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Wearable System for Ambulatory Healthcare Monitoring

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***Abstract*— In this paper, we describe the development of a wearable system for monitoring the healthcare parameters in ambulatory conditions. The system has been developed using Texas Instrument's ADS 1298 (an 8-channel, 24-bit ADC for biopotential measurement) and ST Microelectronics' STM32L431RCT6 microcontroller (an ARM cortex-M4, 80MHz, LQFP-64 MCU). It is a low-cost system capable of recording electrocardiogram (ECG), electroencephalogram (EEG), blood oxygen saturation (SpO2) and body temperature. The recorded ECG and EEG signals can be viewed both on on-board OLED display as well as on the computer via Bluetooth. Thus, the system capable of acquiring both ECG and EEG signals on a single acquisition unit has been developed. This portable, low-cost healthcare monitoring system would not only be advantageous to common people but also could be significantly helpful to the physicians; particularly monitoring the cardiac and neuronal abnormalities.**

Keywords*— *Wearable System, Electrocardiogram (ECG), Electroencephalogram (EEG), SpO2, ADS1298, STM32L431RCT6

I. Introduction

In this era of fast pace and stress-filled lifestyles, cardiological and neuronal disorders are becoming very common even in the people of early age groups. In order to detect the cardiac and neuronal abnormalities, if any, earlier and get properly treated it is necessary to have routine body check-ups and even hospitalization at regular intervals. However, due to time and other constraints it may not be possible, for everyone who is at potential cardiac/ neuronal risk, to maintain regularity in this respect. An easy and convenient option to hospitalization is to use the *wearable devices (WD)*. Many such WDs have been proposed by researchers [1] – [8]. The modern W-ECG/A-ECG recorders not only record the ECG signals and related physiological parameters, but are also capable, due to advancements in telemedicine, of updating the physician whenever an abnormal cardiac event or arrhythmia occurs to the wearer. In [9], [10] authors have classified body movement activities (BMAs) captured in wearable ECG (W-ECG) using various algorithms. In [11], authors have developed wireless patient monitoring system. The designed system will record the physiological parameters - body temperature, oxygen saturation in blood (SpO2), heart rate, as well as two bioelectrical signals electrocardiogram (ECG) signals and electroencephalogram (EEG). The recorded parameters and signals have been transferred via bluetooth communication protocol to an android based smartphone.

In this paper, we have proposed a wearable system for recording the electrocardiogram (ECG) and electroencephalogram (EEG) signals of the subject. It is a convenient option of hospitalization for the patients suffering from various cardiac and neuronal disorders. The cardiac abnormalities like bradycardia, tachycardia, atrial and ventricular fibrillation/flutter and neuronal diseases like epilepsies are increasing in the people of age group 35 to 50 years due to sedentary lifestyles. The significance of the project comprises in two ways: firstly, because it is wearable and ambulatory in nature, subject can perform his/her routine activities. Secondly, the system will be providing both ECG and EEG signals using a single board. Till date the researchers have developed wearable sensor based systems for single parameter monitoring [1]-[8]. But, the system capable of acquiring both ECG and EEG signals has not been reported till date.

The organization of the paper is as follows: Section 1 provides the background information about the wearable systems; section 2 describes the system components as well as the block diagram; section 3 comprises the PCB design layout and in section 4 the conclusion is presented.

II. Description of Stsyem Components

In this section the description of the main system components- ADS 1298, STM32L431RCT6 microcontroller, OLED display module and the HC 05 Bluetooth module is given.

