ARCHITECTURE FOR BODY SENSOR NETWORKS

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ABSTRACT

Recent advances in wireless sensor networks have facilitate the realisation of pervasive health monitoring for both homecare and hospital environments. The concept of Body Sensor Networks (BSN) has been introduced recently where miniaturised wearable or implantable wireless sensors are used for continuous monitoring of patients. To facilitate research and development in BSN, a BSN hardware development platform, called BSN node, is proposed by Imperial College London. With its compact, low power and flexible design, the BSN nodes provide a versatile developing environment for pervasive healthcare applications.

INTRODUCTION

Wireless Sensor Network (WSN) is becoming a significant enabling technology for a wide variety of applications. The rationale behind the distributed sensor network is for detecting, identifying, localizing, monitoring, and tracking one or more subjects of interest. One potential application is in the form of BSN for measuring physiological/context parameters [1]. The aim of the BSN is to provide continuous monitoring of patients under their natural physiological states so that transient but life threatening abnormalities can be detected and predicted.

In order to provide continuous monitoring, micro-powered, miniaturised, and low cost wireless biosensors are required. To enable the development of wireless biosensors and BSN, a flexible and low power wireless development platform is required. Early BSN platforms are developed mainly based on modifying the WSN platforms, and the development WSN has greatly facilitate the development of BSN platforms.

Since the introduction of WSN, a considerable number of different development platforms have been introduced. Especially in the last two years during which more than twenty different WSN hardware platforms are proposed. Table 1 outlines some of the WSN platforms introduced. Despite their architectural difference, these platforms can be categorised into three main classes including ARM based platforms, microcontroller based platforms, and RF integrated platforms.

Because certain WSN applications require a considerable amount of processing power, some WSN platforms are designed based on ARM processors, which are mainly designed for handheld devices, such as PDA. For instance, an Intel PXA271 processor is used in the recently proposed iMote2 platform [1]. The PXA processor is an ARM based processor designed for PDA, and it can run up to 416MHz. With the adjustable operating frequency function, the PXA processor can be configured for low power applications as well as computational demanding tasks, such as acting as a gateway for WSN. In terms of wireless communication, since ARM based processor provides an SDIO (Secured Digital Input/Output) interface, it enables the platform to use different wireless networks, such as Bluetooth or WiFi. However, external ADCs (Analog-to-Digital Converters) are required for the ARM based platform to connect to analogue sensors.

As in most WSN applications, power consumption is a major consideration, conventional low power microcontrollers, instead of the power demanding ARM processors, are often used,. For instance, the Atmel ATmega 128L processor is used in MicaZ [2], DSYS25 [3], EmberNet [4] and Fleck [5]. Compare to the ARM processor, the ATmega processor is a relatively slow 8-bit processor; however, the ATmega processor requires much less power than the ARM processor and it can operate at only 2.7V. On the other hand, without the SDIO interface, these microcontroller-based platforms are all integrated with low power radio transceivers. Since the recent introduction of the IEEE 802.15.4 standard for wireless sensor networks, Chipcon CC2420, one of the first IEEE 802.15.4 compatible radio transceivers, is used in most of the new platforms.

Although microcontroller based platforms are usually small, some WSN platforms are designed based on integrated RF-microcontroller chipsets for further size reduction. For example, the MITes is based on a Nordic nRF24E1 chipset [6]. The Nordic nRF24E1 is a RF transceiver integrated with an Intel 8051 microprocessor core. By using the integrated chipset, the size of the MITes is only 1.2x1.0 inch. However, the drawback of using an integrated chipset is that the processor is relatively slow. In addition, much of the processing resources are mainly used up for handling wireless communications.

Thus far, most of the WSN hardware platforms are designed for network research, environment monitoring or tracking applications, such as Berkeley's Telos [2], Intel's iMote2 and UCC's DSYS25. Although there are a number of context aware sensing platforms such as the Smart-its (Particle2/29 and uPart0140ilmt0) [7] and the MITes, due to the integrated sensor design, the incorporation of physiological sensor will require major redesign of the hardware platform. The lack of a flexible operating system also hinders the extension of the platform for the research community. To facilitate the research and development of BSN, a BSN hardware platform, called BSN node is designed and developed. Figure 1 shows the picture of the BSN node. With its stackable design, different type of sensors can easily be integrated. By adopting the IEEE 802.15.4 standards, sufficient bandwidth is available for demanding continuous physiological and context sensing.

