Information technology tools in the practical courses of Medical Physics and Statistics

Department of Medical Physics and Informatics
University of Szeged
Information technology tools in the practical courses of Medical Physics and Statistics

Tools:
BIOPAC Student Lab data acquisition and processing system
Excel spreadsheets for calculations, reporting and tests
Information technology tools in the practical courses of Medical Physics and Statistics

Topics:
• Electrocardiography
• Spirometry
• Electrodermal activity
• Blood pressure
• CT reconstruction
• Electromyography
ELECTROCARDIOGRAPHY

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Electrocardiography

• Cyclic changes in the cardiac activity generate an electrical field
• Depolarization/repolarization leads to uneven distribution of electrical charges around the heart
• These charges can be detected by body surface electrodes
Electrocardiogram (ECG)

Specialized pacemaker cells start the **electrical sequence** of depolarization and repolarization.

The **electrical signal** is generated by the sinoatrial (SA) node and spreads to the ventricular muscle.

The **electrical activities** of the heart can be detected on the body surface via surface electrodes.
Background

Electrical activity: depolarization-repolarization

Conducting system

Cardiac muscle cells

sinus node

AV node

Common bundle

Bundle branches

Purkinje fibers
ECG waves, intervals and segments

- P wave: atrial depolarization
- PQ interval: atrio-ventricular conduct
- PQ segment: impulse transmission from sinus node to AV node entering the ventricles
- QRS complex: ventricular depolarization
- T wave: ventricular repolarization
Background – Electrode leads

The arrangement of electrodes is a lead

Bipolar (Einthoven)
- Standard Lead I, II and III form a triangle where the heart electrically constitutes the null point.
- Einthoven’s Triangle is used when determining the electrical axis of the heart.

Unipolar augmented leads
- aVR: right arm
- aVL: left arm
- aVF: left foot
Experimental objectives

• To become familiar with the measurement of electrocardiograph
• To observe rate and rhythm changes in the ECG associated with exercise
  – Detect the current heart rate for the study period
  – Identify specific time intervals
    • Length of R-R intervals (complete heart cycle)
    • Length of QT intervals (ventricular systole)
    • Determine their ratio
  – Determine QRS amplitude
Tasks performed by the student

• Place the electrodes to right wrists and both ankles

• Start and set-up the BSL Lessons software

• Sit down and relax
  – record normal resting ECG for 1 min

• Perform a physical exercise
  – Record ECG after exercise for 2 min
Data analysis

- Zoom-in for a closer look at an individual ECG complex
- Determine the characteristic duration parameters in for 3 cycles each
  - QT (ventricular systole), RR interval (complete heart cycle)

- Calculate the current heart rate in BPM for the different conditions
MEASUREMENT OF RESPIRATORY VOLUMES:

SPIROMETRY
spirometer types: open circuit

(others flowmeters: turbine, thermal, ultrasound, etc.)
volume (flow) calibration

Airflow Transducer hangs freely off the end

Calibration Syringe Plunger

Airflow transducer held upright at all times

Correct placement of hands

[Graph showing airflow over time]
flow and volume: VC
flow and volume: FVC
"static" lung volumes

TV: tidal volume
IRV: inspiratory reserve
ERV: expiratory reserve
RV: residual volume
FRC: functional residual capacity
VC: vital capacity
TLC: total lung capacity
"dynamic" lung volumes

FVC: forced expiratory vital capacity
FEV1: forced expiratory volume in 1 s
measurement of tidal volume (TV)
volume of maximum inspiration (TV+IC)
measurement of vital capacity (VC)
measurement of forced vital capacity (FVC)
forced expiratory volume in the 1\textsuperscript{st} second (FEV1)
reference values for vital capacity

males:

\[ VC[L] = 0.052H[cm] - 0.022A[yr] - 3.60 \]

females:

\[ VC[L] = 0.041H[cm] - 0.018A[yr] - 2.69 \]
MEASUREMENT OF ELECTRODERMAL ACTIVITY
Galvanic skin resistance (GSR): a low-intensity current (I) is steadily applied between two electrodes and the voltage difference (U) is recorded between them, the resistance (R) can be calculated this is called galvanic skin resistance.

Conductivity: $G = \frac{1}{R}$

[1/Ohm or Siemens (S)]
Galvanic skin potential (GSP): without externally applied current, electric potential difference can be measured between an active and a passive (reference) electrode.

The combined changes in GSR and GSP constitute the galvanic skin response and are collectively called electrodermal activity (EDA).
The physiological basis of the EDA is the change in the cutaneous blood flow and the sweat gland activity. EDA is the response of the skin to changes in the autonomic (largely sympathetic) tone, and it reflects changes in the emotional state and responses to external stimuli.

