My Open-Research Pool

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Preface

In this document, some of the open-problems that I have been working on, or have came across during the past years are presented. Most of these subjects are in the field of statistical signal processing (especially for biomedical applications) and digital system design, which are my major fields of research. Some of these subjects have already been defined as projects for my students in Shiraz University, on which we have had partial progress. After some years of private circulation between friends and students, I decided to release it online in March 2015, in order to extend its audience and keep an online record of my research interests, and I hope to continue its update rather regularly. So, if you came across this document by surfing the Web and you are interested in working on any of these subjects under my direction or as a joint research, please feel free to contact me for further details and references. I also welcome any feedback on these topics, or references to people or websites, which have partially or fully solved any of these problems.

The following chapters are split in two parts: Research and Development. However, as I'm mainly interested in applied research, you may find much of overlap between the two parts. My ultimate perspective is to have all of these research ideas be developed and used in real world systems at some point.

Contents

Symbol Legend

Throughout the document, the following symbols are used as abbreviations.

Table 1: Status

④	Number of people already assigned to, or working on this project under my supervision
Active/Inactive	Current status of the project
None/Partial/Done	Amount of progress

Table 2: Technical Level

BS^-	Bachelor student's course work
BS	Bachelor student's final project or internship
MS^-	Master student's course work or term paper
MS	Master's thesis
PhD^-	PhD student's course work
PhD	PhD thesis
PhD^+	Post-doc research

Table 3: Estimated Timing

1m	up to 1 month
3m	1 to 3 months
6m	3 to 6 months
1y	6 months to 1 year
2y	1 to 2 years
4y	2 to 4 years

Table 4: Estimated Impact

Low	Low Impact
Medium	Medium Impact
High	High Impact

Part I

Research

Chapter 1

General Signal Processing Problems

1.1 General

1.1.1 FOREX data analysis

The Foreign Exchange Market (FOREX) is a highly decentralized, dynamic, non-stationary, and difficult to predict market. The problem of FOREX signal analysis has very interesting aspects from the stochastic signal processing viewpoint. I have personally worked on this problem as a personal interest for some time and developed algorithms and routines in MetaQuotes Language 4 (MQL4) and MQL5. I also have a MS student (Ms. Zahra Sadeghian) working on aspects of this problem.

Level: *MS*, *PhD* **Duration:** *1y* **Impact:** *High* **Status:** - **Impression:** Lovely problem!

1.1.2 Signal quantization

Modeling data quantization and its effects using Markov Chains is an interesting problem of interest. As we commonly implement signal processing algorithms on digital systems, it is believed that many statistical signal processing algorithms can (and should) be studied over finite fields rather than assuming random behavior for the quantization noise. One of these areas of research are systems described by state-space models that should be revised for finite length data rather than over real numbers. The problem becomes more important when we have few quantization levels (e.g., 8 bits or below). The effect of *dither* should be also studied within this framework. A very interesting textbook to start with is [1]. The project requires some good knowledge of coding and information theory.

Level: *PhD* **Duration:** *4y* **Impact:** *High* **Status:** - **Impression:** Tough maths!

1.1.3 Degrees of freedom in algebraic transforms

The study of general properties of linear or nonlinear one-to-one transforms (such as PCA, SVD, some ICA algorithms, etc.), regardless of their contrast functions, is an interesting problem. We have shown in some previous work that the number of *degrees of freedom* (DoF) remains constant in all the known one-to-one algebraic transforms. A more fundamental question is how to define DoF in a rigorous manner and possibly use it as a design criterion for source separation problems. Moreover, is it possible to prove that the defined DoF is constant under a one-to-one transform? We have made some progress in this area by using information theoretic measures, such as the Shannon Entropy and its extensions, for defining the DoF. In a parallel approach we used ideas from geometry to define the DoF; but the problem is still open for further research.

Level: *PhD*$^{-}$ **Duration:** *2y* **Impact:** *Medium* **Status:** ① **Impression:** Gives a new perspective to readily solved problems!

