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A portable wireless body sensor data logger and its application in video capsule endoscopy

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ABSTRACT

Due to the advancement of low power miniature electronic devices, there is growing interest of physiological data sensing and recording using wireless body sensor networks. The paper presents the design of a portable physiological data logger that includes rechargeable battery, wireless radio frequency and Bluetooth connectivity, and graphical display with touch screen capability. The target application is video capsule endoscopy. Image data are logged in micro SD cards which can be easily transferred to PC or Smartphone using SD card reader, USB interface or Bluetooth wireless link. The hardware design is general and can be used in various medical or industrial applications by changing only the firmware of the microcontroller. The design is prototyped in 109 × 107 × 20 mm printed circuit board (PCB). Tests with animal tissues have been conducted to demonstrate the performance advantages of the data logger. A demonstration of wireless heart pulse monitoring and data logging is also presented.

1. Introduction

Sensing and recording of physiological signals for medical applications are growing rapidly. Miniature bio-sensors convert various body signals such as temperature, blood pressure, breathing [1], and heartbeat [2–4], into electrical signals for processing, transmission and recording by electronic devices [5]. Data coming from implanted or external body sensors can be transmitted wirelessly to a portable and wearable data logger unit, thus giving the patient the freedom to do household works during continuous data logging without the hassle of cumbersome wired devices. After data logging is completed, the data are transferred to a workstation PC and the physicians examine the captured data for medical diagnostics. In this paper, a portable, battery operated data logger unit having wireless connectivity with the bio sensors is discussed. The design of the data logger is general and can be used for several medical applications. In this work, the target application is video capsule endoscopy [6].

Several works are found in the literature related to data logging for medical applications. In [7], a data logger unit for storing galvanic skin response (GSR) for autistic patients is discussed. The data logger receives data using RS232 interface and stores it in 16 MB EEPROM. An ECG signal data logger with custom design ASIC controller for multimedia card (MMC) is discussed in [3]. In [2,8,39], wearable prototypes for fetal electrocardiograph (FECG) monitoring are discussed. These systems obtain signals through 8 ECG leads using wired interface in an FPGA, where an algorithm for FECG signal extraction is implemented. Data are then transferred to PC using Bluetooth for storage and further analysis. A portable data logger with three body-fixed inertial sensors for monitoring the physical activities of Parkinson's disease (PD) patients is proposed in [9]. Note that the above discussed data loggers receive data from body sensors using wired connections which is not comfortable for patients. In [10], an ECG data logging system, which can be attached with the chest of human, is developed. The system board contains analog frontend, 16 bit microcontroller, 1 GB flash memory, and battery. However, the design does not contain wireless link with any implantable body sensor, thus logging data from an implantable sensor is not possible with this design. A wireless data logger for recording human movements is discussed in [11]; however the data logger is not portable as it takes power from house AC line supply, thus restricts the patient's movement near to the data logger. Other than medical applications, microcontroller based data loggers are also found in literature for solar radiation and environmental monitoring [12], ocean bottom seismometers [13], CO_2 and NH_3 density recording along with global positioning system (GPS) data [14], etc.

The data logger presented in this work is portable and has high data rate of 2 Mbps wireless connectivity, high memory capacity of 4 GB micro secure digital (SD) card, graphical display for displaying images, videos, and graphs in real time. The display also has keypad and touch screen interface. After logging, the data can be transferred to PC using a SD card reader at a speed of up to 25 MB/s or using an USB interface. Optionally, the data can also be transferred to PC or Smartphone wirelessly using Bluetooth

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technology. An illustration of a data logging system of a wireless body sensor system using the proposed data logger is shown in Fig. 1.

2. Design specification of the data logger

An application of the proposed data logger focusing on wireless capsule endoscopy (WCE) [6] is discussed in this paper. WCE is a state-of-the-art technology to receive images of human intestine for medical diagnostics. The first commercial capsule endoscopy system, *PillCam*, was developed by Given Imaging in the year 2000 [15]. It was approved by the Food and Drug Administration (FDA) [16] in 2001. Today, more than 1.8 million patients have experienced the benefits from capsule endoscopy [15]. In this procedure, the patient swallows a specially designed electronic capsule which has imaging and wireless transmission capabilities inside it. A portable data logger is worn also around the patients waist. Then the patient is allowed to leave the hospital and go to their regular routine work including walking, sitting, driving etc. [17]. After four hours, the patient may eat some snacks, unless restricted by the gastroenterologist. The patient should avoid strenuous physical activity, especially if it involves sweating, and should not bend or stoop during the procedure [17]. While the capsule travels through the gastrointestinal (GI) tract, it captures images and sends them wirelessly to the wearable data logger unit. The data logger stores the images and later the data are transferred to PC where the images are reconstructed and displayed for diagnosis. Some requirements for designing the data logger for capsule endoscopic system are given below.

