EMG2GO

PROJECT TITLE: EMG2GO - portable, wireless electromyography analysis system
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TI PARTS USED IN PROJECT:

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ABSTRACT
Electromyography (EMG) is the measurement of muscles electrical activity. It is picked up using self adhesive surface electrodes and is in the range of 10 ... 1000µV with a bandwidth up to 1kHz.

EMG2GO is a cost effective EMG-analysis system for residential environment usage, capable of recording with sampling-rates up to 8 kHz. The high sampling rates allow standard EMG-assessment as well as special medical measurements like muscle responses to electrical stimulation (M-Wave, H-Wave, ...).

A new approach is offered by the highly integrated, especially for bio signals developed analogue front-end device ADS1298 by Texas Instruments. The ADS1298 is suitable for battery powered portable devices, providing long lasting battery life time and low cost design. As a portable EMG-device EMG2GO provides complete freedom of movement during applications. These include ambulatory use and rehabilitation exercises at patient’s homes. The later is of particular interest, because enormous costs for the health care system could be saved by decreasing hospital stays.

The emerging Bluetooth low-energy technology allows wireless communication with mobile devices.

EMG2GO can be used as a data logger, whereas data is saved to a SD-card and allows the physician to monitor therapeutic success.

Hardware design targeted small overall size, long battery life-time, cost effectiveness and resistance against external distortion.

Software design focused on easy usability. A graphical user interface on an OLED display on EMG2GO is implemented to select operation mode and parameters using a directional pad.

INTRODUCTION
Information about muscle activity, more precisely about the electrical activity produced by skeletal muscles, can be obtained by electromyography measurements.

Although EMG2GO was designed for EMG measurements it is also possible to measure electrocardiogram (ECG), electroencephalogram (EEG) and electrooculogram (EOG).

A special challenge is the EMG measurement during electrical stimulation of the target muscle. Artefacts and saturational effects have to be compensated to allow assessment of the peripheral properties of the neuromuscular system.
MOTIVATION FOR PROJECT

Having spent plenty of time in setting up EMG-related experiments with bulky recording devices which constrain the patient’s degrees of freedom in movement, we decided to design a handheld EMG device which is not just small-sized, but also allows evaluating the positioning of surface electrodes during examinations.

Usability was a major task. It should not only be possible for trained medical staff to operate the device, but also others like sportsmen who seek to improve their training efforts should be able to operate the device quickly, without extensive advices.

THEORETICAL BACKGROUND

Electromyography

The assessment of muscle properties is important for the evaluation of the physical function of muscles and in the diagnosis of neuromuscular diseases such as neuropathy and myopathy.

Skeletal muscles, which can originate from bone or dense connective tissue directly or via tendons, are actuators of motion. Actions in form of contractions are initiated by muscle fiber depolarization. Hence, muscle contraction is accompanied by electrical signals which reflect the muscle activity.

In more detail, skeletal muscles are made up of collections of motor units, whereas a motor unit is defined as one motor neuron and all of the muscle fibers it innervates. The constituent fibers of a motor unit are activated synchronously. Each motor unit contracts when it is stimulated by a neural signal and causes an electrical signal that is the summation of the action potentials of its constituent cells. During voluntary muscle contractions action potentials from different muscle fibers are not synchronized spatially or in time, the sum of the fiber contributions is called motor unit action potential (MUAP). The myoelectrical signal can be detected transcutaneously with surface electrodes.

The peak-to-peak amplitude of EMG signals acquired using surface electrodes ranges from 10 to 1000µV with a bandwidth of up to 1 kHz.

Recordings of evoked myoelectric signals during electrical stimulation of a motor neurons terminal branches via surface electrodes are of clinical relevance, e.g. during nerve conduction velocity measurements. The electrical stimulation impulse (typ. 1ms, 20-40V) is followed by a compound action potential, the so-called M-wave. The MUAPs are evoked and synchronized by the electrical stimulus and show a time delay of a few milliseconds depending on stimulation and recording site and the patient’s physiology. These recordings require higher sampling frequencies than EMG signals produced by voluntary contraction.
Biosignal acquisition

Common acquisition systems of myoelectric signals are based on a differential amplifier, a filter chain and an analog-digital converter (Figure 1). Electrodes act as the interface between tissue and EMG signal amplifier.

A parameter, describing the immunity to common mode signals (typically from 50Hz power lines) and so a quality criterion of the input stage is the common-mode rejection (CMR). The ability of an amplifier to amplify common-mode components which are picked up by the human body less than the differential signal (the EMG) is stated by the common-mode rejection ratio (CMRR). Per definition $CMRR = 10 \times \log_{10} \left( \frac{G_{\text{Diff}}}{G_{\text{CM}}} \right)^2$, whereas $G_{\text{Diff}}$ is the differential gain and $G_{\text{CM}}$ is the common mode gain. Infinite CMRR would characterize the ideal amplifier.

