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MODELLING OF BASIC PPG SIGNAL

AIM

To model the basic PPG waveform.

OBJECTIVE

Synthetic PPG signal modelling using sinusoids and gaussian functions.

INTRODUCTION

Photoplethysmography measures changes in the blood volume of a vascular tissue bed. Optical radiation is used to illuminate peripheral tissue, where it is scattered and absorbed as it travels through different tissue layers before being transmitted through or reflected from the tissue surface. This attenuated light intensity is detected by an optical sensor and is recorded as a voltage signal known as the Photoplethysmogram (PPG).

A PPG is often obtained by using a pulse oximeter which illuminates the skin and measures changes in light absorption. A conventional pulse oximeter monitors the perfusion of blood to the dermis and subcutaneous tissue of the skin.

A raw PPG waveform reflects the variations in attenuation of incident optical radiation by different tissue components within the tissue volume. High frequency variations (the AC art) are caused by changes in arterial blood volume with each heartbeat, and lower frequency variations (the DC part) are caused by changes in other tissue components such as venous and capillary blood, bloodless tissue, etc. Though, the origins of the PPG waveform have also been attributed to red blood cell orientation, the mechanical movement of cellular components, and a combination of various other factors.

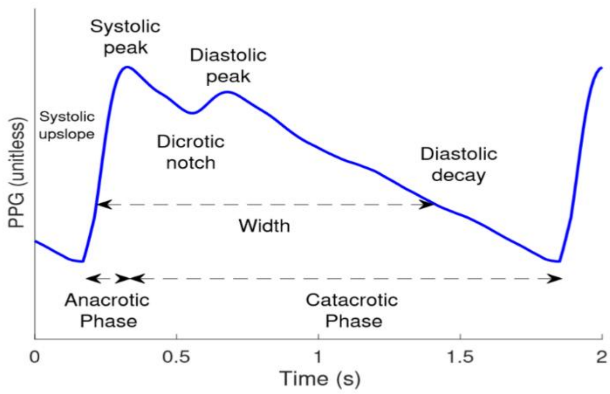
The PPG signal exhibits a quasi-periodic pattern consisting of an arterial pulse wave for each heartbeat. Each PPG pulse wave consists of two distinct phases: the anacrotic and dicrotic phases, corresponding to the rising and falling limbs respectively. The morphology of the PPG pulse wave is influenced by: the heart (characteristics of cardiac ejection including heart rate, heart rhythm, and stroke volume); the circulation (including cardiovascular properties such as arterial stiffness and blood pressure); additional physiological processes including respiration and the autonomic nervous system (which can be affected by stress); and PPG pulse wave shape also changes with healthy ageing.

PPG has become widely recognized as a low-cost non-invasive detection technology for CVDs. The cardiovascular parameters detected using PPG technology include heart rate, blood oxygen saturation, blood pressure, assessment of arterial stiffness, and pulse wave velocity etc. The PPG signal includes information on the hemodynamic process, hemorheology, and tissue status of the peripheral microcirculation system in the human body. That is, the PPG signal is an aggregated expression of many physiological processes in the cardiovascular circulation system.

THEORY

There are several challenges to PPG signal analysis, rendering the extraction of reliable information from the PPG a complex task. The PPG signal exhibits several physiological variations. It is also susceptible to several types of noise. These include motion artefact and probe-tissue interface disturbance, powerline interference, low- and high-frequency noise. The PPG pulse wave often exhibits a diastolic peak in young subjects which diminishes with age.

A typical photoplethysmogram (PPG) waveform can be separated into anacrotic and catacrotic phases, which are dominated by systolic ejection and wave reflections from the periphery respectively. The systolic rising edge in the anacrotic phase is caused by the expansion of the arterial system due to inflow of blood. The rate of expansion is linked to the contractility of the heart, and the amplitude of the systolic peak is linked to the stroke volume. The dicrotic notch and diastolic peak are caused by wave reflections, with their location and timing influenced by arterial stiffness. The diastolic decay is determined by the exponential contraction of the arterial system due to the outflow of blood, and is influenced by the vascular resistance and compliance.