Hieu & Jayson

Gland density
100-2000/cm²
Experimental objectives

Recording and evaluation of EDA and ECG responses to

1. three deep breaths
2. three short trials of reaction time measurements
3. 5-s elevations of the right and left arms
4. answers to questions (optional)

with 20-s relaxed intervals (baseline) before each manoeuvre
Structure of EDA recording
Measurement of peak response ($\Delta G$) and latency time ($\Delta T$) to a stimulus
Measurement of mean heart rate (HRmean) before and peak-to-peak change in heart rate (ΔHR) after a stimulus
Mean values of GSR and HR before (baseline) and during the test trials
Noninvasive measurement of arterial pressure
Pressure in fluids

Pressure in a fluid at rest varies with vertical position (only). If $h$ is the depth of a fluid sample below a reference point where the pressure is $p_0$, the pressure is:

$$p = p_0 + \rho gh$$

- $p_0$ is the pressure at the reference point.
- $\rho$ is the density of the fluid.
- $g$ is the gravitational acceleration (9.81 m/s$^2$).
- $h$ is the height difference.

Medical Physics • blood pressure measurement (2010)
Always measure blood pressure at heart level!

Diastolic Pressure at Top of Head is 45 mm Hg

Diastolic Pressure at the Heart is 80 mm Hg.

Diastolic Pressure at the Feet is 176 mm Hg.

170 cm tall man with a normal blood pressure of 120 / 80. At elevations below the heart the blood pressure is greater while at elevations above the heart the pressure is less.

giraffe has valves in the veins and arteries of its neck, so the extreme pressure does not break the blood vessels when the giraffe lowers its head.
Pressure units

The hydrostatic pressure formula converts pressure measurement to height measurement:

\[ p = \rho gh \]

Measuring fluid: mercury (\( \rho = 13600 \text{ kg/m}^3 \)) \( \rightarrow \) pressure unit: mmHg

water (\( \rho = 1000 \text{ kg/m}^3 \)) \( \rightarrow \) pressure unit: cmH\(_2\)O

(SI Unit: 1 Pa = 1 N/m\(^2\))

Conversion??
The pressure exerted by 1 cm of H₂O column is:

$$1 \text{ cmH}_2\text{O} = 1000 \frac{\text{kg}}{\text{m}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \cdot 0.01 \text{ m} = 98.1 \text{ Pa} \approx 100 \text{ Pa} = 0.1 \text{ kPa}$$

The pressure exerted by 1 mm of Hg column is:

$$1 \text{ mmHg} = 13 600 \frac{\text{kg}}{\text{m}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \cdot 0.001 \text{ m} = 133.4 \text{ Pa} = 1.36 \text{ cmH}_2\text{O}$$
Noninvasive measurement of arterial pressure

the auscultatory technique (Korotkov, 1905)
Noninvasive measurement of arterial pressure: the principle

Nikolai Szergeievitch Korotkov

ECG Lead II

Korotkov Sounds

Cuff Pressure

Systolic Pressure (first sound)

Pressure (mm Hg)

Diastolic Pressure (end of sounds)

1 2 3 4

Time (seconds)
Noninvasive measurement of arterial pressure: mechanisms of the sounds

wall detachment  turbulence  cavitation

other theories and combinations
Noninvasive measurement of arterial pressure: blood pressure measures

systolic (SBP, SYS)

mean (MAP)

diastolic (DBP, DIA)

heart rate (HR):

HR = 60/T [BPM]
Laboratory practical: the setup

BIOPAC STUDENT LAB SYSTEM
Open the lab report in Excel

I. COMPARISON OF BLOOD PRESSURE MEASUREMENT METHODS
Start BSL Lessons ⇒ open Lesson 16: Blood pressure

Do the calibration procedure

Position the measurement devices as indicated

Turn on the Upper Arm Blood Pressure Meter
Start the recording in the BSL system (Record)
Start the Wrist Pressure Meter
Pump the cuff up to about 160 mmHg
The pressure in the cuff will automatically deflate when the pumping is stopped.
While continuously looking at the pressure gauge on the screen read the pressure values
when you start hearing the Korotkoff sounds, and when they stop
Fully deflate the cuff by pressing the button on the side of the pump
Stop recording (Suspend)
Measurement protocol II.

Enter the measured data into the lab report.

Repeat the measurement 3 times on one arm, then move the blood pressure monitors onto the other arms.

If any of the data is missing in a manoeuvre, mark it as FAILED in the logbook. Enter all data into the logbook, and press SUBMIT. (After each patient you start a new logbook.)

Repeat the procedures for a second patient.

