Universidade de Aveiro
2025

Marta Pereira Neves

TÍTULO DA TESE (MÁXIMO 130 CARACTERES)

THESIS TITLE (MAX 130 CHARACTERS)

DOCUMENTO PROVISÓRIO

Universidade de Aveiro
2025

Marta Pereira Neves

TÍTULO DA TESE (MÁXIMO 130 CARACTERES)

THESIS TITLE (MAX 130 CHARACTERS)

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Licenciatura em Engenharia Biomédica, realizada sob a orientação científica da Doutora Susana Brás, Professora Associada do Instituto de Engenharia Eletrónica e Informática de Aveiro (IEETA), Departamento de Telecomunicações e Informática da Universidade de Aveiro.

o júri / the jury

presidente / president	Prof. Doutor João Antunes da Silva professor associado da Universidade de Aveiro
vogais / examiners committee	Prof. Doutor João Antunes da Silva professor associado da Universidade de Aveiro
	Prof. Doutor João Antunes da Silva professor associado da Universidade de Aveiro
	Prof. Doutor João Antunes da Silva professor associado da Universidade de Aveiro
	Prof. Doutor João Antunes da Silva professor associado da Universidade de Aveiro
	Prof. Doutor João Antunes da Silva professor associado da Universidade de Aveiro

agradecimentos / **acknowledgements**

Agradeço toda a ajuda a todos os meus colegas e companheiros.

palavras-chave

texto livro, arquitetura, história, construção, materiais de construção, saber tradicional.

resumo

Um resumo é um pequeno apanhado de um trabalho mais longo (como uma tese, dissertação ou trabalho de pesquisa). O resumo relata de forma concisa os objetivos e resultados da sua pesquisa, para que os leitores saibam exatamente o que se aborda no seu documento.
Embora a estrutura possa variar um pouco dependendo da sua área de estudo, o seu resumo deve descrever o propósito do seu trabalho, os métodos que você usou e as conclusões a que chegou.
Uma maneira comum de estruturar um resumo é usar a estrutura IMRaD. Isso significa:

- Introdução
- Métodos
- Resultados
- Discussão

Veja mais pormenores aqui:
`https://www.scribbr.com/dissertation/abstract/`

keywords

textbook, architecture, history, construction, construction materials, traditional knowledge.

abstract

An abstract is a short summary of a longer work (such as a thesis, dissertation or research paper).
The abstract concisely reports the aims and outcomes of your research, so that readers know exactly what your paper is about.
Although the structure may vary slightly depending on your discipline, your abstract should describe the purpose of your work, the methods you've used, and the conclusions you've drawn.
One common way to structure your abstract is to use the IMRaD structure. This stands for:

- Introduction
- Methods
- Results
- Discussion

Check for more details here:
`https://www.scribbr.com/dissertation/abstract/`

acknowledgement of use of AI tools

Recognition of the use of generative Artificial Intelligence technologies and tools, software and other support tools.

I acknowledge the use of [insert AI system(s) and link] to [specific use of generative artificial intelligence or other tasks]. I acknowledge the use of [software, codes or platforms] to [specific use software, codes or platforms or to other tasks].

Example 1: I acknowledge the use of ChatGPT 3.5 (Open AI, https://chat.openai.com) to summarise the initial notes and to proofread the final draft and the use of Office365 (Microsoft, https://www.office.com) for text writing and productivity.

Example 2: No content generated by AI technologies has been used in this Thesis.

Contents

List of Figures

List of Tables

Glossário

ECG	Electrocardiogram
CPT	Cold Pressor Test
NPS	Numerical Pain Scale

CHAPTER 1

Introduction

A short description of the chapter.
A memorable quote can also be used.

1.1 Acrónimos

Primeira e seguintes referências: Electrocardiogram (ECG), Cold Pressor Test (CPT), Numerical Pain Scale (NPS)

Plural, acrónimo expandido e curto: **h2o!**s (**h2o!**s), **h2o!**, **h2o!**

Com citação[1]: **adsl!** (**adsl!**), **adsl!**

1.2 Fontes

- Tiny
- Scriptsize
- Footnotes
- Small
- Normal
- large
- Large
- LARGE
- huge
- Huge

1.3 Unidades

Utilizando o pacote `siunitx` é possível utilizar unidades do Sistema Internacional. Exemplo: a aceleração da gravidade é de $9.8\,\mathrm{m\,s^{-2}}$ e um ficheiro ocupa $1\,\mathrm{MiB}$.

