, or e-Health are understood. However, available technologies present different innate characteristics and are hard to integrate. This paper presents our WSAN-based smart home project, mySmart, to demonstrate the innovative integration mechanism developed that not only integrates research- and commercial- oriented WSN platforms at the application layer, but also provides a unified application development environment for building WSAN based monitoring and control systems. mySmart integrates cross-domain home applications such as home automation, entertainment, and e-Health and addresses one of the major challenges in the home automation system design: minimizing the power consumption without compromising the customers comfort level. It combines hybrid-node networking with Web access in three-layer architecture. The system integrates TinyOS-based mica motes deployed in mesh network and National Instrument (NI) LabVIEW-based WSN nodes using star topology to monitor the home environment and the health status of the nodes themselves. The environment data includes temperature, humidity, light intensity, sound, motion, as well as the physiological signals such as body temperature and heart beats from a person (e-Health). The health status information of mySmart includes networking reliability (i.e., link quality and packet delivery ratio) and the power consumption of the WSN node that is battery powered. All the monitoring data are wirelessly collected and visualized in an application developed in LabVIEW, which makes control decisions based on the data collected and the control strategy defined by the user. The control commands are then disseminated wirelessly to the specific actuators (fans, LED light, speaker, etc.). The mySmart Architecture provides the flexibility for future expansion by separating the sensing, networking, and controlling and visualization. It can be easily adapted to support various courses in the science, engineering, and technology program from freshman to senior level. The demonstration of the project to our junior level instrumentation and measurement class is very successful. Students get to see how what they are learning can be used in real world project that is highly relevant to their own life.

Introduction

Advances in wireless sensor and actuator networks (WSAN) technology and other emerging technologies are enabling a paradigm shift in the way that traditional domains of smart home, such as entertainment, automation and e-Health, are understood. However, there is no systematic mechanism to integrate them together with guaranteed performance and efficiency.

Our smart home project, mySmart, demonstrates the systematic integration mechanism we developed that seamlessly integrates new and emerging technologies together with performance guarantee. mySmart handles the integration from three aspects: the WSAN based monitoring and control; user interface design; and power management. This paper presents the details of all three aspects, starts from its architecture; integration of research- and industry-oriented WSAN platforms [1-3]; its unified and versatile user interface that incorporates voice recognition [4,5]; and its power management [6,7].

mySmart Architecture

As shown in Figure 1, mySmart has three sub-systems that work cooperatively to deliver its functions with satisfactory performance guarantee: WSAN that monitor the environment and provide automated feedback control to ensure comfort level at home, unified and versatile user interface that provides intuitive human-machine interface; and energy harvesting and power management.

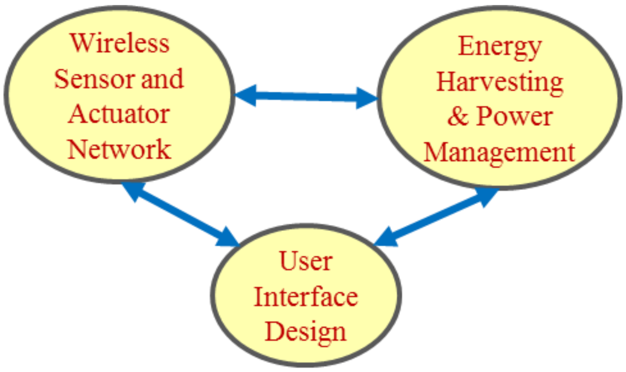

Figure 1 Three Sub-Systems of mySmart

The WSAN monitors the environment and health status of the home appliances (home automation) and the user (e-health). When any abnormality is detected, the control decision will be made to either control the actuator to adjust the temperature and lighting condition, or send out multi-media alert to care takers at the point-of-care about the abnormal condition. The energy harvesting and power management module generates secondary power from vibration and/or solar panel to supplement the primary battery power and sustain the operation of the WSAN. Power management is realized on each node by ensuring low-power listening and at the system level by balancing communication load and identifying the best multi-hop route. The power management functions ensure the sustainability of the whole system, especially the WSAN nodes, so that it can have the longest lifetime and function well without human intervention. The unified and versatile user interfaces, including data visualization, analysis, and control functions, have been developed across multiple platforms (such as PC/Laptop, Webpage, and mobile device) to ensure best user experience with the system. Voice recognition has been incorporated to make the mySmart human-machine interaction more intuitive.

