Design a Customizable Low-Cost, Matlab Based Wireless Data Acquisition System for Real-Time Physiological Signal Processing

Loc Gia Luu, Nam Phuong Nguyen, and Toi Vo Van

Abstract

This paper presents the design of a wireless data acquisition system to acquire and process physiological signals in real-time using Matlab. The system comprises two frameworks: hardware and software. The hardware consists of a wifi connection and four slots to plug in the sensors. The signal on each slot can be sampled at the user determined rate up to 4 K samples-per-second for a 16-bit resolution of maximum analog voltage of 2.5 V. The software is based on Matlab and includes four processing streams for each slot's data and a graphic user interface comprising four data graphs and other settings. Each stream can be processed independently by user-defined algorithms for specific data in real-time. The system also saves all the data into a text file which can be stored, retrieved, viewed, and processed by other software. For testing purpose, three analog front-ends (ECG, EMG, and SPO2) were designed and connected to the system. All the system functions were tested and performed as expected. This low cost, flexible, and easy to use data acquisition system is very useful for biomedical data collection in ambulatory environment and real-time processing the signals in practical settings.

Keywords

Customizable • WiFi • Data acquisition system • Real-time processing • Matlab

1 Introduction

Biomedical engineering (BME) field is constantly developed and advanced by taking advantages of new technologies. Tools such as specific data acquisition system to support research, teaching, and training in this field are also in the high demand. For physiological signal data collection, there are plenty of vendors offering numerous products in the market. However, these products have many drawbacks for specific applications. These limitations include low flexibility, expensive, not wireless, low resolution. Some of the products made by BioPac, National Instruments, Vernier, etc. can be found in the market. In addition, there are many new biomedical sensor categories of various manufacturers which always appear on the market. These sensors need to be integrated into the existent data collection system with ease. Therefore, this work is to design a data acquisition system (DAQ) which can solve the above problems to have an open structure, low-cost, high resolution, wireless connection and works with many types of sensors regardless of their output format (either analog or digital). However, in the scope of this paper, only analog interface will be discussed. The digital interface for digital output sensors such as I2C, SPI and digital I/Os will be investigated in the future.

This DAQ has 8 channels for analog physiological signals and a variable sampling rate chosen by the user. Data converted are transmitted wirelessly using WiFi and TCP/IP technology. The data are easily collected, processed, displayed, and stored by a computer. The overview of the wireless data acquisition system is shown in Fig. 1 below

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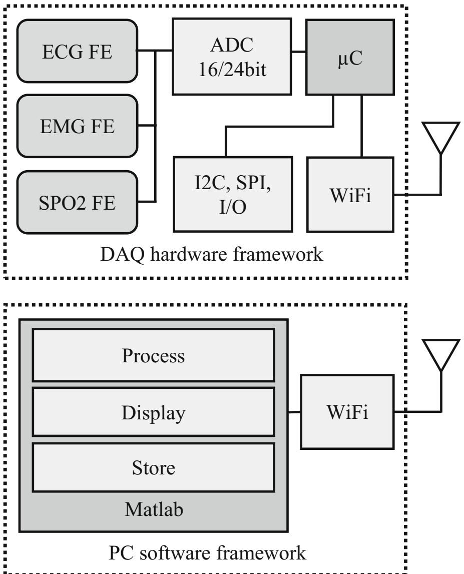


Fig. 1 System overview

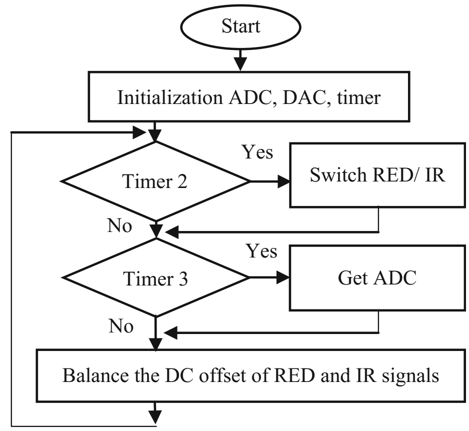


Fig. 2 Flow chart of the program in the STM32F100

and consists of three parts: the analog front-ends (FE), the hardware (HW) framework and the software (SW) framework on the computer.