1.1.4 Interpretive signal processing for non-numeric data analysis

Non-numerical signal processing and matrix decomposition, interpretations and its applications in non-numeric data mining is a problem of interest. The extraction of information from non-numeric data is an important objective of data mining. This field has many applications ranging from bio-informatics to text, image and medical data analysis.

However, due to the broad range of applications and their practical complexities, there are many open problems in this context.

Conceptually, there are many similarities between non-numeric and numeric data from the one-hand, and the notion of data mining and signal processing from the other hand. Due to these similarities, many researchers have reformulated some data mining problems within a signal processing framework. In this context, the main idea has been to assign numerical codes to non-numerical data and to use conventional signal processing techniques to solve the problem in the code space. This approach has been very effective in many cases. However, it seems to be possible to go a step further and re-design the existing signal processing techniques directly for non-numeric data. This idea requires deep revisions in basic principles of signal processing algorithms. For example, basic notions such as summation (integration), product, filtering, convolution, correlation, covariance matrix, etc. should be redefined (from the scratch) for non-numeric data. Therefore, many other issues, including the closedness and completeness of sets should also be restudied in this context.

It is apparent that the idea is very broad and may not necessarily lead into a general solution; but it is believed that the idea may lead into interesting results for specific applications, including "motif matching in DNA or protein sequences using non-numeric derived matched filters" or "matrix decomposition for principal component analysis (PCA) and independent component analysis of non-numeric or binary data". We have already made some progress on this general problem for DNA and protein sequence *matched filtering* [2]; plus the extension of time-frequency transforms to non-numeric data (still unpublished, by August'14). Some related ideas in this area can also be found at [3], for binary matrix decomposition. Interesting applications have been discussed in [4, 5, 6] (for further insight, please view all the other related articles in these journal issues as well). We plan to extend the work to conventional filtering schemes such as Wiener and Kalman filters.

Level: *MS* **Duration:** *2y* **Impact:** *High* **Status:** ① **Impression:** Revolutionary idea!

1.1.5 Factorized matrix interpretation

Interpretation of the eigenvalues and components extracted by SVD of $N \times T$ blocks of data requires some studies. These interpretations can be later extended to non-numeric matrix factorization and used in the idea mentioned in (1.1.4) . I'm already aware of related research in binary matrix factorization and non-negative matrix factorization. I'm also interested in the more general problem of interpreting the elements of factorized matrices.

Level: *MS*$^{-}$ **Duration:** *3m* **Impact:** *Low* **Status:** - **Impression:** Good for insight!

1.1.6 Kalman filter based spectral estimation

Using complex Kalman filters for spectral estimation, based on our Kalman notch filter model [7]. The previous adaptive notch filter can be used for separating stationary and non-stationary signals, e.g., background EEG in brain computer interface applications. The Kalman filter parameters can be chosen by monitoring the energy deviations of different frequency bands. Contact me for further details!

Level: *MS* **Duration:** *6m* **Impact:** *Medium* **Status:** - **Impression:** No prejudgments!

1.1.7 Kalman filters for improving ADC sampling

Using Kalman filters for improving the performance of ADCs in over-sampling scenarios. The idea can benefit from the fact that sampled data are band-limited (sampled at the Nyquist rate or above). The idea may be later implemented on hardware as part of the ADC silicon, or as a pre-processing routine on sampled ADC data.

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** Partial **Impression:** Applied

1.2 Blind and Semi-Blind Source Separation

1.2.1 Linear transformation properties

Study of general properties of linear transforms regardless of a contrast function imposed on them. I know it may seen trivial and over-studied in the first glance. But I think that the problem may be related to or studied in terms of the degrees of freedom discussed in Section 1.1.3. It can give interesting insights to the general problem of source separation under a linear model constrain. What motivated me for this problem, is that different algorithms for BSS tend to give more or less similar results under the linear model assumption. This idea came about from a fruitful discussion that I had with Dr. Vincent Vigneron and Prof. Christian Jutten many years ago.