Figure 2 shows the architecture of the mySmart testbed and provides an overview on WSAN platforms used, voice recognition capability, and application software development environment.

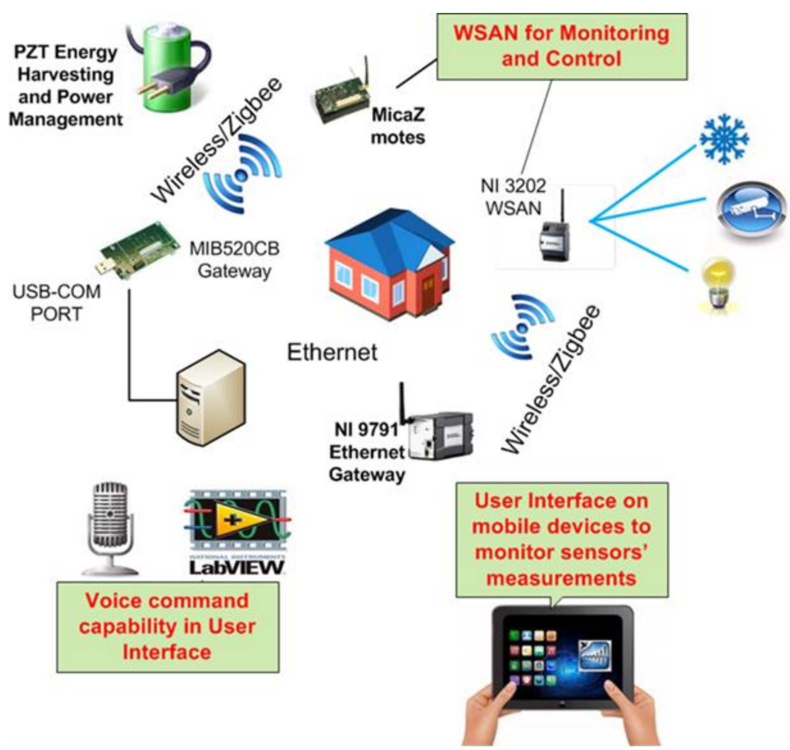

Figure 2 mySmart System Architecture

Wireless Sensor and Actuator Network

Working on an open architecture, the WSAN sub-system employs various sensors and actuators, and provides option to utilize both wired and wirelessly communication. Control logic strives to achieve the balance between maintaining the comfort level of the environment and the energy consumption of the system adaptively and optimally.

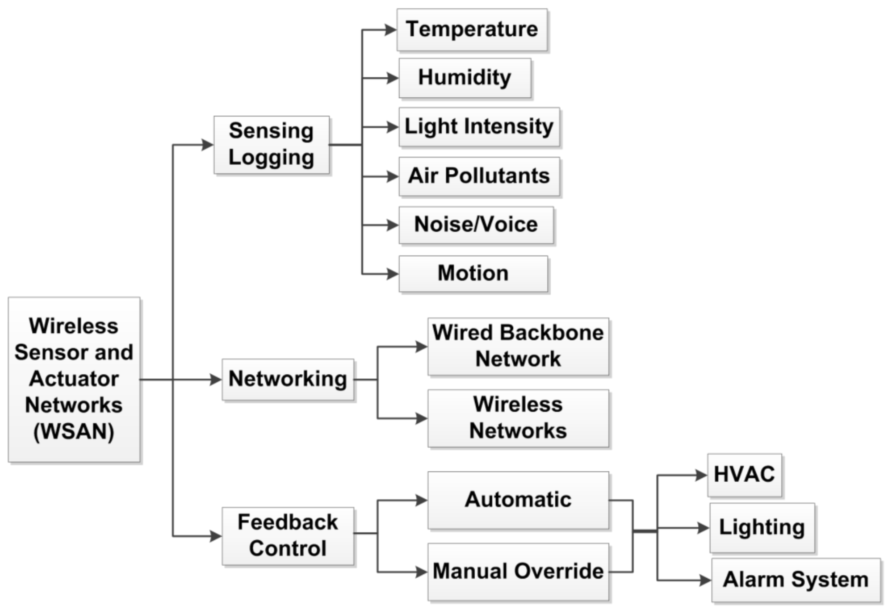

Figure 3 mySmart WSAN Sub-

Figure 3 shows in details the sensors and actuators used in the mySmart test bed; the networking aspects and the decision making functions. mySmart utilizes both WSN based on IEEE 802.15.4, including its extension in Zigbee and the wireline backbone network that enables data sharing via the cloud. It also integrated research-oriented TinyOS-based WSN platform (mica motes) [8-10] and industry-oriented NI WSN nodes [3, 11-13] by developing an application layer system, mySmart, in LabVIEW that takes measurements from both mica motes and NI WSN nodes and provides real-time feedback control via NI's WSN node (NI WSN-3202 [14]). In addition to the data logging and visualization, simple control logic is integrated into the mySmart test bed that automatically control the HAVC (simulated by a fan in mySmart), lighting system (simulated with LEDs), and security system (simulated by speaker that plays alarmingly loud music and flashing bright LED to deter the theft). Users can always override any settings that trigger automatic feedback control. For example, even though ventilation fan is setup to get started when temperature exceeds 78^{o}F, users can always turn it on via user interface even when the temperature is still way below 78^{o}F.

User Interface Design

We design a uniform and versatile user interface before implementing it across multiple hardware platforms, including PC/laptop, to web pages, to mobile devices, as shown in Figure 4 (a). This practice streamlines the human machine interface of the mySmart to ensure best user experience with the system.

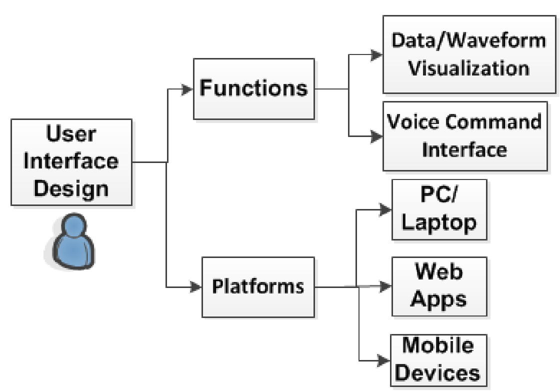

Figure 4 (a) mySmart User Interface

All user interfaces provide data/waveform visualization and simple analysis functions that can be fed into control strategies. In addition, voice recognition capability is also integrated in all user interfaces to provide a more intuitive interaction mechanism. System logic is designed such that human commands (whether in the

Figure 4 (b) Three panels user interface on computer

form of voice or clicking on the control button) always get the highest priority. For example, instead of waiting for the next communication time to read the new monitoring measurement, user can interrupt the system loop and ask for current temperature or humidity values. The system will respond by activating the corresponding sensors and wireless communication radios to deliver the readings within seconds. Figure 4 (b) shows the user interface design and three panels for monitor and control on computer. A similar monitoring user interface was implemented using NI Data Dashboard [11]. User can download the application onto their mobile device and check the home environment condition remotely. Current NI data dashboard does not support feedback control for Android OS [27]. Thus, only the monitoring functions were implemented for the dashboard version of the mySmart.