II. PRESSURE – HEIGHT DEPENDENCE MEASUREMENT:
For this study, use only the wrist BP monitor.

Position your wrist at two different heights (e.g. top of computer house and table), while keeping the upper body (heart) in the same position. Record the readings from the BP monitor, and the height difference between the two positions. Make min. 3 measurements.
<table>
<thead>
<tr>
<th>Patient's ETR code without SZE, like ABCSAAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABCSAAX</td>
</tr>
</tbody>
</table>

## Logbook

### BP_measurement.xls

#### Korotkov

<table>
<thead>
<tr>
<th></th>
<th>UPPER ARM</th>
<th>WRIST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>DIA</td>
<td>DIA</td>
</tr>
<tr>
<td></td>
<td>PULSE</td>
<td>PULSE</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>65</td>
</tr>
</tbody>
</table>

**Notes:**
- Failed
- Failed
- Failed

#### Pressure - Height dependence

<table>
<thead>
<tr>
<th>RAISED POSITION</th>
<th>LOWERED POSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Height difference (cm):** 40
CT reconstruction

backprojection
How can we get a picture of a slice of something without cutting it apart?

(Visible Human Project)
Visible Human Project
CT-Background

• The computed tomography (CT) is a medical imaging method using tomography created by computer processing
• Based on the work Johann Radon in 1917: An image can be created from the scattering data associated to cross-sectional scans of an object.
• In 1972 G.N. Hounsfield and J. Ambrose made the first clinical CT examination

Properties:
• The CT Scan is an extension of the X-Ray technology
• CT Scan uses multiple X-Ray images to create the final image
• A CT Scan can focus on the target area better than an X-ray
• Advanced CT Scan equipment can produce a 3d representation of the target while X-ray is strictly two dimensional
• Equipment for CT Scan costs considerably more than X-ray equipment
• CT Scan exposes the patient to a lot more radiation than X-ray
CT-Principle

• At first (keeping it simple) let’s see the shape of something by looking at shadows.
• Shine spotlights on some different shapes and look at the shadows they make.
• The more directions we use, the more exact shape we can „calculate“.

Let’s start the „projections_L.html“, Click on the spotlights to turn them on and off. Choose different shapes from the menu.
The electromagnetic spectrum

The properties of electromagnetic ray we should use:
- Goes through the human body
- The different tissue absorbs the X-rays on a different manner
- No scattering
Importance of avoiding scattering: higher contrast

Imaging relies on the fact that different tissues of the human body absorb the X-rays at a different rate.

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\mu$ (cm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(100 keV X-rays)</td>
</tr>
<tr>
<td>Air</td>
<td>0.0001</td>
</tr>
<tr>
<td>Water</td>
<td>0.1687</td>
</tr>
<tr>
<td>Saline</td>
<td>0.1695</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.18</td>
</tr>
<tr>
<td>Blood</td>
<td>0.178</td>
</tr>
<tr>
<td>Bone</td>
<td>0.48</td>
</tr>
<tr>
<td>White matter</td>
<td>0.1720</td>
</tr>
<tr>
<td>Grey matter</td>
<td>0.1727</td>
</tr>
</tbody>
</table>
Instead of light: X-ray

Let's start the "projections_X.html. Rotate the object.

The darkness of the shadow depends on the density and thickness of the object.

Then the "tomography.html. Which resembles a human chest.

X-ray passing through the human body produces a shadow.
Transmission

Attenuation of light passing through matter:

**Beer’s Law**

\[ I = I_0 \cdot e^{-\mu \cdot x} \]

- \( I \): Attenuation
- \( I_0 \): Sample Thickness
- \( \mu \): Attenuation Coefficient
- \( x \): Sample Thickness

The addition of multiple layers:

\[ T_1 = e^{-\mu_1 \cdot x_1} \cdot e^{-\mu_2 \cdot x_2} = e^{-\left(\mu_1 \cdot x_1 + \mu_2 \cdot x_2\right)} \]

\[ T_1 = e^{-\mu_1 \cdot x_1} \cdot e^{-\mu_1 \cdot x_2} = e^{-\mu_1 (x_1 + x_2)} \]

Attenuation of the (linear) layers is added together.
Sinogram

- In clinical use, the object (human body) does not turn, but the X-ray tube and its detector (and the bed – 3D achievement).
- Projections are the measurements from different view points. Another concept is the “Sinogram”, which is simply the 2-D array of data containing the projections.
- Computers do the hard work of reconstructing the slices from the x-ray shadows (projections) from many angles into one image.
The task is the calculation of the elements of a matrix from the information of the sum (integrals) of lines, columns and diagonals. The method is based upon the work of Johann Radon in 1917 (not for matrixes). The name of the method is „Invers Radon Transformation“.