2 Analog Front-Ends

2.1 ECG Sensor Front-End

This front-end has two British Telecom Analog (BTA) sockets which support the Vernier sensors and others using BTA interface [1]. These sockets supply 5 V and has an ID pin to detect the type of sensor based on the voltage. A divider is needed to translate 0–5 V range of analog output to the ADC input range of 0–2.5 V. There are two jumper lines to select the input channel of ADC for each sensor socket. For testing, the EKG sensor of Vernier is used to capture the ECG signal.

2.2 EMG Electrodes Front-End

This front-end contains a DB-9 socket used to connect with EMG probe of BioPac [2] and an instrumentation amplifier INA333 of Texas Instruments (TI) is used to amplify the EMG signal. A bandpass filter with cutoff frequencies of 40 and 160 Hz is used to remove the noise and to recover the amplified EMG signal which is dominant within the range of 50–150 Hz.

2.3 Reusable SPO2 Sensor Front-End

This front-end also uses a DB-9 socket to interface with the SPO2 sensor made by Acare Technology [3]. The sensor has one RED LED emitting in the wavelength of 660 nm, one infrared (IR) LED emitting in the wavelength of 940 nm and a photodetector receives the light from the LEDs. The microcontroller STM32F100 (STMicroelectronics) and an H-bridge is used to control the two LEDs on and off in a sequence between 500 µs. The microcontroller also measures the DC offset of the output voltage to balance the emitting intensity of the two LEDs. The flowchart for STM32F100 is shown in Fig. 2.

The op-amp MCP601 (Microchip) is used to convert the output current of the photodetector to an output voltage. Because the output voltage is the combination of the RED and IR signals in time slots, an analog switch TS3A24159 (TI) separates the RED and IR signals. Then each signal passes through each band pass filter in the range of 0.6–3.5 Hz of the arterial pulse to eliminate 1 kHz of the on/off frequency and the power line interference.

3 Hardware Framework

3.1 DAQ Hardware Design

The DAQ hardware comprises an ARM microcontroller, a dedicated analog to digital converter (ADC), a WiFi module and a power management with rechargeable battery. All of components are assembled in a single PCB and supplied 3.3 V DC to operate the system. All of these off-the-shelf components can be found easily on the market. The microcontroller LPC1768 in LQFP100 package belongs to Cortex-M3 series of NXP Semiconductors. This microcontroller has 512 KB flash, 64 KB data memory and runs at the maximum speed of 100 MHz. This chip also provides the I2C, SPI interfaces and digital I/Os for future work with digital output sensors.

Although the microcontroller has an on-chip ADC, a dedicated ADC—the ADS131E08 (TI)—is used to convert the signals. The reason is the on-chip ADC has low resolution 12-bit (1.5 bytes per sample) which has less efficient in real-time transferring data comparing with higher resolution 16/24-bit (2 or 3 bytes per sample) of the TI's ADC [4]. In addition, some studies require the precise time difference of samples between channels, and the cycle sampling of the on-chip ADC can cause some delays between channels while the TI's ADC converts signals simultaneously for eight channels. The ADS131E08 in TQFP64 package has accurate internal oscillator and voltage reference, so it requires only few external components to function.

The wireless communication is provided by a WiFi module—the WizFi220 (Wiznet). This module supports a data rate up to 11 Mbps and is compliant with 802.11 b/g/n standards. The WiFi module has an internal power amplifier which increases the maximum output power up to 17 dBm and is connected to an external Omni antenna to achieve better signal comparing with an on-board chip antenna.

