Signal Processing 1TE651
– Project Description –
Reconstruction of ECG Signals

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Contents

1 Introduction

This project is motivated by the 2010 PhysioNet challenge: "Mind the Gap" [1, 2]. It focuses on reconstructing of ECG signals.

1.1 PhysioNet Challenges

PhysioNet is an online forum which facilitates the exchange of recorded biomedical signals and open-source software for the analysis of these signals. It is a part of a collaboration program which aims to simulate research in the study of cardiovascular and other biomedical signals. The participating institutions of this collaborative program include Beth Israel Deaconess Medical Center/Harvard Medical School, Boston University's Center for Polymer Studies, Division of Health Sciences and Technology of Harvard University-Massachusetts Institute of Technology, and McGill University's Centre for Nonlinear Dynamics in Physiology and Medicine [3].

Every year, PhysioNet announces a different "challenge." Each challange focuses on a different issue that is of interest to biomedical research community. Researchers from different institutions submit their solutions. These solutions are compared according to their reconstruction performance and the winner is announced. The resulting research papers are presented in academic conferences and journals.

1.2 "Mind the Gap"

This course project is based on the 2010 PhysioNet Challenge: "Mind the Gap" [1, 2]. This challenge focuses on reconstruction of missing parts of biomedical signals.

In intensive care units (ICUs), having clear measurements of patient physiological signals, such as ECG or PLETH signals, is of great importance. On the other hand, disturbances can make these physiological signals unreadable or completely lost for some periods of time. This makes the accurate monitoring of the condition of the patients difficult.

To solve this problem, one can attempt to reconstruct[1], i.e. estimate, the lost signal values by utilizing other correlated signals which has reliable data during these periods. This reconstruction can be done using various methods. During PhysioNet 2010 challenge, the most successful methods are found to be either neural network based methods or adaptive filtering methods [2, Fig. 2], [4]. As such, we will investigate usage of adaptive filters and the relevant trade-offs in this project.

2 Problem Set-up

We will consider a scaled down version of the PhysioNet challenge. We will focus on the reconstruction of ECG signals. Here, "reconstruction" of a signal means "estimation" of signal values. In Part A, we will use Recursive Least Squares (RLS). In Part B, you will propose your own solution.

2.1 Background

The data we will use for this project has been provided as Matlab mat files on Studium. The data consists of only ECG signals. Data for eight patients is supplied.

[1]Throughout this document, the terms "reconstruction" and "estimation" of a signal is used interchangeably

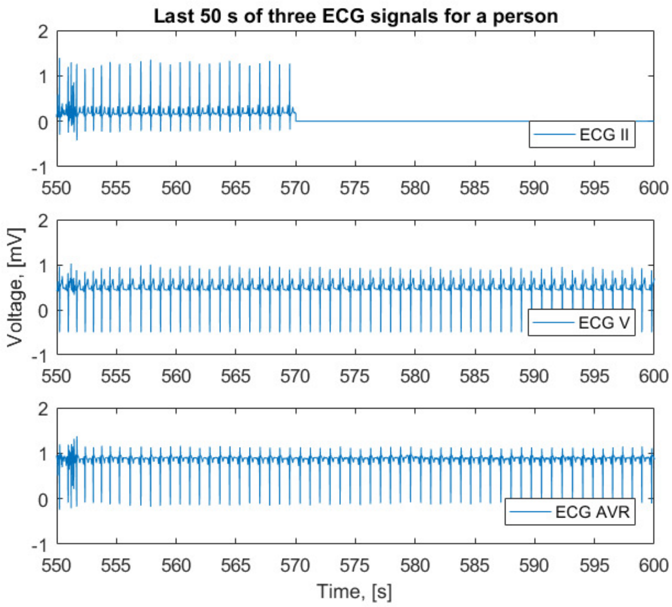


Figure 1: An illustration of the three ECG signals of interest. The zeroed part of the first signal is the part to be reconstructed.

The ECG signal *ECG II* will be estimated using the other ECG signals *ECG V* and *ECG AVR*. The ECG signal *ECG II* is called target signal throughout this document. The *ECG V* and *ECG AVR* signals encompass recordings of a total of 10 minutes. The last 30 seconds of the target signal, which was originally of the same length as the *ECG V* and *ECG AVR* signals, is removed. This last 30 second is the part that we assume to be missing. An illustration of these signals is provided in Fig. 1.