Analysis of EMG Data

Digital signal processing allows quantitative analysis of EMG signals. Amongst others these methods include moving averaging, spectral analysis, calculations of peak-to-peak amplitude and number of zero-crossings.

IMPLEMENTATION

EMG2GO consists of four modules:

- **Main Unit**: system management, USB and Bluetooth connectivity, battery charging and power supply
- **Trigger Module**: analog input trigger with user selectable thresholds; galvanic isolation for USB connection
- **Docking Station**: stand and fast charge port; galvanic isolation for USB connection
- **Breakout-board**: mechanical adapter for easy electrode cable soldering
Main Unit

The main unit is built around the **ADS1298** (Texas Instruments), a fully integrated eight channel analog front-end device for bio-electrical signal acquisition. Our design uses two of these highly sophisticated 24-bit analog-to-digital converters in a daisy-chain mode to offer the possibility to acquire 16 independent EMG channels (Figure 2). Simultaneous sampling of up to 32kSps for each channel is possible. Features, making the ADS1298 best choice for small sized medical instrumentation are low power, extremely high CMRR (typical -115 dB), and the software settable gain of 1 to 12 for each channel.

All inputs of the ADS1298 were equipped with **TPD4E001** diode arrays to protect the electronics against ESD pulses and contact discharge. Due to low IO capacitance (1.5pF) and ultra-low leakage current (<1nA max) specifications this ESD solution offers little or no signal distortion during normal operation.

In multi-channel surface electromyography there is always a trade-off between the number of locations to be examined and the time and effort of wiring the corresponding number of electrodes. Experience in routine clinical investigations showed, that flexibility in the number of input channels used is very important and that unused electrodes should not be pre-assembled, because they are sources of artifacts and tend to bother the examiner and the patient. For this reason the EMG2GO is equipped with a breakout-board which allows any medical connector to be used. The common reference electrode is connected to the RLDOUt pin of the ADS1298.
The ADS1298 is connected to a 32bit microcontroller, which takes care of configuring the ADS1298, interfacing a SD-Card for data storage and communicating with personal computers or smartphones wirelessly via Bluetooth module or via USB.

Wireless communication was implemented using the ultralow power consumption CC2541 System-on-Chip transceiver with a package size of 6mm x 6mm and maximum transmit power of 0 dBm and receiver sensitivity designed to be -88 dBm in standard mode and -94 dBm in high-gain mode (at 1Mbps, GFSK, 250-kHz Deviation). The CC2541 has an inbuilt industry-standard enhanced 8051 MCU, which can be programmed to perform the communication with sensors and other MCUs using the Bluetooth Low Energy stack.

Preceding experiments with different antennas showed that a meandered inverted-F antenna (MIFA) would suit best in terms of RF performance and size. The MIFA was designed on PCB as described in TI application note AN043 (http://www.ti.com/lit/an/swra117d/swra117d.pdf). The CC2540 USB Dongle from the CC2540 Mini Development Kit was used as receiver unit. The connection was tested using TI BTool.

CC2541 operates at supply voltages between 2.0V and 3.6V but internally the supply is regulated down to 1.8V using LDOs, thus losing much of the energy when supplying with the battery (3.1V – 3.7V). The external DC/DC step-down converter TPS62730 is used to produce the supply voltage down to 2.1V and therefore increases the overall efficiency. The device would automatically switch to bypass mode if the battery voltage falls below a certain threshold.

Wireless data transmission using the Bluetooth Low Energy Stack was tested in preceding experiments using two CC2540 USB Dongles. Each one was attached to a CC-Debugger (http://www.ti.com/tool/cc-debugger) and a data stream was created and simulated with TI tools SmartRF Studio 7.

The start of data collection from different sensors must be time-synchronized. This can either be done using I²C or alternatively by using the SN65HVD231 controller area network (CAN) transceiver which is fed by a trigger signal. The SN65HVD231 was chosen, because it is a 3.3V supply CAN transceiver.

Our power supply requirements (Vin Min: 3.3V, Vin Max 3.3V, Vout: 3V, Iout: 0.3A, Amb. Temp: 36 °C) fed as input to WEBENCH Designer (http://www.ti.com/ww/en/analog/webench/) in combination with our demand for low current consumption revealed that the LDO TPS73630 would be the optimal solution (which was available from our distributor) for the analog power supply voltage of ADS1298. It features ultra-low dropout voltage of typ. 75mV and low noise (typ. 30µV_{RMS}).
**PCB Layout considerations**
The PCB design was based on EMC guideline for reduced electromagnetic influence into the analog part of the design and reduced electromagnetic radiation, enabling the design to pass EMI test required by European laws for electrical medical devices.