A. ADS 1298

ADS 1298 is a low-power, 8-channel, 24-bit analog front end for biopotential measurement. With high levels of integration and exceptional performance, the ADS129x and ADS129xR enables the development of scalable medical instrumentation systems at significantly reduced size, power, and overall cost. Typical applications of ADS 1298 include measurement of ECG, EEG and electromyogram (EMG); event, stress and vital parameter monitoring; evoked audio potential (EAP) and sleep study monitoring. Following are the features of ADS 1298:

• Eight Low-Noise PGAs and Eight High-Resolution ADCs

• Low Power: 0.75 mW/channel
• Data Rate: 250 SPS to 32 kSPS
• CMRR: –115 dB
• Programmable Gain: 1, 2, 3, 4, 6, 8, or 12
• Built-In Right Leg Drive Amplifier, Lead-Off Detection, Wilson Center Terminal, Pace Detection, Test Signals
• Built-In Oscillator and Reference
• SPI Compatible Serial Interface

The ADS1298 has a highly-programmable multiplexer (mux) that allows for temperature, supply, input short, and RLD measurements. Additionally, the mux allows any of the input electrodes to be programmed as the patient reference drive. The PGA gain is chosen from one of seven settings: 1, 2, 3, 4, 6, 8, or 12. The ADCs in the device offer data rates from 250 SPS to 32 kSPS. Communicate with the device by using an SPI-compatible interface. The device provides four GPIO pins for general use.

B. STM32L431RCT6 microcontroller

The STM32L431xx devices are the ultra-low-power microcontrollers based on the high-performance ARM Cortex-M4 32-bit RISC core operating at a frequency of up to 80 MHz. The Cortex-M4 core features a Floating point unit (FPU) single precision which supports all ARM single-precision data-processing instructions and data types. It also implements a full set of DSP instructions and a memory protection unit (MPU) which enhances application security. The STM32L431xx devices embed high-speed memories (Flash memory up to 256 Kbyte, 64 Kbyte of SRAM), a Quad SPI flash memories interface (available on all packages) and an extensive range of enhanced I/Os and peripherals connected to two APB buses, two AHB buses and a 32-bit multi-AHB bus matrix. The STM32L431xx devices embed several protection mechanisms for embedded Flash memory and SRAM: readout protection, write protection, proprietary code readout protection and Firewall.

The devices offer a fast 12-bit ADC (5 MSPS), two comparators, one operational amplifier, two DAC channels, an internal voltage reference buffer, a low-power RTC, one general-purpose 32-bit timer, one 16-bit PWM timer dedicated to motor control, four general-purpose 16-bit timers, and two 16-bit low-power timers. They also feature standard and advanced communication interfaces: Three I2Cs, Three SPIs, Three USARTs and one Low-Power UART, One SAI (Serial Audio Interfaces), One SDMMC, One CAN, One SWPMI (Single Wire Protocol Master Interface).

B.1 Adaptive Real time memory (ART) Accelerator

The ART Accelerator is a memory accelerator which is optimized for STM32 industry-standard ARM Cortex-M4 processors. It balances the inherent performance advantage of the ARM Cortex-M4 over Flash memory technologies, which normally requires the processor to wait for the Flash memory at higher frequencies.

To release the processor near 100 DMIPS performance at 80MHz, the accelerator implements an instruction prefetch queue and branch cache, which increases program execution speed from the 64-bit Flash memory. Based on CoreMark benchmark, the performance achieved thanks to the ART accelerator is equivalent to 0 wait state program execution from Flash memory at a CPU frequency up to 80 MHz.

B.2 Memory Protection Unit (MPU)

The memory protection unit (MPU) is used to manage the CPU accesses to memory to prevent one task to accidentally corrupt the memory or resources used by any other active task. This memory area is organized into up to 8 protected areas that can in turn be divided up into 8 subareas. The protection area sizes are between 32 bytes and the whole 4 gigabytes of addressable memory.

The MPU is especially helpful for applications where some critical or certified code has to be protected against the misbehaviour of other tasks. It is usually managed by an RTOS (real-time operating system). If a program accesses a memory location that is prohibited by the MPU, the RTOS can detect it and take action. In an RTOS environment, the kernel can dynamically update the MPU area setting, based on the process to be executed. The MPU is optional and can be bypassed for applications that do not need it.