To make it possible for you to evaluate the goodness of your reconstructions, the missing part of *ECG II* is provided under a separate variable. This data will be used for "testing" purposes.

2.2 Part A: RLS

Our aim is to reconstruct the missing part of the target signal $x_T[n] =$*ECG II* signal using $x_1[n] =$ *ECG V* and $x_2[n] =$*ECG AVR*. We will use the recursive least-squares (RLS) algorithm.

Assume that $x_T[n]$ can be written as a linear combination of samples of $x_1[n]$ and $x_2[n]$. Hence, we have the following signal model

$$x_T[n] = \sum_{i=0}^{N} a_i x_1[n-i] + \sum_{i=0}^{M} b_i x_2[n-i] + w[n]$$

where a_i and b_i are unknown coefficients to be determined and $w[n]$ is unknown disturbance. Here, N and M are unknown.

We adopt the following approach:

1. Using the first 9.5 minutes of $x_T[n]$, $x_1[n]$, $x_2[n]$, train the RLS filter and estimate the coefficients a_i and b_i.
2. Freeze the estimates $\hat{a}_i$ and $\hat{b}_i$ at the end of 9.5 minutes.
3. Using the last 30 seconds of $x_1[n]$ and $x_2[n]$, form an estimate of $x_T[n]$ for the last 30 seconds.

$$\hat{x}_T[n] = \sum_{i=0}^{N} \hat{a}_i x_1[n-i] + \sum_{i=0}^{M} \hat{b}_i x_2[n-i]$$

In Part A, we solely focus on real-time processing.

The above procedure should be done for each patient. Hence, each patient will have a different set of a_k, b_k values. **The scenario we consider here is the following:** All signals are available for some time for a given patient. Then, $x_T[n]$ becomes missing. We use the previously trained filters to estimate the missing signal for this given patient.

We can evaluate the goodness of our estimate using the true value of last 30 seconds of *ECG II* provided in the course folder. See also Section 2.4.

2.3 Part B

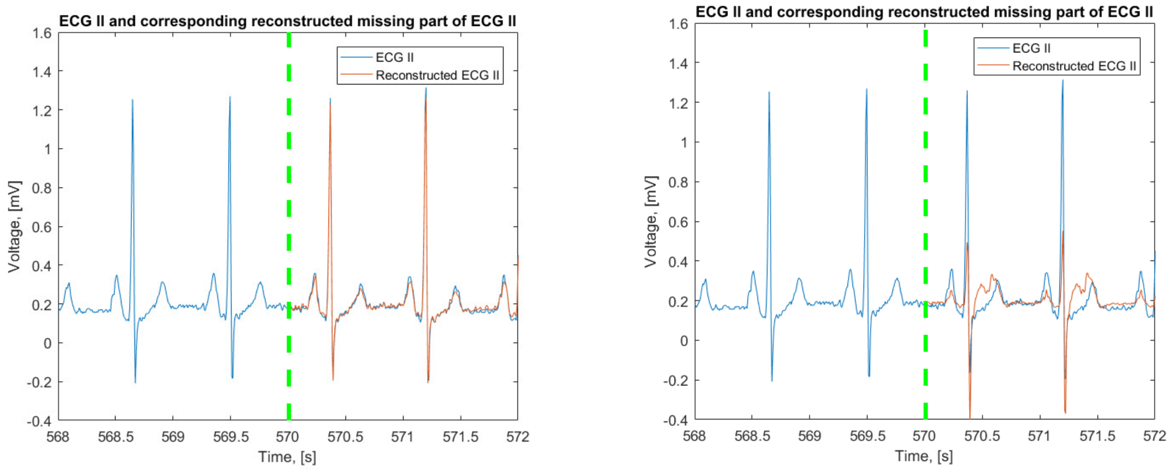
In Part B, your task is to suggest another method for this reconstruction problem and investigate its performance. You also need to compare the performance of the suggested method with RLS. Choose a method that allows real-time operation during actual estimation, i.e. do not use the future values of $x_1[n]$ and $x_2[n]$ while estimating the last 30 seconds of $x_T[n]$.

