# Singular Spectral Analysis on Doppler Ultrasound Records Acquired from Healthy Subjects and Intrinsic Sphincter Deficiency Subjects

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***Abstract*** **- