PERVASIVE CARDIOVASCULAR AND RESPIRATORY MONITORING DEVICES

Main Content

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This code was developed by Miodrag Bolic for the book PERVASIVE CARDIOVASCULAR AND RESPIRATORY MONITORING DEVICES

Introduction

This is the main Matlab Live Editor file. It contain links to all other live editor files used in this book.

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Chapter 1 Concepts in Performance Evaluation and Uncertainty Analysis

This chapter presents steps needed to evaluate performance and quantify uncertainty in biomedical monitoring devices. The performance metrics are considered for cases when true reference values are known. We also consider more common situations in biomedical instrumentation where the true reference values are unknown. In this case, we show how one can calculate the agreement between the results obtained from two devices. Uncertainty quantification is of utmost importance during measurements since the result of any measurement contains the error, and the exact value of the error cannot be computed without having the true reference value. Uncertainties in measurements are modeled and calculated based on the probability theory. Therefore, we introduce the concept of confidence intervals and uncertainty propagation. Sensitivity analysis allows for selecting parameters whose variations affect the output the most. Even though we present basic mathematical analysis, we focus on computational methods and simulation.

Probability

Central Limit Theorem and confidence intervals, Example 1.1, Fig. 1.1-1.2

Sensor model, accuracy and agreement

Sensor model, evaluating accuracy and non_linearities, Example 1.2, Fig. 1.3-1.6

Bland Altman plot, Example 1.3, Fig. 1.7

Uncertainty propagation

Uncertainty propagation of correlated variables and GUM, Example 1.4, Example 1.5

Uncertainty propagation in a differential amplifier, Example 1.6a, Fig. 1.10, 1.11

Sensitivity analysis

Sensitivity analysis of a differential amplifier, Example 1.6b, Fig. 1.12

Chapter 2 Transducers

In this chapter we introduce transducers that are commonly used in biomedical devices. The students will learn basic operations of these transducers and how to model them using circuit models. Models that are developed in this chapter will be used in later chapters as one of the components of biomedical devices.

Transducers

Piezoelectric transducer, Fig. 2.2 and 2.3

Optical sensors

Models of LEDs and photodetectors, Fig. 2.4-2.7

More complex photodetector model (modification is needed), Fig. 2.15, Problem 2.15

Electrodes

Electrodes, Fig. 2.10-2.14

Chapter 3 Electronics

This chapter describes electronic components used in biomedical devices, including operational amplifiers, filters, analog to digital and digital to analog converters, and others. The goal is for readers to understand how to connect transducers with digital systems using conditioning or interfacing circuits. In addition, we will explain the effect of filtering and aliasing on the signal. We will also simulate different components and understand performance metrics and errors in these components. New developments in the field, including state-of-the-art integrated solutions that include many analog components in a single chip, will also be presented.

Electronics

Bridges, Fig. 3.1a, 3.7-3.9

Op amp model and basic configurations: inverting, noninverting amplifiers, differentiator, Fig. 3.2, 3.3, 3.29

Amplifiers Fig. 3.4 -3.6, 3.10- 3.15

Filters

RC Low pass filter, Fig. 3.16, 3.17

Second order active filter, Fig. 3.18, 3.19

ADCs

Antialiasing, Fig. 3.20, 3.21, 3.22, Example 3.3, 3.4

Analog to digital converters Fig. 3.23, 3. 25, 3.26, 3.22 is extracted from ADCTestSim1.slx, Example 3.5, 3.6, Table 3.4

Signal generation

Generating signals, Fig. 3.29

Chapter 4 Modeling and simulation of biomedical systems

In this chapter, we describe the principles of modeling biomedical systems as well as propagating the uncertainty through the system and performing sensitivity analysis. The objective is to put together components and techniques studied in Chapters 2-4 in the context of modeling a biomedical device. We describe models that allow us to generate data, add noise and interference, include tolerance of the electronic components, and so on. In addition, we consider systems that are modeled using mathematical models as well as using electrical circuits and show how one can propagate uncertainties through both models. We show

how one can develop an end-to-end model that includes different sub-models presented before and where processing is done in software or analog hardware. In the end, we briefly discuss the power consumption in the system.

Data collection and databases

Databases, Fig. 4.2

Models for signal generation

Example: Windkessel model, Fig. 4.3-4.5

Modeling noise and assessing signal quality

Noise, Fig. 4.6-4.9

Signal quality Fig. 4.10 - 4.12, Table 4.3

Uncertainty propagation in systems

Example: Charge amplifier, Fig. 4.13

Modeling software and Real-time signal processing

Block processing, Fig. 4.14

Example: stop-breathing detection system Fig. 4.15-4.19

Modeling power consumption

A/D converter example, Fig 4.20

Chapter 5 Devices based on Oscillometric Signal: Blood Pressure

This chapter describes the principles of operations of oscillometric blood pressure devices. Issues in measuring blood pressure and the overview of recommendations and standards related to blood pressure are presented. Oscillometric algorithms and circuits are described and simulated. More advanced topics include a model of the artery and cuff to simulate the generation of the oscillometric signal, a model of the overall blood pressure system, and performance analysis. We also present recent advancements in the field and discuss research problems related to oscillometry. Also, the use of oscillometry in assessing arterial stiffness is briefly discussed.