Open the CT.xls file, Projection0 sheet:

- Calculate the projections to the coloured cells
- Calculate the (reconstructed slice) values.
- Do we have only one solution?
- Calculate again but let’s use the third projection of 45°.
Calculating the projections from 1 and 2 directions

CT.xlsx excel file: Projection1 sheet:

Calculate the projections to the coloured cells.
Make the sinogram.
Calculating the projections from 1, 2 and 3 directions

CT.xls excel file: Projection1, 2 sheet:

Calculate the projections to the coloured cells.
Look at the sinogram (making automatically).
Start the "backprojection.html"
Although the CT scanners nowadays use highly complex programs to calculate the slices, but this simple method for two X-ray projections gives an idea of how it works. The "random scan" button sets the 2 projections, the backprojection can be made by pulling the red and blue rings. (Of course from 2 directions we cannot see whether the object is a square or a circle shaped, to this we need projections from more directions.)
Backprojections

Start the „final_rib_cage.html”

1. Press the "Scan" button to make a single scan.
2. Now click and drag the figure on the left to turn it.
3. Press "Scan" again...this time the new scan gets averaged into the previous one.
4. Continue to turn and scan. If you space your scans evenly you will get the clearest results.
5. Let’s see from how many directions we receive a good slice.

When we make a scan, the projection (in the middle window) gets "projected back" or "smeared out" in the window on the right. When we turn our object, the window on the right turns, too. Then, when we make another scan the new projection gets averaged in with whatever is already there.
Slice calculation from 1 and 2 projections

Calculate the values of the slice from the projections with the backprojection method from two directions.
Slice calculation from 3 projections

Calculate the values of the slice from the projections with the backprojection method from three directions.
electromyography
basics
Background

- The mechanized work is performed by the muscle fibers originating from the spinal cord and the nerve roots.
- The activity of the muscles is expressed by the action potential generated by the nervous system.
- The mechanized work performed by the motor units is arroyed by the bony muscle mass.
- The skin surface provides the muscle activity, leading to the generation of electromyographic signals (EMG).

measurement tasks

• measurement of EMG during stepwise changes in grip force
• computation of EMG intensity
• correlation analysis between grip force and EMG activity
• relationship between grip force and EMG intensity during maximum effort
computer-aided measurements: EMG

measurement protocol
computer-aided measurements: EMG

preprocessing
computer-aided measurements: EMG

evaluations (1)
BIOPAC STUDENT LAB SYSTEM
channel measurement boxes:

<table>
<thead>
<tr>
<th>channel #</th>
<th>measurement type</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>mean</td>
<td>4.99054 Kg</td>
</tr>
<tr>
<td>3</td>
<td>p-p</td>
<td>2.56824 mV</td>
</tr>
</tbody>
</table>

BIOPAC Student Lab

menu commands

lesson buttons

channel boxes

append markers

marker label

event markers

lesson buttons

horizontal scale

horiz. scroll bar

journal tools

journal

This is the JOURNAL display. When you record a lesson, brief directions will be shown here.
The toolbar

Forearm 1, Increasing clench force

13.36791 Kg

3

p-p

1.95923 mV
Setting of channels

**ANALOG INPUT CHANNELS**

- **CH1**: Force
- **CH2**: CH2 Input
- **CH3**: EMG
- **CH4**: CH4 Input

**DIGITAL INPUT CHANNELS**

- **D1**: D1 - Digital Input
- **D2**: D2 - Digital Input
- **D3**: D3 - Digital Input
- **D4**: D4 - Digital Input

**CALCULATION CHANNELS**

- **C1**: Integrated EMG
- **C2**: C2 - calculation - OFF
- **C3**: C3 - calculation - OFF

**Presets**

- Default
- Accelerometer (5 g's max.)
- Accelerometer (50 g's max.)
- Airflow (SS11LA)
- Airflow (SS52L)
- Blood Pressure Cuff
- BNC (SS9L, -10 to +10 Volts max.)
- BNC (SS9L, -50 to +50 Volts max.)
- BNC (SS70L, -10 to +10 Volts max.)
- Cardiac Output - Z
- Cardiac Output - dZ/dt
- Clench Force (kg)
- Clench Force (lbs)
- CO2 Expired (GASSYS2)
- O2 Expired (GASSYS2)
- ECG (.5 - 35 Hz)
- ECG (.05 - 35 Hz)
- ECG (.05 - 100 Hz w/Notch)
- ECG (.05 - 100 Hz, AHA)
- ECG (.05 - 150 Hz)
- EDA (GSR) (0 - 35 Hz)
- EDA (GSR) Change
- EEG (.5 - 35 Hz)
- EGG
- EMG (30 - 250 Hz w/Notch)
- EMG (30 - 500 Hz)