METHODOLOGY

Apparatus Required

- MATLAB Software

In simulating PPG signals, we initially explore the use of sinusoids to capture waveform characteristics, generating a vector of x-axis data from 0 to 2π. However, one sinusoid proves inadequate, prompting the recognition of the necessity for at least two sinusoids to represent systole and diastole phases. Subsequently, Gaussian functions are employed to enhance the simulation. Using parameters such as peak height, center, and standard deviation, one Gaussian function is applied to generate a waveform, but it becomes apparent that at least two Gaussian functions are required to emulate the complexity of the PPG waveform. Another method involves employing circular motion to signify the periodicity of PPG. By replacing the independent variable with an angle in the range $[-\pi, \pi]$, circular motion offers a more natural representation, where one cycle on the circle corresponds to a PPG pulse, emphasizing the periodic nature of PPG signals.

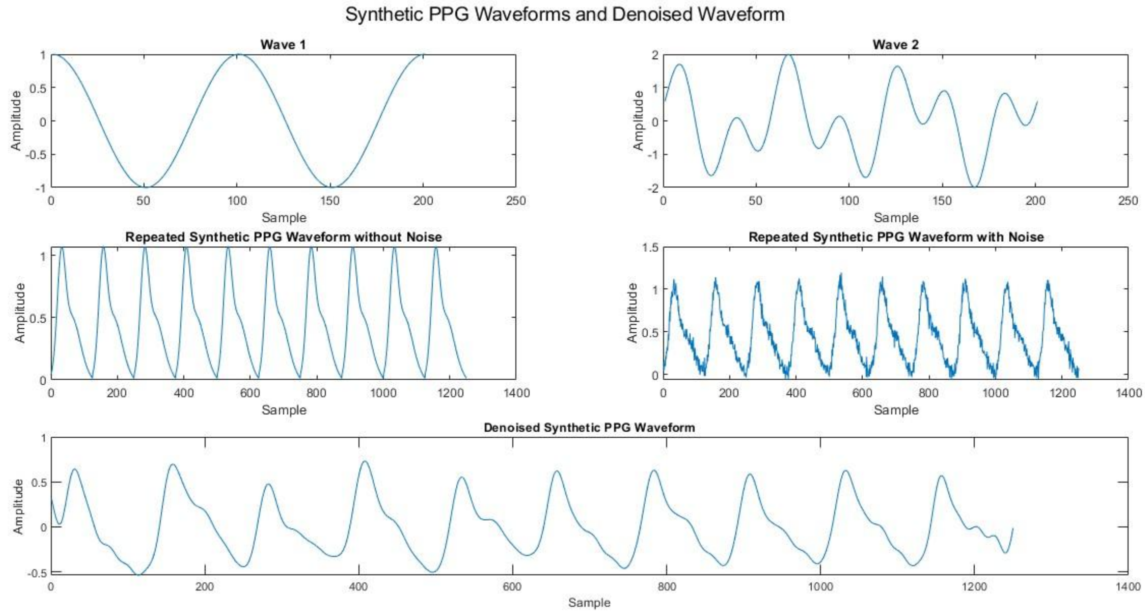
The experimentation extended to introducing baseline wander and noise to emulate realistic PPG signals, prompting observations on how these additions affected the waveforms. Furthermore, the denoising aspect can be explored by implementing a low-pass filter, adjusting parameters such as cutoff frequency to effectively reduce noise. This comprehensive exploration provides a foundational understanding of PPG waveform simulation and the practical challenges associated with signal processing, offering valuable insights for applications in biomedical signal analysis.