In capsule endoscopy, images are generally transmitted in compressed form at 2 frames-per-second for about 8–10 h [18,19]. The storage space required, S, for this application can be expressed using (1), where, W is the image width, H is the image height, BPP is the bits-per-pixel, FPS is frames per second, CR is the compression ratio, and T is the duration of data logging in hour.

$$S = W \times H \times BPP \times (1 - CR) \times FBS \times T \times 3600 \quad (1)$$

- In order to store color QVGA (320×240, 24 bits-per-pixel) images transmitted at 2 FPS having 80% compression ratio for 10 h, at least 3.1 GB memory space is required.
- The data rate of the wireless transceiver must be high enough to support the above mentioned transmission which is calculated as 720 kbps.
- It must consume low power so that battery is able to supply power continuously for at least 10 h.
- The data logger should be able to communicate with the capsule in real-time during logging and control various features of the capsule, such as, changing image size, imaging mode (e.g., white light imaging, narrow band imaging), frame rate, etc. The interface used for this interactive control operation must be easy to use.
- Real time viewing of the images, while the capsule is in operation and the data logging is in process, is another important feature. Using it, a physician can take decision to change imaging mode, image size, or frame rate of a certain region of the GI tract for better viewing. The data logger must have necessary hardware for displaying color images and firmware to decompress and display compressed image data.
- After data logging is completed, there must be easy and fast way to transfer the data to workstation PC or Smartphone for diagnostics.
- The physical size and weight of the data logger must be as less as possible.

3. The data logger architecture

The data logger is designed having four layers as shown in Fig. 2. Each layer completes its functionality by using the resources of its lower layers. By only changing the application layer firmware, the data logger can be used in several applications, without modifying the lower level driver and hardware layers. A brief description of each layer is given below.

3.1. Hardware layer

The overall block diagram of the hardware is shown in Fig. 3. The design consists of a microcontroller (MCU) and several peripherals connected with it. Each major component of the design is briefly described below.

3.1.1. Microcontroller

A microcontroller from the XMEGA-A1 [20] family is chosen for this design. To increase the data sample rate and writing speed in the storage device, a high speed MCU is required. Moreover, several peripherals are connected with the MCU using SPI and UART protocol. The XMEGA microcontroller has more hardware SPI and UART which works faster than software SPI or UART. The chosen MCU also has 78 programmable I/O lines, 128kB flash for program storage, 8kB SRAM to store user defined variables temporarily and 2kB EEPROM to store variables permanently.

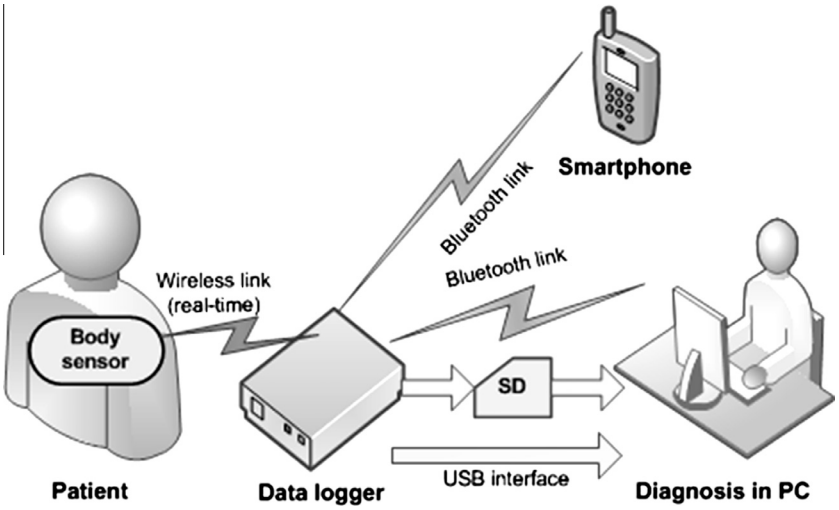

Fig. 1. Wireless body sensor data logging system.