- **As long as you justify your choice, you can use any of the methods we have covered in the class except plain Least Mean Squares (LMS) and the Normalized LMS (NLMS).** Although plain LMS and the NLMS are applicable to this problem, we prohibit the usage of these methods for Part B to encourage you to explore other ideas.
- Performance of the solution you have proposed will not be used to grade your work. Hence, you can investigate a solution which you expect to be inferior to the RLS.
- You do not have to perform real-time processing during training. You only need to perform real-time processing while estimating the last 30 seconds. For instance, you can perform batch processing on the training data to estimate the statistical properties of the signal and use this information to perform real-time processing during the last 30 seconds.

2.3.1 Suggestions from the course staff

In Part B, you are most encouraged to investigate an aspect of this problem that is *interesting for you*. In any case, below are some ideas that you may use if you want to:

- You can use a modified version of LMS with Adam optimizer and compare its performance with that of RLS. Adam optimizer is a stochastic optimization method, which has been introduced in [5]. It has been quite influential, for instance Ref [5] has been cited more than 32700 times although this is a recent article that has first appeared online in 2014. Moreover, Adam



(a) A "good" reconstruction

(b) A "not so good" reconstruction

Figure 2: Example Reconstructions

optimizer is used in various modern machine learning methods, for instance for optimization of neural networks, and has become a standard option in various software platforms, for instance in TensorFlow. A short overview of Adam optimizer is provided in Section 4.

- You can use Kalman filtering and compare its performance with that of RLS.
- The reconstruction performance is only one aspect of the performance of a solution method. Another aspect is computational time. Throughout the course, we have claimed some methods are better than the others in terms of computational time. You can investigate this claim. For instance, you can define a least-squares problem and try to solve the problem directly using LS formulas instead of using RLS.
- An important aspect of practical implementations is the quantization of filter coefficients and signal values. This aspect becomes more significant if you want to implement these algorithms with low-cost embedded systems with limited memory. Hence, an investigation of the effect of quantization is an interesting line of study here.
- Looking at the plots of ECG signals, we observe that they seem to be periodic. This suggests that a frequency domain analysis or power spectrum analysis may be particularly useful.

Note that the aim is to pick one aspect/idea and investigate it throughly. Do not try to cover all the ideas here. Pick one of these (or another one of your choice) and study it systematically.

2.4 Evaluation of the Reconstruction Performance

Evaluate the goodness of reconstruction performance using both of the following methods:

- Illustrate the performance by comparing your estimate with true values of the reconstructed signal on a plot for 2-3 patients. Example reconstructions are shown in Fig. 2.

- Calculate the value of the quality functions *Q1* and *Q2* defined below for all eight patients. These quality functions are used to evaluate the competing solutions in the original Physionet's challenge. *Q1* and *Q2* values for 8 patients should be presented in a table. A table for both Part A and Part B should be provided.

Given the last 30 second part of the target signal, $x_T[n]$, and the estimated, (i.e. reconstructed), signal $\hat{x}_T[n]$, the first quality function is defined as

$$Q1 = 1 - \frac{mse(x_T[n], \hat{x}_T[n])}{var(x_T[n])}, \tag{1}$$

where $mse(x_T[n], \hat{x}_T[n])$ is the mean square error between the missing and the reconstructed part of *ECG II* and the $var(x_T[n])$ is the variance of the missing part. The second quality function is defined as

$$Q2 = \frac{cov(x_T[n], \hat{x}_T[n])}{\sqrt{var(x_T[n])var(\hat{x}_T[n])}}, \tag{2}$$

where $cov(x_T[n], \hat{x}_T[n])$ is the covariance between the missing and the reconstructed part of the target signal.

Both $Q1$ and $Q2$ is expected to take values satisfying $|Q_1| \leq 1$ and $|Q_2| \leq 1$. Here higher values indicate better reconstruction.

Calculation of $Q1$ and $Q2$ values require you to create empirical estimates of the mean-square error, the covariance and the variances. These emprical values can be calculated by changing the expected values in the definitions of these quantities with sample averages. For instance, $cov(x[k], y[k])$ can be calculated as

$$cov(x[k], y[k]) = \frac{1}{|\mathcal{K}|} \sum_{k \in \mathcal{K}} (x[k] - m_x)(y[k] - m_y) \tag{3}$$

where $\mathcal{K}$ is the set of indices in the interval we're interested in and $|\mathcal{K}|$ is the cardinality of the set K, i.e. the number of indices in $\mathcal{K}$. Here, m_x and m_y are the mean-values over this interval, i.e. $m_x = \frac{1}{|\mathcal{K}|} \sum_{k \in \mathcal{K}} x[k]$, $m_y = \frac{1}{|\mathcal{K}|} \sum_{k \in \mathcal{K}} y[k]$.