[1]Necessária entrada na bibliografia

1.4 Code Blocks

Uma listagem pode ser apresentada com o ambiente `listing`, que é um float (objeto flutuante, tal como uma figura ou uma tabela).

A listagem em Código **??** mostra um exemplo em C.

1.5 Citações

Algumas formas distintas de citar:

- **Apenas referência**: **rfc44**
- **Apenas data**: **rfc44**
- **Apenas ano**: **rfc44**
- **Apenas autor**: **rfc44**
- **Apenas editor**:**rfc44**
- **Autor e referência**:**rfc44**

CHAPTER 2

Theoretical Introduction

CHAPTER 3

Methods and Procedure

In figure 3.1, the processing pipeline for this project is shown.

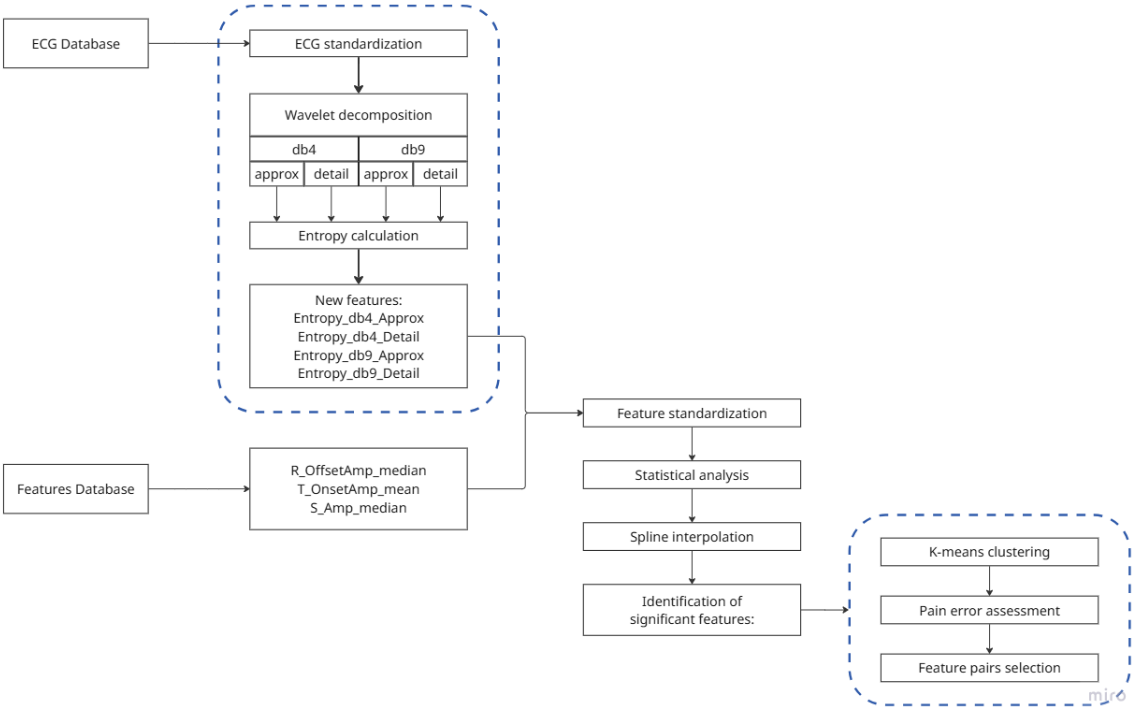

Figure 3.1: Processing pipeline.

3.1 Database Acquisition

In this project, two databases were used: one has data from an ECG signal while the other contains features extracted from that ECG, as described in the article by Alves et al [1].

The protocol that was carried out to create the databases began with a 5-minute baseline period, during which only physiological signals were collected while participants sat in a relaxed position without any stimuli. Next, participants viewed a 10-minute video composed of segments from comedy, horror or documentary films to elicit positive, negative or neutral emotional states, respectively. After the video, another 5-minute stimuli-free period was conducted. Following this, participants immersed their non-dominant hand in a tank of cold water (7 ± 1°C), inducing pain through a Cold Pressor Test(CPT), and reported their pain using the NPS at four key points: before immersing their hand, when pain was first felt (Pain Threshold), when the pain became unbearable (Pain Tolerance) and 3 minutes after removing their hand from the water. The CPT section ended when the limit of pain tolerance was reached, or after 2 minutes if the participant didn't reach theirs before that. Finally, the 5-minute period with no stimuli was repeated, being characterized as a rest period. This process is depicted in figure 3.2.