The design includes split ground planes, a multi-layer-stackup and well considered signal and power routing to reduce loop areas and EM influence (Figure 3).

**BGA challenge**
For personal motivation, we decided to implement a (at least for us) new technology to the PCBs. This included the design and soldering of Ball-Grid-Array parts. This step was necessary to provide future upgrades with an ADS1298R (since this part is not available in TQF packages).
Housing

The PCB was designed to fit a commercial available continuous casting aluminum case. The case had to be modified by CNC machining and was equipped with 3D printed end caps that provide access to connectors and a mechanic fastening for the display (Figure 4).

![EMG2GO in case](image1)

![EMG2GO without case](image2)

Fig. 4: EMG2GO in case (left) and without (right)

Various other system components were created with the 3D printer as well. These include battery mounting clamps, the button and the light-pipe for the buttons LED backlight. The overall size of the device is 95x61x13mm and its weight is 91g.

Trigger Module

The trigger module provides 3 trigger inputs. The input levels for those can be set by software between 0V and 3.3V in 0.1V steps. One additional outgoing trigger channel allows the synchronization of external acquisition systems with the ADS1298 units.
Docking Station
For fast charging of the device, a docking station with integrated USB isolation was designed. The docking station (Figure 5) includes 6 RGB LEDs to give visual feedback of the current device state and is controlled over I²C from the plugged device, providing visual status feedback even without a connected computer. The docks power supply is provided by a commercial medical grade power supply (5V, 3A). The internal power for the microcontroller for the LEDs is provided by a LDO from TI (TPS73033).

Software
The PC software was built with Microsoft C# and the Windows Presentation Foundation (WPF) libraries. Connection to the device is done with the free libUSB driver library (http://libusbdotnet.sourceforge.net). The libUSB driver is a free general implementation for USB device drivers, capable of being used on many different platforms such as Windows, Linux (including Android) or MacOS.
The Software is capable of managing the device maintenance functions (battery level etc.) and for setup of the two ADS1298 frontends. The setup can be done either in a guided manner or in a real basic binary access on any ADS1298 register.
During measurement electrode application, a live-view can help the user to check proper electrode placement on the patient. Due to the limitations on the Bluetooth connection, only a small number of channels can be used for live data view in this mode.

Patient Safety
The IEC60601 defines multiple design goals for medical devices to ensure sufficient patient safety during normal operation. To fulfill those requirements, the EMG2GO system is equipped with galvanic isolation on the computer interface and current limiting resistors on all EMG measurement lines.

EXPERIMENTAL RESULTS
As mentioned before M-Wave measurements are more challenging than voluntary EMG acquisition due to the presence of high voltage stimulation pulses and their related amplifier saturating artefacts. Fig. 6 shows M-waves (following the stimulation artifact) recorded simultaneously from 6 different locations on the upper thigh (Figure 6).
Fig. 6: Measurement results of evoked potentials. 6 channels were used in a bipolar electrode configuration to test different recording electrode positions

CONCLUSIONS
The device is capable of sampling a total of 64 kSps, composed out of either two channels at 32 kSps (utilizing only one ADS1298 chip) or at maximum 4 kSps with all 16 channels enabled. Input channel selection can be done using our software. During data acquisition EMG2GO has an overall power consumption of about 175 mW. The low power consumption guarantees a lifetime on battery of at least 24h.

SUMMARY
We successfully built up a portable EMG device using off-the-shelf components that fulfills our requirements. The design does not only make a great visual impact, it also works. We found out that ADS1298 can be used for many more applications than stated in the data sheet. Various bio-signals can be acquired including M-Waves. The small size, the low supply voltage and low power consumption make it especially suitable for small, battery powered, portable solutions. Different electrode connectors are available on the market so attention was paid to a flexible electrode connection solution, not restricting the user to specific ones. Our electrode connector breakout-board allows EMG multichannel electrode arrays to be easily connected too.

FUTURE PLANS
In order to perform intensive tests with untrained users, we will assemble a few more EMG2GO devices. Furthermore the wireless configuration of the device using Bluetooth Low Energy will be extended by a live preview for a limited number of channels. An ADS1298R would provide the possibility to perform respiration rate measurement based on impedance pneumography. If tests with the Texas Instruments ADS1298R ECG Front End Performance Demonstration Kit are promising, we think about implementing the respiration rate measurement in the future design.