What is measured using a blood pressure device

Plot BP signals, Fig 5.1, 5.3, 5.4, 5.17

Modeling the signal

Oscillometric model, Fig 5.4, 5.5, 5.6, 5.7, 5.9, 5.13, Table 5.3

Sensors and circuits

Oscillometric circuit, Fig 5.11, Table 5.5

Chapter 6 Device based on photoplethismogram and pulse oximetry

In this chapter, we describe operation behind photoplethysmography (PPG) and pulse oximetry devices. These devices are mainly used for estimating heart rate and oxygen saturation level noninvasively. We start with explaining what is measured with PPG and pulse oximetry and what the issues are in the measurements. We present PPG and pulse oximetry systems, sensors, circuits and algorithms. More advanced topics that are covered include: propagation of the light through the skin and modeling the complete system that includes models of tissue and the propagation of light through the skin as well as the sensor and the circuit. In the end of the chapter, we explain how one can use PPG signal to estimate blood pressure as well as to estimate the shape of the jugular vein pulse. New developments in the field including miniaturization of the systems, modeling approaches and advanced algorithms are presented too.

Introduction, Optical properties of tissues

Plotting PPG signal and absorption coefficients, Fig. 6.1b, 6.4, 6.6

Performance measures

Simulating propagation of light through the tissue, Fig. 6.3, 6.7-6.10

Design of a PPG device

LED driving circuit, Fig. 6.11, 6.12

Transimpedance amplifier, Fig. 6.13, 6.14

Algorithms, Fig. 6.17, 6.20, 6.21

Putting it all together

Modelling tissue, circuit and analysing pulses, Fig. 6.15, 6.16

Chapter 7 Devices based on the ECG Signal

In this chapter we discuss issues related with acquisition and processing of electrocardiogram (ECG) signal. ECG signal is related to the electrical activity of the heart and therefore it is measured using electrodes. When measuring ECG signal, we first need to know where to place and how to connect the electrodes – this is described in the part of the chapter that talks about the ECG leads. In pervasive computing, mainly two to three electrodes are used representing single lead ECG configuration. We briefly introduce how the ECG signal can be generated using simulators, sources of noise and artifacts and how to measure the quality of the signals. ECG device types and standards are introduced next. To develop electronics for ECG, we need to know what standards/regulations need to be followed as well as what kind of processing will be performed. Therefore, next we will introduce algorithms for heart rate estimation and beat segmentation. The next section is about ECG electronics followed by the current solutions and research direction. In the end, we discuss how ECG signal can be further processed to extract heart rate variability.

Signal properties, simulators and databases

Simulators, Fig. 7.4

Processing ECG signal

Heart rate estimation and segmentation of the ECG signal, Fig. 7.7

Simulation of a single lead ECG system

Simulation, front-end circuits, interference in ECG circuits, Fig. 7.9-7.16

Current trends and research directions

Heart rate variability, Fig. 7.18

Chapter 8 Devices based on Time Difference between Signals: Continuous Blood Pressure Measurements

In this chapter, we will show ways of combining different signals by looking mainly at time difference between characteristic points on the pulses from these signals obtained during the same cardiac cycle. It has been shown that time delay between the signals called pulse transit time is proportional to blood pressure and therefore it is a basis for continuous blood pressure devices. This chapter is different from the others in a way that the relationship between the temporal features and the parameter of interest is given through a mathematical model and therefore the most important part when developing the device for continuous blood pressure is the model that relates the parameters and the pressure. Therefore, we will focus more on modeling and less on instrumentation in this chapter. In addition, we will discuss arterial stiffness and oscillometric blood pressure devices based on time differences between signals.

Temporal relationship between physiological signals

PTT and PAT surrogates, Fig. 9.2, 9.3

Modelling the relationship between PTT and blood pressure

Moens-Korteweg equation, Example 8.1

Cuffless blood pressure monitoring

Model-based blood pressure estimation, Fig. 8.6

Chapter 9 Continuous monitoring of breathing

In this chapter, we describe operation of devices for acquiring breathing signal and then estimating breathing rate. We introduce devices that can extract breathing signal from cardiac signals such as ECG and PPG as well as devices that obtain breathing signal based on movements of the chest wall of by measuring temperature or pressure changes during inhalation and exhalation. In addition, we show some developments of wearable devices for tidal volume and airflow measurements as well as systems for classifying breathing patterns.

What is measured?

Volume and flow, Fig. 9.1, 9.2, 9.15

Features of the signal and the noise

Signal quality, Fig. 9.3, 9.4

Breathing rate estimation

Breathing rate estimation algorithms, Fig. 9.5

Extracting breathing rate from cardiac signals, Fig. 9.6, 9.7

Chest wall movement

Accelerometers, Fig. 9.9

Impedance changes, Fig. 9.12, 9.13

Chapter 10 Wearable devices

Wearable devices are becoming pervasive. They can sense vital signs for hours and days. They come in different shapes and forms and can measure several quantities of interest and estimate multiple indices. Some issues related to the design of wearable devices are discussed in this chapter, such as power consumption. We showed several examples of how power consumption can be estimated. We also introduce different classifications of wearable devices. Sensors and sensing modalities currently used in wearable devices were mainly covered in previous chapters. In this chapter, we introduce three biomedical signals: seismocardiogram, arterial tonometry signal, and phonocardiogram. Examples of commercial and research-based wearable devices are shown at the end of the chapter.

Sensors and sensing modality

Seismocardiogram, Fig. 10.3

Phonocardiogram, Fig. 10.4

Designing for low-power

Modeling power consumption of the overall system, Fig. 10.9-10.11

Chapter 11 Conclusion and research directions: beyond wearable devices

The goal of this chapter is to review topics covered in the book, point out new directions and challenges, and present alternative approaches to continuous monitoring of patients. We discuss approaches where the patient is not required to wear any devices. Instead, the sensors are integrated into the objects that patients use, such as a chair or a bed. In addition, we discuss long-range contactless monitoring where sensors, such as radars and cameras, are integrated into the environment where patients live.

Beyond wearables: contactless monitoring

Cameras, Fig. 11.4

Radars, Fig. 11.6