Level: *PhD⁻* **Duration:** *1y* **Impact:** *Medium* **Status:** ① **Impression:** It has a possibly high impact!

1.2.2 Subspace separation by deflation

We developed a novel deflation algorithm for subspace separation in [8, 9]. The effectiveness of this method has since been evaluated for various applications [10, 11, 12]. This method seems to be related to Donoho's wavelet denoising scheme. I have some good ideas for this formulation and did some primary work on it. It is a very promising and high impact research problem.

Level: *PhD⁻*, *PhD* **Duration:** *1y* **Impact:** *High* **Status:** ① **Impression:** Very nice and important problem!

1.2.3 Spikes and bumps phenomenon

The theoretical justification of the *spikes and bumps* phenomenon in multichannel blind source separation problems and the study of the relevance of the extractable components in presence of background noise.

Level: *PhD⁻* **Duration:** *6m* **Impact:** *Medium* **Status:** ① **Impression:** Can be rather applied

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1.2.4 Distributed component analysis

The problem of extracting principal or independent sources from distributed (non-punctual) sources is a very practical problem of interest. I have made some progress in formulating this problem, but there's still a long way to go.

Level: *PhD* **Duration:** *2y* **Impact:** *High* **Status:** ② **Impression:** I love this problem!

1.2.5 Filter banks vs. blind source separation

A general framework for unifying different source separation techniques and filter banks, using the concept of "predictability" and whitening in its most general sense and formulation of the idea for $N \times T$ blocks of data. This may result in a joint spatio-temporal source separation and may also be related to the problem described in 1.1.3.

Level: *PhD⁻* **Duration:** *1y* **Impact:** *Medium* **Status:** ① **Impression:** Interesting and applied

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1.2.6 Blind source separation implementation issues

Effect of quantization error effects and sampling rate on PCA, ICA and other source separation algorithms. A rigorous approach is to study the general problem of "finite field signal processing", which refers to signal processing algorithms implemented on finite-length machines. The problem can also be related to the number of required quantization levels (and ADC number of bits). Mono-bit systems and binary operations (including binary matrix factorization) is a special case for this general framework.

Level: *PhD* **Duration:** *2y* **Impact:** *High* **Status:** ① **Impression:** Very nice and applied problem!

1.2.7 Oblique projection operators vs. ICA

ICA can be studied within *oblique projection* framework. Within this framework, issues such as singular mixtures and noise amplification/attenuation in noisy ICA algorithms can be studied and explained.

Level: *PhD⁻* **Duration:** *1y* **Impact:** *Medium* **Status:** Rather theoretical **Impression:**

1.2.8 Under-sampled BSS

Blind Source Separation of under-sampled data. This idea can be used for separating high-frequency sources (such as radar and UWB signals), by under-sampling the signals and using them in ICA. One might conclude that Nyquist rate sampling is not necessary for source separation. In other words, BSS algorithms may be able to retrieving the mixing matrix of aliased data; although the data itself might not be exactly retrieved.

Level: *PhD*$^{-}$ **Duration:** *6m* **Impact:** *Medium* **Status:** - **Impression:** A potentially practical problem

Chapter 2

Modeling

2.1 Biological Modeling

You can find many open-problems on biological signal and system modeling in my graduate course slides on *Biological System Modeling* and my publications. Refer to my courses webpage or contact me for further details. A few of these problems have been listed in this chapter.

2.1.1 Probabilistic fractal modeling

Fractal models have been used in various applications. However, real-world systems (such as biomedical systems) only show partial fractal properties. It is believed that by combining fractal models with probabilistic models such real-world applications can be better studied. An interesting application includes respiratory system modeling.