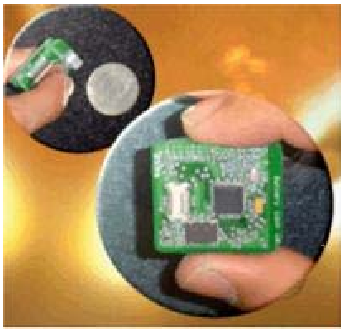

Figure 1 BSN Node

BSN ARCHITECTURAL DESIGN

Figure 2 illustrates the basic structure of the BSN node. It consists of 4 major components, which are the microcontroller, RF module, flash memory and board connector.

The BSN node is designed based on the Texas Instrument (TI) MSP430F149 microcontroller. The MSP430 processor is a 16-bit ultra low power RISC processor with 60KB flash memory, 2 KB RAM and 12-bit ADC. The ultra low power processor can operate at minimum of 1.8V, and requires only 3mW at active mode and 15μW at sleep mode, which is much less than the Atmel processor. In addition, it provides a wide range of interconnection functions, such as 12-bit ADCs and serial programming interface.

For wireless communication, the Chipcon CC2420, is used in the BSN node. The CC2420 has a maximum throughput of 250kpbs with a range of over 50m. In addition, it has a built-in the AES-128 (Advanced Encryption Standard) hardware encryption/decryption and the IEEE 802.15.4 MAC (Medium Access Control) functions. With the built-in buffers and MAC, the CC2420 can act as a coprocessor to handle all the packet communications, and which significantly reduce the computational demands on the microcontroller.

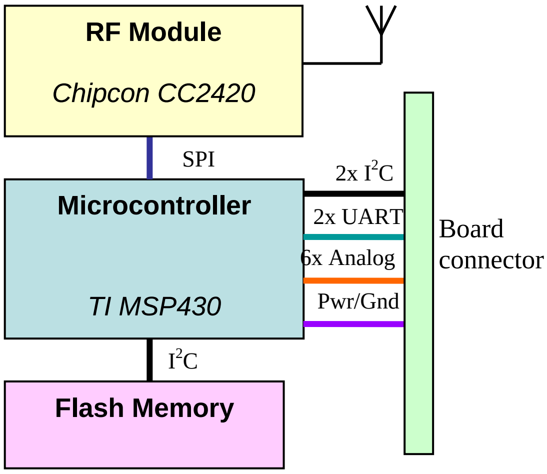

Figure 2 BSN node architecture

To facilitate the sensor data collection and enable dynamic reprogramming of the BSN node, 512KB of serial flash memory is incorporated in the BSN node. With the 512KB of memory, almost 1.5hour of ECG (100Hz) data can be stored without any compression. By applying the DPCM and LZW in series, ECG data can be compressed down to 11% of its original size, which means that the memory may be able to hold up to 13 hours of ECG data [8].

Stackable design is adopted in the BSN node, where different sensor boards can be stacked on top of the BSN node. By using the 20-pins connector, various digital and analogue interfaces are provided, which includes two I^2C buses, two UART interfaces, six analogue channels, power and ground signals. In addition to providing sensor interface, the board connector is also used for programming the BSN node where separate a USB programmer is designed for programming the node.

In terms of software, the BSN node is designed to run TinyOS by U.C. Berkeley, which is a small, open source and energy efficient sensor board operating system. It provides a set of modular software building blocks, of which designers can choose the components they require. The size of these files is typically as small as 200 bytes and thus the overall size is kept to a minimum. The operating system manages both the hardware and the wireless network—taking sensor measurements, making routing decisions, and controlling power dissipation.

By using the ultra low power TI microcontroller, the BSN node requires only 0.01mA in active mode and 1.3mA when performing computational intensive calculation like a FFT. With a size of 26mm, the BSN node is ideal for developing wireless biosensors. In addition, the stackable design of the BSN node and the available interface channels ease the integration of different sensors with the BSN node. Together with TinyOS, the BSN node can significantly cut the development cycle for wireless biosensor development.