Energy Harvesting and Power Management

Due to the desire of minimum human intervention after deploying a WSAN, various power management mechanisms have been developed to minimize power consumption at each node [6-7, 15,16], and to budget power consumption of the whole network [17-21]. Power management is realized in mySmart from two levels. (1) At the node level, in the interest of extending battery

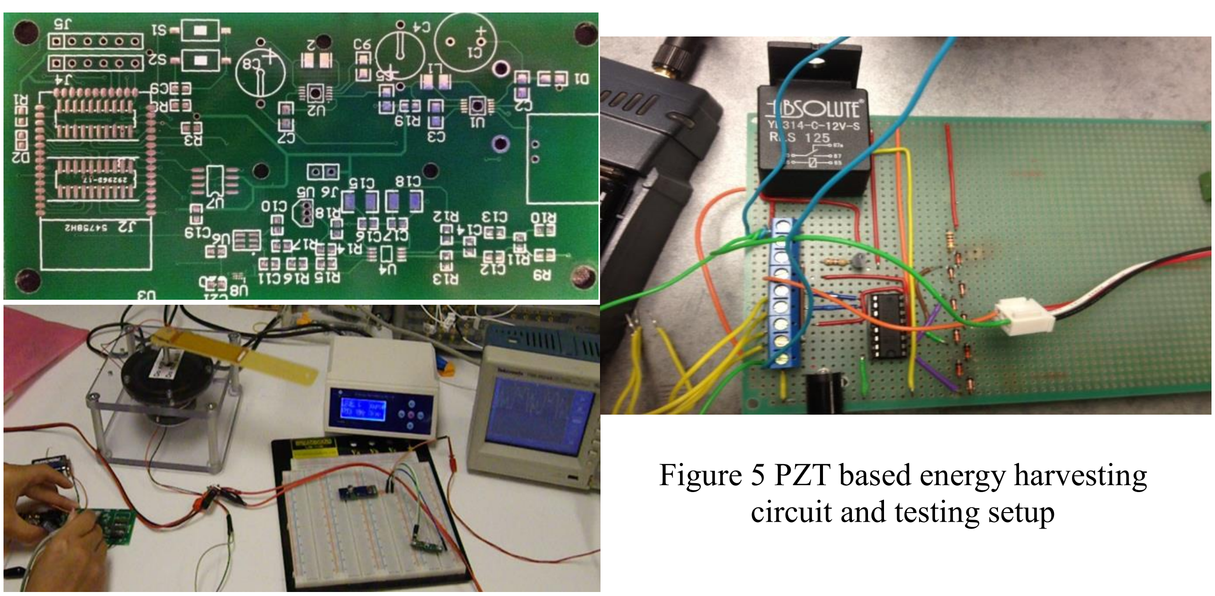

Figure 5 PZT based energy harvesting circuit and testing setup

lifetime, communication radio is duty cycled on and off to prevent any waste of energy. For example, the two popular radios (CC1000 [22] and CC2420 [23]) used in wireless communication consume anywhere from 7.4 to 18.8 mA power when they are turned on and listening. (2) At the system (i.e., network) level, communication load is balanced by forming energy-efficient clusters [20] and identify the best multi-hop route [18].

Novel piezoelectric based energy harvesting circuits were also been developed to enable simultaneous vibration monitoring and energy harvesting [24]. Such mechanism enhances the sustainability of WSAN used in mySmart by providing supplement to each node's primary power source. Figure 5 shows the energy harvesting circuits designed and testing setup. Further developed is underway to incorporate the setup with WSAN.

Conclusion

We successfully integrated the research-oriented WSN platform and the industry-application oriented WSN platform at the application layer. The paper demonstrated the capability of such integration by presents the design, development, and implementation of a WSAN-based smart home application, mySmart, across multiple domains from entertainment, to home automation, to e-Health. Figure 6 shows the current version of mySmart testbed. We are extending the concept to incorporate more sensors and actuators to incorporate power harvesting capability from ambient vibration sources as well as transforming the application to run as a real-time stand-alone system on hardware such as NI cRIO [25] or Crossbow Stargate [26]. In addition, we are working with NI engineers to introduce feedback control capability to its Android dashboard version.

Figure 6 mySmart: smart home monitoring and control

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