Level: *MS^{-}* **Duration:** *3m* **Impact:** *Low* **Status:** - **Impression:** Good for a course project

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2.1.2 Dynamic modeling of ECG & MCG signals

Dynamical models of Electrocardiogram (ECG) and Magnetocardiogram (MCG) signals have been developed in previous studies [13]. These models have various applications including synthetic generation of adult and fetal ECG/MCG signals [14, 15], denoising cardiac signals of adults and fetuses [16], compression of cardiac signals [17], and the detection of cardiac anomalies [18]. The problem is still open for further research, especially by adding biological system-level parameters (such as respiration and harmonic mechanisms), into the model, and abnormal beat modeling using Markov Chains (partially done in [15]).

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** Active **Impression:** Good for MS projects

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2.1.3 Morphological modeling of ECG

We worked on a generalized framework for morphological modeling of ECG signals in the MS thesis of Mr. Kheirati [19]. The problem is still open for research. My ultimate goal is to see if we can find a fully linear dynamical model for the ECG. Such a formulation can be useful for optimal ECG filtering as discussed in Section 3.1.3. I recently (Jan. 2015) found a nice formulation for this using B-Splines.

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** ② **Impression:** I personally enjoy this work!

2.1.4 Fourier-based model of the ECG

ECG modeling using Fourier series expansion, with some parameter deviations for tracking the signal variations in time. We partially did this in the MS thesis of Mr. Kheirati [19], and it's closely related to the problem described in Section 2.1.3.

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** ① **Impression:** -

2.1.5 Phonocardiogram modeling

We presented a novel adult/fetus PCG modeling framework in the MS thesis of Ms. Maryam Samienasab in Shiraz University. The work is a nice combination of morphological and stochastic process modeling using the innovation process. We later intend to incorporate this model in a PCG denoising system. Aspects of this problem are still open for research.

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** ① **Impression:** A very nice model!

2.1.6 Realistic EEG modeling

Realistic models for generating biosignals such as the EEG are very useful for forward and backward EEG modeling and analysis. We have done some partial work in this area in the MS thesis of Mr. Behnam Tavakol in Shiraz University. We developed a spatially distributed EEG model that generates synthetic EEG with realistic EEG spectra and inter-sensor spatial correlations. The problem is still open for further research.

Level: *MS* **Duration:** *6m* **Impact:** *Medium* **Status:** ① **Impression:** Has some future applications!

Chapter 3

Biomedical Signal Processing

3.1 Electro Magneto-Cardiography

3.1.1 Abnormal cardiac beat classification

In this research, the idea is to use the Kalman filtering framework developed in [16] for abnormal beat detection and classification. For this application, the *innovations signal* of the Kalman filter can be used as a measure of beat abnormality as compared with the average beat. Therefore, depending on the type of abnormality of interest, Hidden-Markov Models (HMMs) can be used as a probabilistic framework for detecting abnormal beats. The proposed tools would in fact be a processing block that follows the Kalman filtering framework that we previously developed in [20].

As a starting point, the premature ventricular contraction (PVC) can be used as a special case. For this case, the required parameters such as the beat morphologies and the transition probabilities (normal beat to normal beat, normal beat to abnormal beat, etc.) can be calculated from large databases and used as initial conditions for the detection block.

Due to the morphologic similarity of the ECG and the MCG, the same methods and tools can be exactly used for MCG signals.

In case of success for adult ECG/MCG signals, the same framework can be extended to fetuses for known abnormalities such as the Wolff-Parkinson-White syndrome (WPW). For this application, the detection block would follow the fetal ECG/MCG extraction units developed in [20], and might possibly require the tracking of fetal signals.

The MIT-BIH arrhythmia database [21], is suggested for the first step of the project (adult abnormalities). This database contains abnormal beat annotations, which can be directly used for calculating the required parameters and probabilities.

For fetal abnormalities, appropriate ECG or MCG databases are required (cf. [22] and other accessible datasets).