If the quality function Q1 or Q2 takes a negative value, set it to 0. Does this make sense? Why/why not?

While presenting the Q1 and Q2 values for different patients, you must keep the parameters of your solution that are not found automatically fixed, such as the filter length. See Section 5 for further discussions.

Note: You are not allowed to use Matlab function `immse()` for calculation of the above quantities. Implementation of this function changes from one Matlab version to another and causes issues regarding reproducibility of the results.

2.5 Hyperparameter study

We would like you to perform a systematic study of at least one hyper-parameter (any parameter that is chosen by the user). Here, you will keep all the other parameters of the method fixed and change only this parameter of interest. You need to present your results in a clearly identifiable table/plot.

2.6 Hints

- For Part A, you are not allowed to use MATLAB implementation of the RLS filter. If you want, you can start with the RLS implementation provided under the course folder in the Studium under Lecture Notes, Supplementary Material. Note that you will need to modify that implementation. **Note that many of the previous course participants thought that it is actually easier to use that m-file only to understand the RLS filter, and then write your own code from scratch for the project.**

- **We suggest you first work with Patient 2.** First, perform the reconstruction of the target signal $ECG\_II\_2.mat$ using only $ECG\_AVR\_2.mat$ which has a high correlation with the target signal. Your implementation should provide reasonably good results with this data.

- If you just want to pass the project module with the minimum effort, it may be beneficial to pursue the LMS with Adam optimizer idea presented in Section 2.3.1 for Part B. This is suggested due to ease of applying LMS with Adam optimizer at this problem, similarities between RLS and LMS.

- Making the signals zero mean before processing may be a good idea. To do this, you can use the MATLAB function `mean` on the signals and subtract this value from every signal sample. Don't forget to save the mean and add this mean value to every sample of the reconstructed signal. Why do you think this preprocessing is suggested?

- If you are going to investigate aspects related to computational time, you can find the Matlab commands `tic`, `toc`, `profile` useful.

- **Make sure to check Section 8 to see common mistakes and other hints.**

3 Administrative Issues

3.1 Important Dates:

- The submission deadline for the quiz, the slides, the code and the deadline for booking an oral exam slot are on 17:00, Dec. 8.

- Oral exams will be held on Dec. 12-13. How to book time slots for the oral exam will be explained on the project page in Studium.

3.2 Project Groups

The project is to be completed in groups of 1-2. Even if you're going to work with the same group you worked on the assignments, you need to register to a new project group.

3.3 Consultation Hours

There will be consultation hours for the project. The schedule will be published on Studium at the project page.

3.4 Evaluation of the Project

In order to pass the project module, you need to get a Pass grade for the following components:

- Quiz
- Code
- Slides
- Oral exam

In the below, we give the details for the evaluation of each component.

3.4.1 Quiz

There is a mandatory quiz on RLS, see Studium. **The problem setting in the quiz is different than the one in the project.** The aim of the quiz is give you an opportunity to test whether you can hand-trace RLS correctly before moving onto the setting of the project.

3.4.2 Code

The code should be submitted through Studium in a form we can run them directly, for instance no pdf/html files are allowed. **For Matlab, this means you should provide m-files.** Please note that if there are no executable files, your first submission will be considered as “Fail”. Your code should be commented appropriately. If you have multiple m-files, please put all of your code in one folder (compress the folder) and upload it.

Part A should be written in Matlab. You can use Python in Part B, but note that we do not provide any support for Python. Use this option only if you know what you're doing.

The grading rubric that will be used by the course staff for evaluating the code is presented in Section 6.

Recall the rules for assignments and projects. In particular, note that:

- You are not allowed to copy code from anybody, including students in your class or students from previous years.
- You are not allowed to share your code with other students outside your group.
- You are not allowed to copy code from an external source.