(Referenciar todos os acrónimos?)

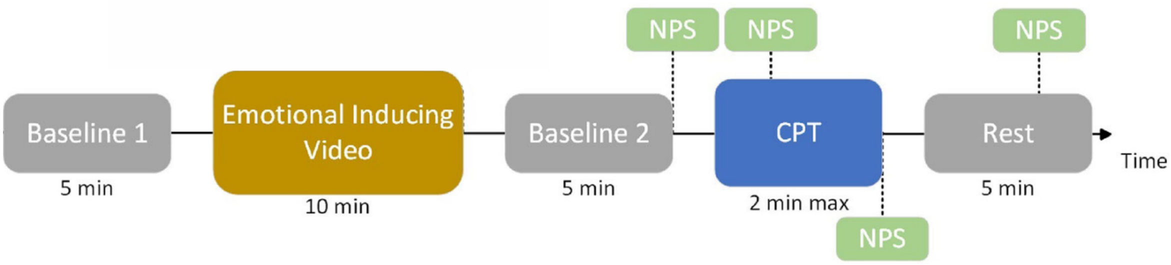

Figure 3.2: Scheme of the protocol applied to obtain the database. (Adapted from [1])

During the study, three physiological signals were recorded, more precisely, ECG, EDA and EMG from trapezius and triceps muscles. The ECG was recorded in a database, that was later used in this project. Following up in the article, heart rate (HR), the amplitude of wave peaks, the amplitude of onsets and offsets of the waves, the distance between consecutive onsets and offsets and the distance between consecutive peaks were extracted in the form of time series, using 10-second windows with 50% overlap. Then, for all of these, statistical metrics, like the mean, median and variance, were computed for each window, resulting in 237 features that were later processed. These are all included in the features database, also used in this project.

3.2 Feature Extraction

In the aforementioned article, the features of the ECG that can be used to best describe pain are defined. Hence, the top four features were selected for analysis, namely, the median of the R wave offset amplitude, the median of the T wave onset amplitude, and the mean and median of the S wave peak amplitude.

To enhance this research, new features were sought out. For this reason, analysis of the ECG database itself was deemed necessary.

3.2.1 ECG Data Exploration

When looking at the time series of the signal, in figure 3.3, it's noticeable that the range of amplitudes of the QRS complex is way bigger than that of the P and T waves. To tackle this, the ECG signal was standardized according to equation 3.1, where X is the original ECG, μ is the mean, σ is the standard deviation and Z is the standardized signal, which has mean zero and standard deviation one. This means the range of values is the same for all participants, which allows for comparison between them.

$$Z = \frac{X - \mu}{\sigma} \tag{3.1}$$

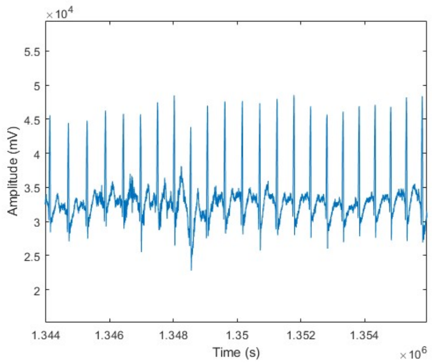

Figure 3.3: Section of the ECG signal of a participant.

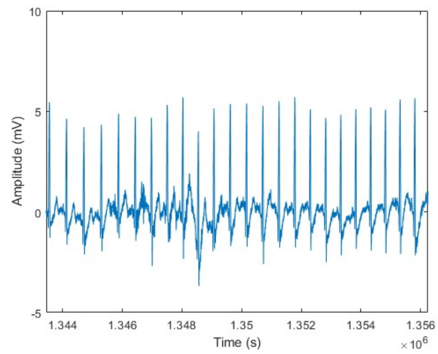

Figure 3.4: Section of the standardized ECG signal of a participant.

Once the signal was standardized, fluctuations were noticed in the time series. By removing high frequencies from the signal, by filtering for example, these would be alleviated. However, there could be information related to pain associated to those frequencies.