Level: *MS* **Duration:** *2y* **Impact:** *Medium* **Status:** Active **Impression:** Part of my continuous research

3.1.2 Nonlinear ECG filtering

Linear methods are very common in biomedical signal processing. Specifically, many linear methods have been used for ECG filtering and denoising with different performances [16]. These methods have been rather effective with well-defined theoretical basis. On the other hand, in [20], we found that, as compared with conventional linear methods, nonlinear filters such as the median filter are more effective for baseline wander removal. However, theoretical justification of the performance of nonlinear filters is commonly complicated; therefore the validation of these methods is usually *ad hoc*. In [23], a broad class of nonlinear filters has been studied in a theoretical framework. It seems that these aspects have not yet been considered or customized to the biomedical domain. In this research we intend to test and validate some of these methods for biomedical applications, especially for ECG denoising and filtering. This objective was partially accomplished in the MS thesis of Ms. Zahra Kheradpisheh in Shiraz University.

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** ① **Impression:** May result in better filters than the existing ones

3.1.3 Bayesian filtering of biological signals

We have already developed a Bayesian filtering framework for ECG filtering in [16]. This framework may be extended to Particle filters, PHD filters, H_∞ and other types of filters for biological signal modeling. This objective was partially accomplished in the MS thesis of Mr. Hadi Narimani in Shiraz University for ECG filtering using H_∞ filters.

Level: *PhD⁻* **Duration:** *1y* **Impact:** *Medium* **Status:** Active **Impression:** Part of my continuous research

3.1.4 Theoretical performance bounds for biological signal filtering

Biological signal filtering performance is bounded by the intrinsic uncertainties in these signals and observation noise. It should be possible to find theoretical performance bounds such as the Cramer-Rao lower bound (CRLB) for denoisers such as our ECG Kalman filter [16], or other filters. I have some ideas for this approach. Please contact me in case of interest.

Level: *PhD* **Duration:** *2y* **Impact:** *Medium* **Status:** - **Impression:** Very nice contribution

3.1.5 The cardiac phase signal

We introduced and utilized the *cardiac phase signal* in some of our previous works. It was initially introduced as a means of converting the ECG dynamics from the Cartesian to polar coordinates [24] and for ECG filtering using Kalman filters [16]; but we soon noticed that it has greater potentials for ECG phase-wrapping and semi-blind source separation using multichannel ECG [25]. I think that the phase signal has greater potentials for finding system-level properties of the heart and also optimal periodic filtering of the ECG. Some of these objectives were followed in the MS thesis of Mr. Bahman Vahabzadeh who studied ECG beat alignment and the linearity and time-warping of the cardiac phase signal in various heart-beats [26], and currently in the PhD thesis of Ms. Fahimeh Jamshidian on optimal ECG filtering, both in Shiraz University. I've also done some simulations using a time-varying (local in time) auto-correlation function for retieving the cardiac phase from real data. There seem to be many more applications for the cardiac signal. You can contact me for further details.

Level: *MS*, *PhD* **Duration:** *2y* **Impact:** *High* **Status:** ② **Impression:** I really enjoy this work

3.1.6 Multichannel clinical ECG features

Defining clinical indexes based on measures extracted by PCA and ICA. The measures can be evaluated on a large database. We have done some work in this area in [27, 20], the MS thesis of Mr. Sajad Niknam in Shiraz University, and a very applied research project that we are currently conducting with Dr. Mohammad-Hossein Nikoo from Shiraz Medical University.

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** ② **Impression:** Very applied and well-defined project

3.1.7 The ECG manifold

A study of the ECG geometric manifold, using its dynamical representation and possibly the KF framework for simplifying the ECG manifold. The problem is related to the vectorcardiogram (VCG) representation of the ECG, and may be later related to the concept of distributed component analysis described in Section 1.2.4.

Level: *PhD⁻* **Duration:** *6m* **Impact:** *Medium* **Status:** - **Impression:** Blind Source Separation

3.1.8 Heart rate variability and spectral analysis

The RR-interval time series is a non-uniformly samples signal. Therefore, conventional spectral estimation techniques based on Fourier analysis are not appropriate for such data [28]. In this context, the impact of R-wave detection approach on HRV time-series and its spectra are of interest. This problem may require a restudy or even redefinition of HRV. We partially addressed this problem in the MS thesis of Mr. Bahman Vahabzadeh in Shiraz University. Other aspects of this problem are open for research.

Level: *MS* **Duration:** *1y* **Impact:** *Medium* **Status:** ① **Impression:** Requires knowledge of nonuniform sampling theory.

3.1.9 Cepstral analysis of ECG signals

A rough signal model for the ECG is an impulse train (corresponding to the heart beat time-series) convolved with an average ECG morphology. Based on this model, I've done some work on the inverse problem of retrieving the average ECG morphology from a given ECG signal using the cepstrum transform. It's a small but mathematically interesting contribution, which might result in novel models or ECG processing methods. Please contact me in case of interest.

Level: *MS* **Duration:** *6m* **Impact:** *Medium* **Status:** ① **Impression:** Nice maths!

3.2 Fetal Cardiography

3.2.1 Fetal ECG/MCG tracking

For long fetal monitoring trials, the fetus may be in any position and can move during the data registration. In this research, the idea is to track (and correct) the morphological changes of the fetal ECG/MCG signals from multichannel recordings after pre-processing and maternal ECG/MCG interference removal [20]. Due to the correspondence between the fetal position and its cardiac signal morphology, the result of the tracking procedure can be used to monitor the movements of the fetus. One basic idea in this field, is to define the *standard* or *canonical* representation of the fetal ECG/MCG (e.g., as the first few principal or periodic components of the preprocessed fetal ECG/MCG signals). Due to the motions of the fetus, the canonical representation can change from one block of data to another (e.g. using 10s blocks). Therefore, we can model the rotations and movements of the fetus in terms of multiplicative rotation and/or scaling matrix, which alters the canonical representation of one block to another. The problem can be studied in two levels, either by using simple least square error estimation between the different time blocks (as proposed in [20, Ch. 7]), or by proposing a dynamic model, to model the temporal dynamics of the rotation angles of the fetus in time. Due to the rather slow and limited possible movements of the fetus, a first order auto-regressive model may be initially sufficient to model the fetal dynamics. The result of this study would be a signal that represents the angle of the fetus with respect to some reference position. This information can also be used to compensate the fetal movements and to find a canonical representation of the fetal cardiac signals in long monitoring sessions. A more interesting, but more sophisticated, problem is the tracking of multiple fetuses in multiple pregnancies. We have addressed this problem using online subspace tracking algorithms in the MS thesis of Ms. Marzieh Fatemi [29, 30], and currently in the MS thesis of Ms. Hadis Biglari and the PhD thesis of Ms. Fahimeh Jamshidian, using ECG and MCG signals. The problem is still open for further research from both methodological and applied aspects.

Level: *MS*, *PhD* **Duration:** *2y* **Impact:** *High* **Status:** ③ **Impression:** Very applied!

3.2.2 Fetal HRV analysis

The fetal ECG/MCG signals are relatively low in SNR (even after pre-processing and maternal interference cancellation). Hence, the detection of the fetal R-waves and the calculation of its HRV is not always straightforward. Therefore, an interesting topic for research is the problem of robust R-peak detection in low SNR scenarios. In this context, one idea is to use multichannel ECG/MCG recordings for R-peak detection, instead of the common single-channel approach. This idea would be a multichannel extension of the matched filter proposed in [20, Appendix 4]. The idea is also expendable to HRV analysis of more than one fetus in multiple pregnancies. The problem can also be related to the problem of fetal movements and morphological changes that we are currently working on in the MS thesis of Ms. Hadis Biglari. As a starting point, the proposed methods should be developed and tested for adult ECGs/MCGs. The research can be conducted and verified over real and simulated data using OSET [31].

Level: *MS* **Duration:** *1y* **Impact:** *High* **Status:** ① **Impression:** Very applied!

3.2.3 Fetal cardiac signal extraction benchmarking

After several decades of work on noninvasive fetal ECG extraction, benchmarking of the different signals extraction and processing algorithms is a necessity. The problem should be studied from two separate aspects: methods for heart rate extraction, and the methods for fetal ECG morphology extraction. In fact, although these two problems are fully related; but they are methodologically different in practice. Therefore, their benchmarking should also be done separately.

Level: *MS*, *PhD* **Duration:** *2y* **Impact:** *High* **Status:** ① **Impression:** A very useful and practical problem!

3.2.4 ECG channel selection

In multichannel adult/fetal ECG recording systems, it is difficult to guarantee a persistent signal quality over all channels in long recording sessions. Therefore, some sort of online channel selection or data fusion is required between all or groups of channels. We have partially addressed this problem in the MS thesis of Mr. Sajad Niknam and a proprietary work that I've personally done for a company.

Level: *MS*, *PhD* **Duration:** *1y* **Impact:** *High* **Status:** ② **Impression:** A very nice and applied research.

3.2.5 Abnormal fetal ECG/MCG classification

Fetal ECG/MCG extraction methods and tools are rather mature now. In this research, the objective is to focus on the detection and classification of fetal ECG anomalies. I have some ideas for this problem as discussed in Section 3.1.1, plus other fetal-specific techniques. The problem can be addressed at various levels and from different aspects.

Level: *MS*, *PhD*$^-$, *PhD* **Duration:** *2y* **Impact:** *High* **Status:** - **Impression:** Very practical

3.3 Electro Magneto-Encephalography

3.3.1 Fetal EEG/MEG analysis

The extraction of fetal EEG and MEG signals from noninvasive abdominal recordings is a very interesting and promising direction of research. We have addressed this challenging issue in several research including [32, 33, 34], and the MS thesis of Ms. Fatemeh Razavipour [35]. One of the major and challenging issues is the validation procedure of any proposed technique [35].The problem is still open for research from various aspects.

Level: *MS*, *PhD* **Duration:** *2y* **Impact:** *High* **Status:** ② **Impression:** Very practical and interesting

3.3.2 EEG-based seizure detection

On the occasion of the Kaggle seizure prediction challenge (`https://www.kaggle.com/c/seizure-prediction`), I found a chance to work on seizure data and develop dozens of methods and functions for pre-processing and processing EEG signals for seizure detection and prediction. I am interested in posting my codes online and extending this research.

Level: *MS* **Duration:** *1y* **Impact:** *High* **Status:** ① **Impression:** A personal interest!

3.3.3 Brain dipole tracking

In this project, the tracking of brain dipoles using the Kalman filter and the inter-channel phase information of the EEG is of interest. Please contact me in case of interest.

Level: *MS* **Duration:** *2y* **Impact:** *High* **Status:** ① **Impression:** Well-defined and nice problem!

3.3.4 EEG phase analysis

The definition of the EEG phase and its synchrony has been the subject of numerous research. We have done some work in this area in the MS thesis of Ms. Fatemeh Razavipour [], and recently the MS thesis of Mr. Esmaiel Seraj in Shiraz University. The problem has various applications in ERP detection and the tracking of EEG phase coupling in different frequencies for estimation of anesthesia depth (related to Dr. Behnam Molaee's PhD thesis).

Level: *MS*, *PhD* **Duration:** *2y* **Impact:** *High* **Status:** ② **Impression:** Nice topic!

3.3.5 EEG frequency tracking

Tracking the average EEG frequency in time has various applications, including the detection of anesthesia depth. We did some work in this area in the time-frequency course project of Mr. Amirreza Lashkari using time-frequency transforms. The problem is still open for research using classical tracking algorithms and may lead into new devices for EEG-based detection of depth of anesthesia.