The power management with four switching regulators supplies four different levels of voltage including 5, 3.3, 2.5 and −2.5 V to be capable to support various types of sensors. In addition, a charge controller MCP73831 (Microchip) handles the battery charging. Figure 5 shows the photograph of the DAQ board which has a dimension of 12 × 12 cm and the front-ends for sensors.

3.2 Firmware Design

The flowchart for the DAQ hardware is shown in Fig. 3. When the DAQ is supplied with power, it initiates all variables and peripherals including USART, SPI and I/O ports. If this is a first start, the hardware creates a self-access-point (AP) by default. Then, the DAQ is looking for computer to connect and executes commands or settings from that computer. If a start command is received, the DAQ will start collecting data, pack the data and send the data to the computer via WiFi module. The stop command will disable the AD process and stop sending the data. If the command is the network settings, it contains all network parameters of an external AP. The DAQ then stops the self-AP and connects to the external AP.

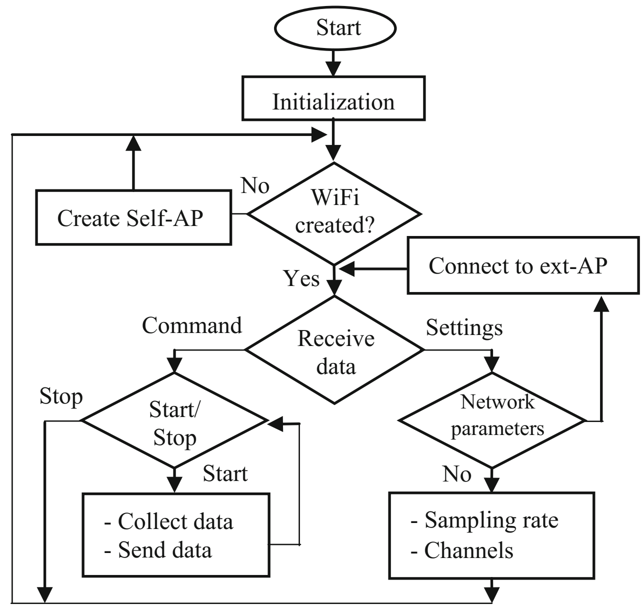


Fig. 3 Flowchart of the DAQ hardware

4 Software Framework

The software framework is based on Matlab program and operates according to the flowchart in Fig. 4. The framework has the setting and control panel on the left side and four graphs on the right side. Once the computer connects to the self-AP made by DAQ hardware, the framework can configure the sampling rate, the network parameters of external AP and control the operation of the DAQ. When the framework receives data from the DAQ hardware, it separates the data for each channel from the coming packages. The data of each channel then pass through the corresponding processing streams to be processed by the user-defined algorithms. The results and processed data are displayed on the user interface (as shown in the testing result section). The user can also change the range of the displayed amplitude and the window view during acquisition (see Fig. 6). Figure 5 displays the pictures of DAQ and analog front-ends.

5 Testing Results

The designed wireless DAQ system was connected to a three front-ends including ECG, EMG, and SPO2 to test the connection and processing blocks. The EKG sensor was connected to the ECG simulator—Fluke's MPS450, the output waveform of which was monitored by an oscilloscope and set as normal ECG with 66 BPM. The EMG probe was connected to the electrodes attached on the hand's skin. The SPO2 sensor was clamped on the SPO2 simulator INDEX