(Falar das famílias de wavelets para análise de ECGs?)

To choose the best type of wavelet, two criteria were established: one's format should be similar to that of the ECG wave and the other should have a higher frequency, while still maintaining its smoothness. Accordingly, Daubechies-4 ('db4') and Daubechies-9 ('db9') were chosen. Regarding the number of levels of decomposition, as can be seen in figure 3.5, when there are two levels the R peak is noticeable in the first detail, which is not something this project means to highlight. Therefore, only one level of decomposition was applied.

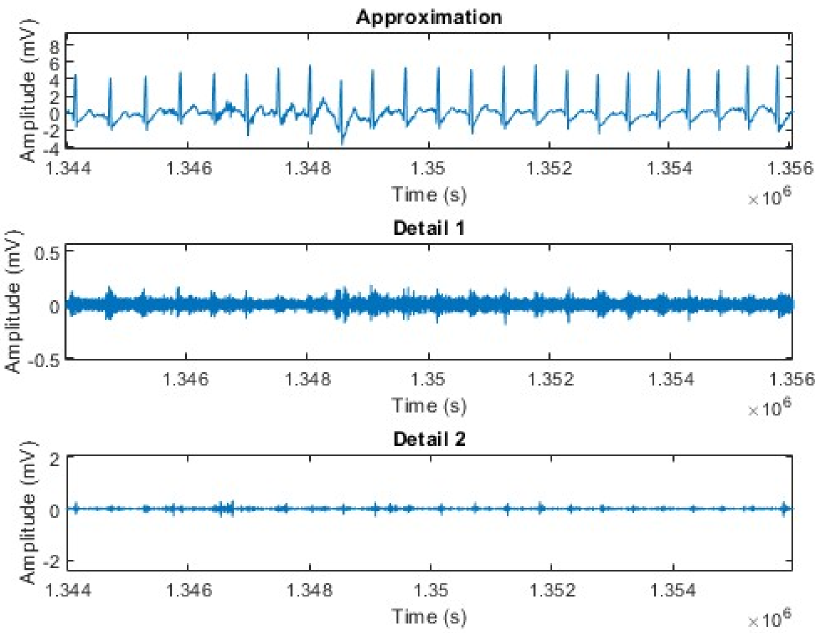

Figure 3.5: Daubechies-4 Wavelet Decomposition - level 2.

3.2.2 Entropy Calculation

Entropy quantifies the order or disorder of information that a signal presents. Since this quantity might be affected in the ECG when someone feels pain, it was extracted from the resulting wavelets, functioning as a new feature. In order to keep consistency with the other features, a same sized window was used, that is, 10 seconds with 50% superposition.

(Justificar tipo de entropia que escolhi? - approximation)

3.3 Data Analysis

To do the optimal processing of the features, fifteen participants were selected at random. After standardizing the features, so that they're comparable with each other, graphics of the time series of the features were plotted for each participant. An example can be seen in figure 3.6, in which a clear change can be seen when the participant dips their hand in water, feeling pain. Since the timeseries of the mean and median of the S wave amplitude were so similar, it was decided that only the median would be analysed.

(Falta ajustar imagem para eixo do y não ficar sobreposto.)

Afterwards, statistical analysis was done using histograms of the features of the participants, depicted in figure 3.7. These show that the features don't have a normal distribution, so it makes sense to use the median and interquartile range as the central tendency and dispersion measures, respectively. These, calculated for each feature, were considered "new features", which will be analysed further.

The goal of this project is to select features that distinguish pain from no pain. To do this, it's important that each step of the protocol has the same size, so that they're comparable.