Level: *PhD^{-}* **Duration:** *6m* **Impact:** *Medium* **Status:** ① **Impression:** Applied!

Part II

Development

Chapter 4

Hardware

4.1 Biomedical Instruments

4.1.1 Portable fetal ECG monitor

Level: *PhD*$^{-}$ **Duration:** *6m* **Impact:** *Medium* **Status:** ① **Impression:** Blind Source Separation

4.2 Telecommunications

4.2.1 On-campus GSM network

Use Raspberry-Pi, USDP and OpenBTS for this project

Chapter 5

Software

5.1 Biomedical

5.1.1 Open-source electro-physiological toolbox (OSET)

Our Open-source electro-physiological toolbox (OSET) has been active for some years now [31]. We currently need collaborators for documentation, web design and maintenance of OSET. Please contact me in case of interest.

Level: *BS*$^-$, *BS*, *MS*$^-$ **Duration:** *1y* **Impact:** *High* **Status:** ② **Impression:** A necessity!

5.1.2 Biomedical signal processing benchmarking

A website for benchmarking different biosignal processing algorithms in terms of performance, speed, complexity, etc. Please contact me in case of interest.

Level: *MS* **Duration:** *1y* **Impact:** *High* **Status:** ① **Impression:** Very useful

5.1.3 Online biomedical signal processing

Customization of some of our existing algorithms for real-time processing and denoising, which can be integrated in embedded systems. This includes, the implementation of the developed methods in C++ and Java (for machine independence).

Level: *BS*, *MS*$^-$, *MS* **Duration:** *6m* **Impact:** *Medium* **Status:** ③ **Impression:** Useful

5.1.4 Biomedical signal processing for mobile systems

The implementation of our developed methods on embedded systems, mini PCs, Android, and iOS is very useful for industry. We have partially and continuously been doing this in Shiraz University; but the problem requires a dedicated engineering team to work on it. Please contact me in case of interest.

Level: *BS*, *MS*$^-$, *MS* **Duration:** *2y* **Impact:** *High* **Status:** ③ **Impression:** Very applied

Chapter 6

Computer Architecture

6.1 Digital Algorithm Design

6.1.1 Variable-length median filter implementation on FPGA

Done by Mr. Eesa Nikahd and Mr. Payman Behnam in Shiraz University

6.1.2 Hardware-efficient sliding DFT implementation on FPGA

6.1.3 Automatic gain control on FPGA

Done by myself!

6.1.4 Hardware-efficient pulse detection on FPGA

Done by myself!

6.1.5 Digital instantaneous frequency measurement

Done by myself!

6.1.6 Unstable feedback for making accurate clock oscillators on FPGA

6.1.7 Finite-state automata on FPGA

6.1.8 A tool for generating customized standard RISC CPU on FPGA

In Matlab, Java, etc. Something like Xilinx Microblaze

6.1.9 An FPGA-based linear algebra toolbox

Comparison and benchmarking of this toolbox on MicroBlaze, GPU and FPGA with standard toolboxes such as LAPACK and PC-based. Currently the MS thesis of Mr. Mohammad-Ali Abbasi and Roohollah Mohammadzadeh.

6.1.10 FPGA-based analog components

Building FPGA-based elements with analog characteristics. For instance making a filter, PLL, oscillators (e.g., using unstable feedback loops to generate limit cycles), etc. using digital control theories and FPGA primitive components. Altera and Lattice Semiconductor have also made ADCs using the analog front-ends of their FPGAs.

6.1.11 Parametric implementation of spread-spectrum on FPGA

6.1.12 FPGA-based Kalman filter

Comparing Mealy and Moore state machines with state-space representations in signal processing context and implementing a Kalman filter on FPGA

6.1.13 Extended CORDIC machines

The objective is to extend CORDIC-like architectures for merely any arbitrary nonlinear transform, using shift and add operators. I have some good ideas for this problem.

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