Matlab code:

```
clc;
close all;
clear all;

% Step 1: Generate and Plot Simple Sinusoidal Waveform (Wave 1)
x = 0:pi/100:2*pi;
wave_1 = cos(x*2);

% Step 2: Simulate PPG Waveforms Using Sinusoids (Wave 2)
wave_2 = cos(x*3) + cos(x*7 - 2);

% Step 3: Generate Synthetic PPG Waveforms
Duration = 1;
Fs = 125; % Sampling Frequency
a = [0.82, 0.4];
mu = [-pi/2, 0];
sigma = [0.6, 1.2];
Samples = Fs * Duration;
V_angle = 2 * pi / Samples;
angle = (-pi + V_angle) : V_angle : pi;
y1 = a(1) * exp(-(((angle - mu(1)) / sigma(1)).^2) / 2);
y2 = a(2) * exp(-(((angle - mu(2)) / sigma(2)).^2) / 2);
y = y1 + y2;

% Step 4: Add Baseline Wander and Noise to Synthetic PPG Waveforms
baseline_amplitude = 0.1; % Amplitude of baseline wander
baseline_frequency = 0.5; % Frequency of baseline wander (in Hz)

t = linspace(0, Duration, Samples);
baseline_wander = baseline_amplitude * sin(2 * pi * baseline_frequency * t);

repetitions = 10;
y_repeated = zeros(Samples * repetitions, 1);
y_repeated_with_noise = zeros(Samples * repetitions, 1);

for i = 1:repetitions
    % Combine baseline wander with the PPG waveform
    y_with_baseline = y + baseline_wander;
    % Combine noise with the PPG waveform
    noise = 0.05 * randn(Samples, 1);
    y_with_noise = y + baseline_wander + noise';

    % Add the waveform to the repeated waveform
    y_repeated((i - 1) * Samples + 1 : i * Samples) = y_with_baseline;
    y_repeated_with_noise((i - 1) * Samples + 1 : i * Samples) = y_with_noise;
end

% Step 5: Denoise the PPG waveform using a low-pass filter
cutoff_frequency = 10; % Cutoff frequency of the low-pass filter (in Hz)
% [b, a] = cheby2(6, cutoff_frequency / (Fs / 2), 'low');
y_denoised = bandpass(y_repeated_with_noise, [0.6 5], 125);

% Plotting all waveforms using subplots
figure;
```

```
% Plot wave_1
subplot(3, 2, 1);
plot(wave_1);
xlabel('Sample');
ylabel('Amplitude');
title('Wave 1');

% Plot wave_2
subplot(3, 2, 2);
plot(wave_2);
xlabel('Sample');
ylabel('Amplitude');
title('Wave 2');

% Plot y_repeated
subplot(3, 2, 3);
plot(y_repeated);
xlabel('Sample');
ylabel('Amplitude');
title('Repeated Synthetic PPG Waveform without Noise');

% Plot y_repeated_with_noise
subplot(3, 2, 4);
plot(y_repeated_with_noise);
xlabel('Sample');
ylabel('Amplitude');
title('Repeated Synthetic PPG Waveform with Noise');

% Plot denoised PPG waveform
subplot(3, 2, [5, 6]);
plot(y_denoised);
xlabel('Sample');
ylabel('Amplitude');
title('Denoised Synthetic PPG Waveform');

% Adjust subplot spacing
sgtitle('Synthetic PPG Waveforms and Denoised Waveform');
```

Results:



Outcome: The experiment successfully generated synthetic PPG waveforms, incorporating sinusoidal and Gaussian functions to simulate physiological variations. By introducing baseline wander and noise, the experiment realistically replicated challenges encountered in real-world PPG signals. Visualization through subplots highlighted the variations in different components, providing a comprehensive understanding of synthetic PPG signal generation.

Conclusion: In conclusion, the experiment showcased MATLAB's versatility in simulating and analyzing synthetic PPG waveforms. The inclusion of baseline wander and noise adds realism to the generated signals, and the denoising step exemplifies the application of filters for improved signal quality. This experiment serves as a valuable foundation for studying PPG signal processing, contributing to advancements in physiological monitoring and healthcare applications.