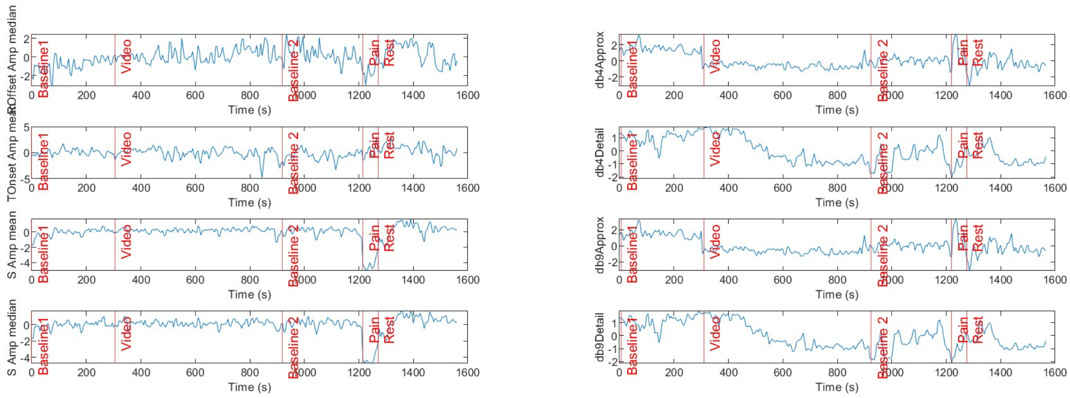

Figure 3.6: Standardized features' time series.

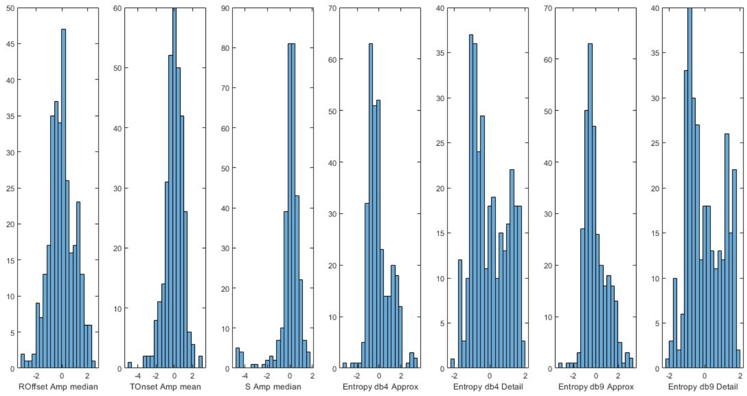

Figure 3.7: Histograms of the features.

With this aim, spline interpolation was done in each step, so they all had exactly the equivalent to 60 seconds of length. The result of this method is portrayed in figure 3.8.

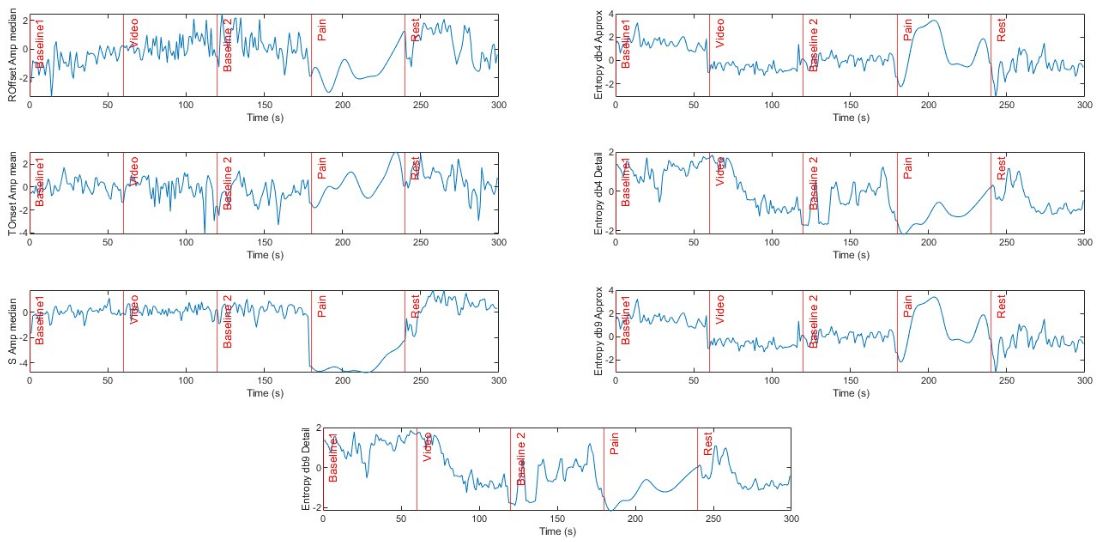

Figure 3.8: Features normalized in time after interpolation.

References

[1] B. Alves, S. Brás, and R. Sebastião, "Decoding pain: Prediction under different emotional contexts through physiological signals", *International Journal of Data Science and Analytics*, Oct. 2024, ISSN: 2364-415X. DOI: 10.1007/s41060-024-00649-z.

APPENDIX A

Additional content