3.4.3 Slides

You will submit your findings with a set of slides. The slides should be submitted in **pdf/pptx** form to Studium before the project deadline. Note that your slides should contain the results/discussions for both parts. You need to follow the template for the presentation given in Section 7. See also Section 3.5 for the assessment criteria.

During the oral exams, you will be asked to give a short summary (approximately 5min) of your results focusing on either Part A or Part B using your slides. After asking each group to give a short summary of one of the parts, we will use your whole presentation slides to compare and discuss the results of different groups.

3.4.4 Oral Exam

There is a mandatory oral exam connected to the project. Please sign-up for a slot using Studium. See Section 3.5 to see the evaluation guidelines. See Section 9 to get a better understanding of the setting.

3.5 Evaluation of Slides and Oral Exams

To be able to pass, you need to present a systematic study of the properties of the reconstruction methods you have implemented and connect your findings to the theoretical results. The following are some desirable properties that will be taken into account during evaluation:

- Submitted implementation successfully reconstructs the signals. **Provided you get reasonably good reconstruction results, the reconstruction performance will NOT be used to grade your work.**
- The presented results illustrate that authors' implementation successfully reconstructs the signals.
- Parameters of the signal reconstruction methods are explained appropriately.
- Presentation of the findings is clear.
- Findings are illustrated by plots and quantitative results. These findings are discussed thoroughly.
- Authors show that they are aware of what the important aspects of an estimation problem/method are.
- Authors show that they are aware of what the important aspects of performance in an estimation problem are.
- Conclusions drawn by the authors are supported by the presented results.
- Observed results are compared with the expected results. Discrepancies between these are acknowledged and discussed appropriately.
- Organization and English usage is satisfactory.
- Plots are labelled appropriately.

These aspects will be evaluated both in oral exams and the slides whenever applicable. Please also see the general information document on the assignments/projects on the Studium to recall the rules about assignments/projects.

4 Appendix: Adam Optimizer

In this section, we provide a short overview of LMS with Adam optimizer [5]. We use the notation in the LMS lecture notes, which can be found on the Studium. Define the filter input at iteration n as $\boldsymbol{y}[n]$ and the filter coefficients at iteration n as $\boldsymbol{h}[n]$. Define the cost function as in plain LMS: $f(\boldsymbol{h}[n-1]) = \frac{1}{2}e^2[n]$ where $e[n]$ is the a-priori estimation error $e[n] = d[n] - \boldsymbol{h}^T[n-1]\boldsymbol{y}[n]$. Let $\boldsymbol{g}_n$ denote the gradient of $f(\boldsymbol{h}[n-1])$ with respect to $\boldsymbol{h}[n-1]$. The Adam optimizer is presented in Algorithm 1.

Algorithm 1: Adam optimizer

Initialize: Set the initial values for the filter coefficients $\boldsymbol{h}[0]$. Set the initial values $\boldsymbol{m}_0 = \boldsymbol{v}_0 = \boldsymbol{0}$ for the first and second moment estimates. Initialize the step size α, the decay rates β_1, β_2 and ϵ.

for $n = 1$ *to* N **do**

$\boldsymbol{m}_n = \beta_1 \boldsymbol{m}_{n-1} + (1-\beta_1)\boldsymbol{g}_n$

$\boldsymbol{v}_n = \beta_2 \boldsymbol{v}_{n-1} + (1-\beta_2)\boldsymbol{g}_n^2$

$\hat{\boldsymbol{m}}_n = \boldsymbol{m}_n/(1-\beta_1^n)$

$\hat{\boldsymbol{v}}_n = \boldsymbol{v}_n/(1-\beta_2^n)$

$\boldsymbol{h}[n] = \boldsymbol{h}[n-1] - \alpha\, \hat{\boldsymbol{m}}_n/(\sqrt{\hat{\boldsymbol{v}}_n} + \epsilon)$

end

return $\boldsymbol{h}[N]$

- All operations that involve vectors are performed element wise. For instance, the squared gradient $\boldsymbol{g}_n^2$ indicates the vector whose elements are the squared elements of $\boldsymbol{g}_n$.
- Note that the decay rates β_1, β_2 are scaled with the iteration index. For instance, β_2^n is the n^{th} power of β_2.
- Keep in mind that the variable $\boldsymbol{g}_n$ is a vector with the same dimensions as $\boldsymbol{h}[n]$, and so are the variables $\boldsymbol{m}_n, \boldsymbol{v}_n, \hat{\boldsymbol{m}}_n, \hat{\boldsymbol{v}}_n$.
- Start your experiments with the following values $\alpha = 0.001$, $\beta_1 = 0.9$, $\beta_2 = 0.999$ and $\epsilon = 10^{-8}$. Ref. [5] claims that these values are universally good default choices for these parameters. Do your results support this claim? Why/why not?
- How should you change Algorithm 1 so that it corresponds to plain LMS?