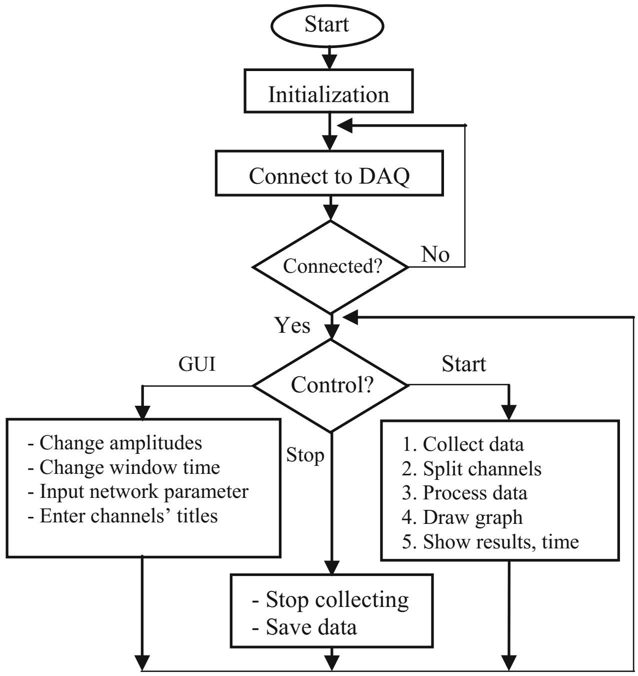
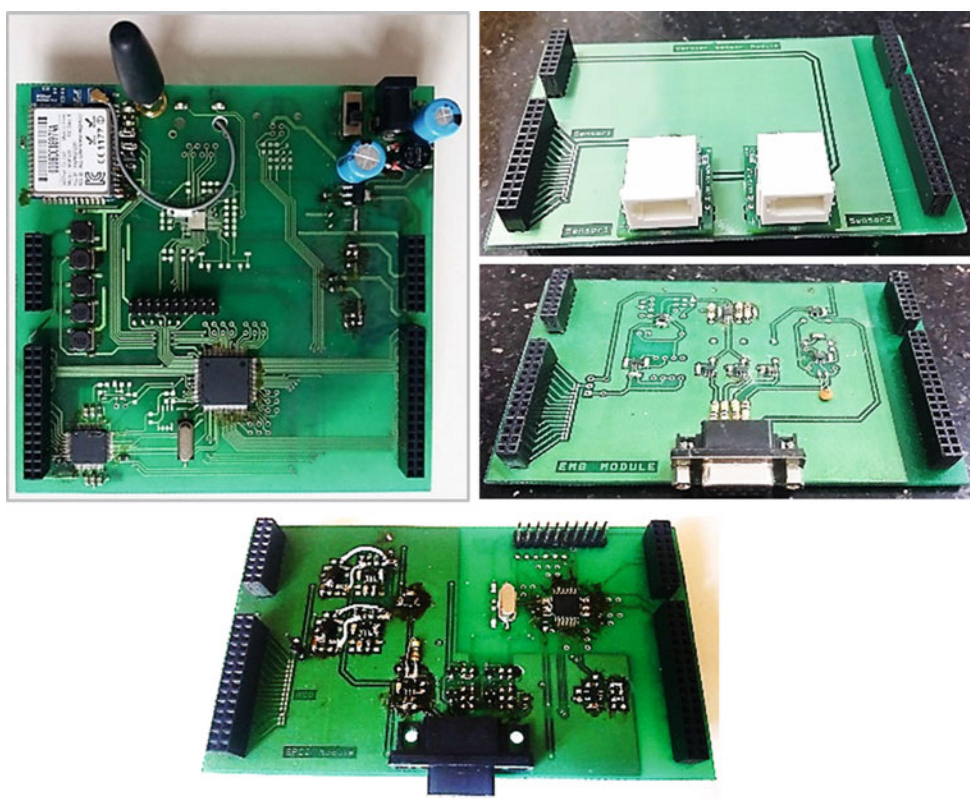


Fig. 4 Flowchart of the Matlab framework

Fig. 5 Photograph of the DAQ and front-ends (power supply and rechargeable battery are not shown)



2XLFE of Fluke with setting of 96% and 86 BPM. Each sensor associated with one ADC channel except SPO2 used two ADC channels for RED and IR signal. The other four channels are left unconnected. A screen capture of the data displayed on a laptop placing in the same room with HW Kit and running the Matlab framework is shown in Fig. 6.