PROTOTYPE

With the proposed BSN architecture, a number of wireless biosensors including 3-lead ECG, 2-lead ECG strip, and SpO2 sensors have been developed [9]. To facilitate the incorporation of context information, an integrated sensor has been designed and developed. Figure 3 shows a picture of the integrated sensor. In addition to the BSN node, the integrated sensor consists of an ECG sensor, a 2-axis accelerometer, a temperature sensor, battery power sensor and a re-chargeable battery. With size of 3.1cm x 4.6cm, the integrated sensor is much smaller than any commercially available ECG holter monitoring systems. In addition, the system is embedded with the context sensors such that activities can be detected to achieve fully context-aware sensing. Furthermore, the integrated sensor is designed with an extension connector to enable addition of sensors and battery modules.

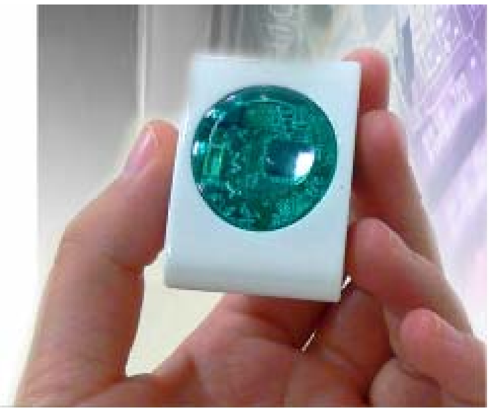

Figure 3 BSN Integrated Sensor

CONCLUSION

Due to the wide range of potential applications of WSN, many different hardware platforms have recently been introduced. Most of the platforms are designed for general purpose wireless network research. In terms of BSN, although WSN hardware platforms can be modified for BSN applications, only a few platforms can actually be used for BSN in practice due to the extensive bandwidth and computational requirement and size constraint for BSN. For instance, due to the limited bandwidth, the Berkeley's Mica2 are not suitable for BSN. Although attempts have been made to modify the Mica2 platforms to create wearable biosensors, such as the Mica2Dot based ECG (Electrocardiogram) sensor developed at Imperial College [10], very few sensors can be set up in a network due to high bandwidth and high sampling rate required for ECG sensors (200Hz). Although Telos has much higher bandwidth than its predecessor, Telos is relatively big and heavy, due to its design with an USB interface and mounting for two AA batteries. As miniaturised and light platform is required for the practical deployment of BSN, this can present a problem.

To facilitate the development of BSN, the BSN node is designed and developed for BSN research. Based on the ultra-low power TI MSP430 processor and the CC2420 transceiver, the BSN node is a low power wireless sensor development platform for BSN. With its stackable design, physiological and context aware sensors can easily be integrated. By using the BSN node, a number of BSN prototypes have been proposed for pervasive health monitoring.

Table 1 Wireless Sensor Network Platforms

Platforms	CPU	Radio Transceiver	Organisation
Telos*	TI MSP430F149	Chipcon CC2420	UC Berkeley/ Moteiv
M1010[11]*		Chipcon CC1000	Dust Inc
BSN node	TI MSP430F149	Chipcon CC2420	Imperial College
Mica-Z*	Atmel Atmega 128L	Chipcon CC2420	Crossbow
CIT Sensor Node [12]	PIC16F877	Nordic nRF903	Cork Institute of Technology
MITes	nRF24E1 (8051 based)	Nordic nRF24E1	MIT
Particle2/29*	PIC 18F6720	RFM TR1001	Teco
Pluto[13]	TI MSP430F149	Chipcon CC2420	Harvard
DSYS25	Atmel Atmega 128	Nordic nRF2401	UCC
eyesIFXv2 [14]	TI MSP430F1611	Infineon TDA5250	TU Berlin
iMote 2	Intel PXA 271	CC2420	Intel
uPart0140ilmt*	rfPIC16F675	rfPIC16F675	Teco
Tmote sky [15]*	TI MSP430F1611	Chipcon CC2420	UC Berkeley/ Moteiv
EmberNet*	Atmel Atmega 128L	Ember 250	Ember
XYZ sensor node [16]	OKI ML67Q500x (ARM/THUMB)	Chipcon CC2420	Yale
Ant[17]*	TI MSP430F1232	Nordic nRF24AP1	Dynastream Innovation inc
M2020[18]*			Dust Inc.
OEM100* [19]			Sensicast
OEM200* [20]			Sensicast

* Commercially available platforms

REFERENCES

[1] L. Nachman, "Imote2," TinyOS Technology Exchange II, http://www.tinyos.net/ttx-02-2005/platforms/ttx05-imote2.ppt, 2005.