5 Appendix: Further Information On the Hyper-Parameter Choices

While presenting the Q1 and Q2 values for different patients, you must keep the hyper-parameters of your solution fixed, such as the filter length (but not the filter coefficients). This is due to the fact that in a practical application scenario, we will not have the chance to tailor our hyper-parameters to each patient. Imagine yourself implementing this solution in a ECG monitoring device: For instance, you will not be there to change the filter length or the step size yourself.

Hence, it is desirable that you try different parameters with different patients to see the effect of parameters for different signals. This will allow you to get insights to the problem. Based on these observations, you need to make a reasonable choice about which parameters your solution will use in the end.

Another approach would have been to write a procedure so that good choices for the hyper-parameters are determined automatically with the software together with the coefficients. We consider this type of approach beyond the scope of this project.

To summarize, **we would like to have a general idea about reasonable parameters to use but finding the best parameters is not the main of the project.** Instead of spending too much time on this aspect, we suggest you reflect on how your observations connect to theory we covered in this class and the other aspects in Section 3.5.

6 Appendix: Grading rubric for the code

Your code should be consistent with the instructions given in this document, such as real-time processing, and the results you have presented in your slides. We will perform the first evaluation of the code according to the below rules. All of these are necessary conditions for passing the project.

We check the following for both Part A and Part B whenever applicable:

- There exists code for the method you present.
- There exists code for calculating **scalar** Q1 and Q2 values.
- The parameters of the methods and the code for finding Q1/Q2 values are clearly labelled in the code.
- The method uses both signals, i.e. $x_1[n]$ and $x_2[n]$, to create the estimates.
- The method can handle different N and M values (checked by running the code for arbitrary N and M values).
- The values in the tables match the values the code produces (checked by running the code for some of the scenarios using the values of the parameters presented in the slides).
  - If your code uses some random numbers (such as for initialization), either make sure to write the file so that it allows us to produce the same random numbers or take average over enough realizations so that the results does not vary much. In Matlab, check `rng()` for reproducibility of random number generation.

7 Appendix: Template for the Slides

The below presentation template is motivated by discussions with colleagues working in industry. We have tried to match the style they use to communicate internally within the company.

While arranging the order of your slides, keep in mind that you will be asked to give a short summary of your results focusing on either Part A or Part B during the oral exams. Your slides should provide clear statements of your results/guidelines/justifications etc.

- Introduction: Give a general description of the problem we're interested in. A short explanation is sufficient. (Recommended length: 1 slide)
- Methods: Provide a short explanation of the two methods you have implemented in Part A and Part B under clearly identifiable headings. (Recommended length: 1 slide (Part A) + 2-3 slides (Part B))
  - Make sure to use the notation used in this document. For instance, if your explanations include a variable $\boldsymbol{\theta}$, it should be defined in terms of the variables in this document.
  - Clearly give the dimensions of all vectors/matrices involved
- Numerical Results:
  - Part A and Part B: Provide all necessary parameters of your methods so that your results are reproducible. (Recommended length: 1 slide (Part A) + 1 slide (Part B))
  - Part A and Part B: Illustrate the performance by comparing your estimate with true values of the reconstructed signal on a plot for 2-3 patients.
  - Part A and Part B: *Q1* and *Q2* values for 8 patients should be presented in a table. A table for both Part A and Part B should be provided.
  - Choose Part A or Part B: Provide a systematic study of at least one hyper-parameter (any parameter that is chosen by the user). Here, you will keep all the other parameters of the method fixed and change only this parameter of interest. Give your results in a clearly identifiable table/plot.
    - It is sufficient to do this only for Part A or only for Part B.
  - Discuss the above numerical results. **Clearly write down your main observations as full statements on the slides. This is a necessary condition to pass the project.** These include the following:
    - state your theoretical expectations with motivations and discuss whether your results are consistent with the theoretical results, for instance "we expect that X increases when a smaller value for Y is chosen since Z. In Table 2, we see that ...".
    - point out any discrepancies clearly and try to explain them.
- Discussions: Provide guidelines about best practice and provide justifications for your guidelines. For instance, try to answer questions such as "which method should we use?", "how should we choose the parameters?". (Recommended length: one slide)
- Conclusions: Give a short summary of your conclusions and point out at least one "future work", i.e., an aspect of the problem that you think is important and would have investigated if you had more time. (Recommended length: one slide)