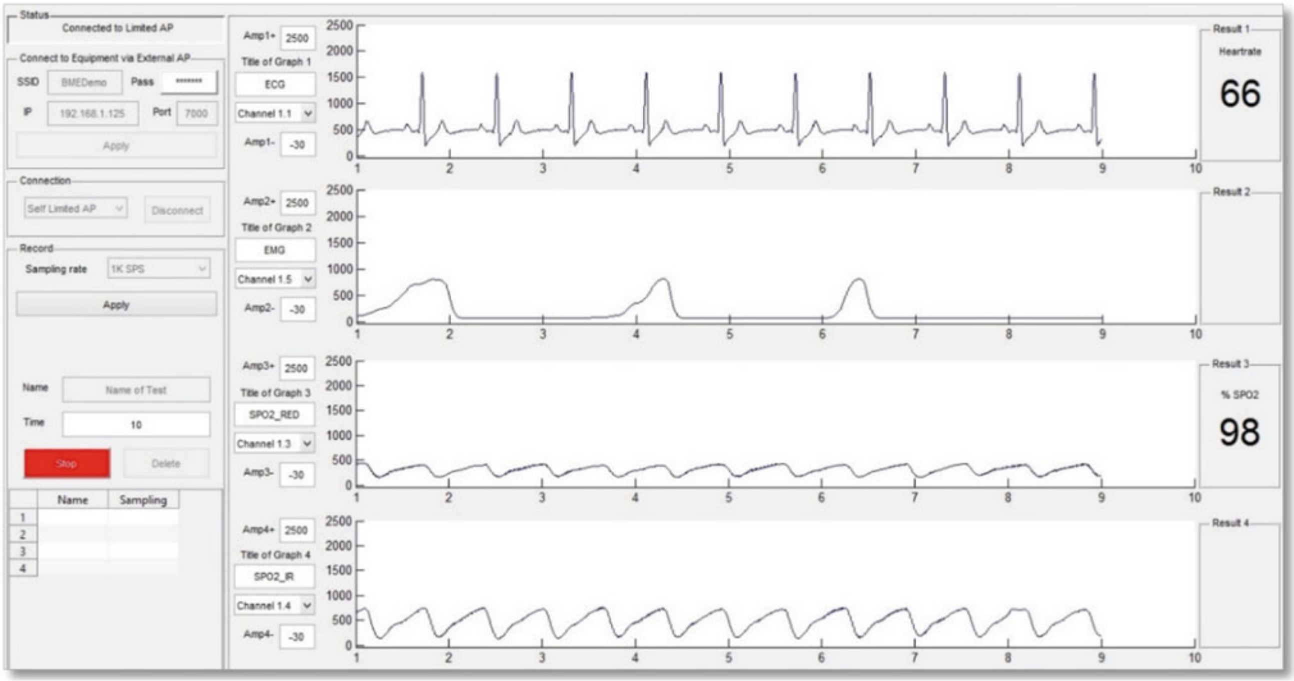


Fig. 6 Screen capture of the DAQ user interface on the computer

The data are displayed in the order of channel 1 to channel 4 respectively ECG, EMG, RED signal, and IR signal. The ECG waveform and rate were matched with the settings of MPS450. The EMG signal responded to muscle contractions. The computed oxygen saturation was close to the value set on the simulator. Readers interested in ECG, EMG and SPO2 can refer to [5–7] for more information. All signals were received without error or package drop in the short range. In the end of the data collection session, the data are saved in a text file with tab delimiter. The tabs separate the channels make it easy for any post-processing software.

6 Conclusion

Using commercial available, a wireless DAQ system was designed and built to interface with different sensors of various manufacturers. Flexibility of the software in the DAQ allows the users to change the sampling rate to specific applications. Wireless connection eliminates the limitation of wire connection and allows the unit collecting data with high accuracy while the subjects are in mobile. Due to the maximum throughput of the WiFi module is around 40 KB/s, the sampling rate was limited at 4 K samples-per-second even the ADC chip supports up to 64 K samples-per-second. The Matlab framework can assist in testing new algorithms in practical settings by processing the signals in real-time. The support of digital output sensors will be conducted in the future.

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