[2] J. Polastre, R. Szewczyk, and D. Culler, "The Mote Revolution:Low Power Wireless Sensor Network Devices," presented at Hot Chips 16: A Symposium on High Performance Chips, Stanford University, 2004.

[3] A. Barroso, J. Benson, T. Murphy, U. Roedig, C. Sreenan, J. Barton, S. Bel-lis, B. O'Flynn and K. Delaney, "Demo Abstract: The DSYS25 Sensor Platform," In Proceedings of the SenSys '04, Baltimore, Maryland, USA, 2004.

[4] "Ember JumpStart Developer Kit Proof-of-Concept Prototype for Embedded Wireless Applications," FACT–000–JUMPST–0405, Ember Corporation, 2005.

[5] P. Corke, "Wireless Sensor Network Devices," CSIRO http://www.ict.csiro.au/page.php?cid=87, 2005.

[6] E. M. Tapia, N. Marmasse, S. S. Intille, and K. Larson, "MITes: Wireless portable sensors for studying behavior," In Adjunct Proceedings of the Ubicomp 2004: Ubiquitous Computing, Nottingham UK, 2004.

[7] "Selection of Smart-Its Particle Prototypes, Sensor and Add-On Boards," Teco, http://particle.teco.edu/devices/devices.html.

[8] S. Kwan, The representation, transmission and storage of data for Ubiquitous monitoring applications, MSc Thesis, Imperial College, Sept 2004.

[9] B. Lo, S. Thiemjarus, R. King and G.Z. Yang, "Body Sensor Network – A Wireless Sensor Platform for Pervasive Healthcare Monitoring", In Adjunct Proceedings of the PERVASIVE 2005, 2005.

[10] J. Ng, B. Lo, O. Wells, M. Sloman, C. Toumazou, N. Peters, A. Darzi, G.Z. Yang, "Ubiquitous Monitoring Environment for Wearable and Implantable Sensors (UbiMon)," In Adjunct Proceedings of the UbiComp 2004, Nottingham, UK, 2004.

[11] "M1010 Mote," Dust Networks, http://www.dust-inc.com, 2004.

[12] C. Lynch and F.s O' Reilly, "PIC-based TinyOS Implementation," presented at the 2004 IT&T Annual conference, 2004.

[13] M. Welsh, "CodeBlue: Wireless Sensor Networks for Medical Care," Harvard University, http://www.eecs.harvard.edu/~mdw/proj/codeblue/, 2005.

[14] V. Handzisk and T. Lentsch, "The eyesIFX platform," TinyOS Technology Exchange II, http://www.tinyos.net/ttx-02-2005/platforms/ttx2005-eyesIFX.ppt, 2005.

[15] "Tmote sky Ultra low power IEEE 802.15.4 compliant wireless sensor mod-ule," Tmote sky : PRELIMINARY Datasheet Moteiv, http://www.moteiv.com/, 2005.

[16] D. Lymberopoulos and A. Savvides, "XYZ: A Motion-Enabled, Power Aware Sensor Node Platform for Distributed Sensor Network Applications," In Proceeding so f the IPSN 05, Los Angeles, CA, 2005.

[17] "The wireless personal area network," Dynastream Innovations Inc, http://www.thisisant.com, 2005.

[18] "M2020 Mote," Dust Networks, 2005.

[19] "OEM100 – Wireless Integration Module," OEM100 Datasheet, Sensicast Systems, Inc., www.sensicast.com, 2005.

[20] "OEM200 – Wireless Integration Module," Sensicast Systems, Inc., www.sensicast.com, 2005.