8 Appendix: Further Hints

In the previous years, some of the course participants utilized the following information:

- The signals are obtained by "digitilization" with 125samples/sec. It is not entirely clear whether the data is directly sampled at this rate or this was obtained by some postprocessing but you can treat this number as the original sampling frequency if you need one.

Below are some hints based on the mistakes previous years' students made. You will need to do a supplementation if you fail to handle these issues:

1. Check the indexing your code uses and the indexing in Section 2.2. For instance, check if your code correctly implements the following example:
   - Let $N = 1$, $M = 2$ and $n = 100$. The estimate of $x_T[100]$ should be in the following form: $a_0 x_1[100] + a_1 x_1[100-1] + b_0 x_2[100] + b_1 x_2[100-1] + b_2 x_2[100-2]$.

   This is by far one of the most common mistakes. Make sure to check this issue properly.
2. In your slides, make sure to use the notation used in this document. For instance, if your explanations include a variable $\boldsymbol{\theta}$, it should be defined in terms of the variables in this document. We consider this as an indication of your mastery of the method. You cannot get a passing grade if this issue is not handled properly.
3. Do not forget to provide all parameters of the methods.
4. In Part A, the filter is trained for each patient. In Part B, you are allowed to explore other options if you can justify your setting.

9 Appendix: Oral Exam

Course participants and the instructor will discuss the project. The instructor will have the opportunity to evaluate the level of understanding in the group and students will have the opportunity to discuss their findings and ask questions to learn more. Each group will share the session with one or two other groups and you will discuss the project with each other and the instructor. The link for signing-up for the oral exam schedule will be announced in Studium.

- Active participation is of vital importance for the quality of each session. Please be prepared for explaining your approach to other participants. Note that we will put up slides as well as code of participant groups on the screen and discuss them both in terms of basics and high-level understanding. Our past experience shows that if the groups are prepared, we can skip the details on the basics very easily and focus on interesting aspects and have a more fruitful discussion session.
- Recall that each group member is completely responsible for all parts of the project, including the implementation, technical calculations, discussions and the slides.
- In addition to the aspects explained in the evaluation part of the project description, a necessary condition to pass the oral exam is to have a "professional" attitude. Among other things, you are expected to be polite to each other, let others speak when needed, listen and discuss different opinions in a cordial manner. This rule applies to all activities related to the oral exam.
- During the session, all participants are expected to illustrate their knowledge about the project. Hence, any of these behaviors are inadvisable: i) to answer all questions yourself which will cause other participants to fail, ii) to let fellow course participants answer all questions which will cause you to fail.
- Although we will do our best to stay on schedule, we may have slight delays. Try to choose a slot where you will be least affected by some delay, i.e. you have some more free time (approximately 15 minutes) after your slot.
- Please also see the general information document on the assignments/projects on Student Portal.

References

[1] "Physionet challenge: Mind the gap." https://physionet.org/challenge/2010. Accessed 2017-10.

[2] G. B. Moody, "The physionet/computing in cardiology challenge 2010: Mind the gap," in *Computing in Cardiology, 2010*, pp. 305–308, 2010.

[3] A. L. Goldberger, L. A. Amaral, L. Glass, J. M. Hausdorff, P. C. Ivanov, R. G. Mark, J. E. Mietus, G. B. Moody, C.-K. Peng, and H. E. Stanley, "Physiobank, physiotoolkit, and physionet," *Circulation*, vol. 101, no. 23, pp. 215–220, 2000.

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[5] D. P. Kingma and J. Ba, "Adam: A method for stochastic optimization," in *International Conference on Learning Representations (ICLR)*, 2015. Latest version can be accessed from: https://arxiv.org/abs/1412.6980.