B.3 ST-Link/V2 In-circuit Debugger and Programmer

The ST-LINK/V2 is an in-circuit debugger and programmer for the STM8 and STM32 microcontroller families. The single wire interface module (SWIM) and JTAG/serial wire debugging (SWD) interfaces are used to communicate with any STM8 or STM32 microcontroller located on an application board. In addition to provide the same functionalities as the ST-LINK/V2, the ST-LINK/V2-ISOL features digital isolation between the PC and the target application board. It also withstands voltages of up to 1000 Vrms. STM8 applications use the USB full-speed interface to communicate with the ST Visual Develop (STVD) or ST Visual Program (STVP) software. STM32 applications use the USB full-speed interface to communicate with Atollic, IAR, Keil or TASKING integrated development environments.

Fig. 1. ST-Link/V2 In-circuit Debugger and Programmer

C. OLED Display Module

The DD-160128FC-1A, an RGB colour OLED display module, from Densitron has been used. Following are the main features of this display module:

- Supply voltage is 2.8V
- Display format of 160 (RGB) x 128dots
- Overall dimension of 35.80mm x 30.80mm x 1.6mm
- Viewing area of 30.78mm x 25.02mm
- Passive matrix display
- 1/128 duty driving
- SEPS525F driver IC
- Operating temperature range from -20°C to 70°C

The SEPS525F display driver controller has three high-speed system interface: a 68-system, an 80-system 8/9/16/18 bit bus, and a clock synchronous serial (SPI: Serial Peripheral Interface). Among the interface modes, a specific mode is selected by the setting of PS pin and MEMORY_WRITE_MODE register (16h). The SEPS525 has 3-type registers: an index register (IR) 8-bits, a write data register (WDR), and a read data register (RDR). The IR stores index information for the control registers and the DDRAM. The WDR temporarily stores data to be written into control registers and the DDRAM, and the RDR temporarily stores data read from the DDRAM. Data written into the DDRAM from the MPU is first written into the WDR and then it is automatically written into the DDRAM by internal operation. Data is read through the RDR when reading from the DDRAM, and the first read data is invalid and the second and the following data are valid.

D. HC05 Bluetooth Module

HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. Serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). It has the footprint as small as 12.7mmx27mm.

Fig. 2. HC 05 Bluetooth module

Following features are incorporated with the HC 05 module:

- Typical -80dBm sensitivity
- Up to +4dBm RF transmit power
- Low Power 1.8V Operation ,1.8 to 3.6V I/O
- PIO control
- UART interface with programmable baud rate
- With integrated antenna
- With edge connector
- Default Baud rate: 38400, Data bits: 8, Stop bit: 1, Parity: No parity

Supported baud rate: 9600, 19200, 38400, 57600, 115200, 230400, 460800

III. Schematic and PCB Design Layout

ADS1298 has been interfaced with STM32L4 microcontroller for the acquisition of ECG signals. The schematic is designed for interfacing Bluetooth module HC-05 over UART terminals. The temperature sensor module based on MAX30205 is used for the body temperature measurement. This module provides the temperature data over I2C bus. Hence I2C module of STM32L4 is used to acquire body temperature data. The power supply requirement is met with mini USB port interfaced with personal computer. STM32L4 requires +3.3 Volts while the OLED requires +14 Volts. Buck and Boost switching regulators MP1584 and MT3608 respectively are used for generating +3.3 Volts and +14 Volts from available +5 Volts at USB port.

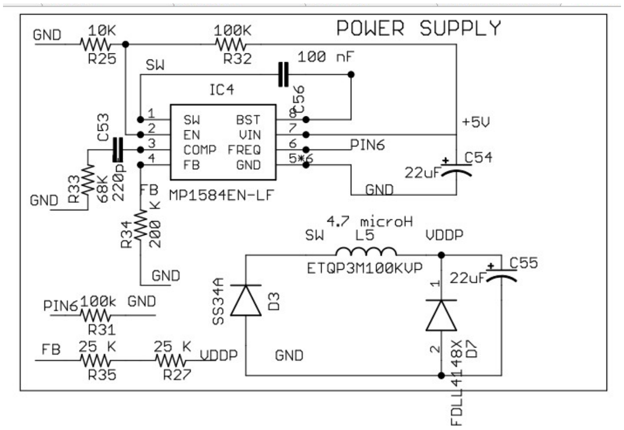

Fig. 3. Switching Regulator for +3.3 Volts

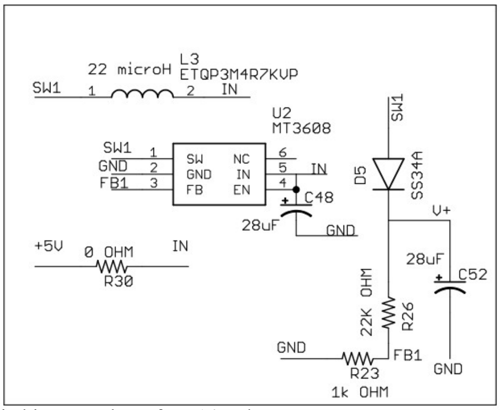

Fig. 4. Switching Regulator for +14 Volts

Four keys for supporting menu operations are interfaced with GPIO port of microcontroller. SPI port of microcontroller is used to interface serial Flash memory of 8Mbytes. Fig. 5 shows the double sided PCB design of the system with dimension 55 mm X 85 mm. Complete implementation of the prototype is shown in Fig. 6.

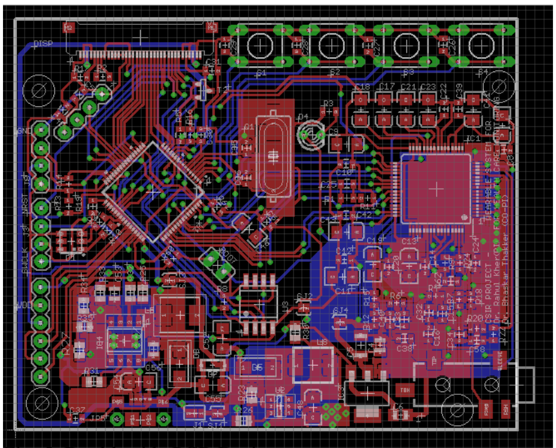

Fig. 5. Double side PCB Design

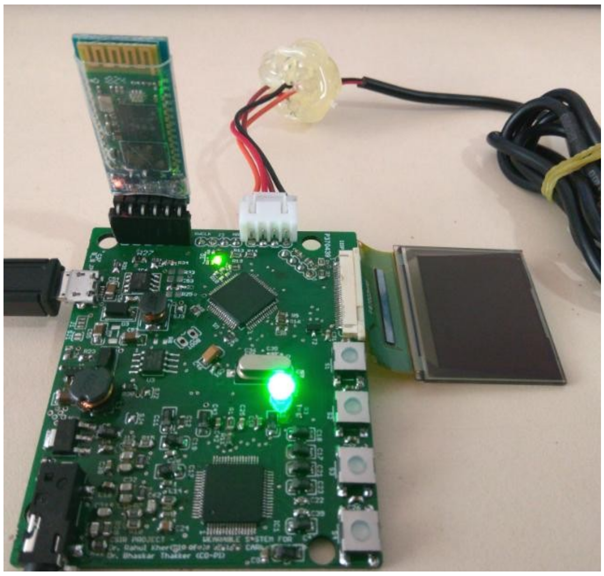

Fig. 6. Prototype of Ambulatory Health Monitoring unit

IV. Conclusion

A low-cost, wearable system for ambulatory health monitoring system has been designed for acquiring and monitoring the vital health parameters like body temperature, ECG and EEG signals of a subject. Up till now, the PCB design, interfacing of temperature sensor module and the HC-05 bluetooth module has been completed. Currently, we are working on establishing the data communication between ADS 1298 and the microcontroller. Thereafter, the channel 1 of ADS 1298 will be used for acquiring the ECG signal and channel 2 will be used for acquiring the EEG signal of a subject. Finally, the ECG and EEG signal will be displayed on the OLED display.

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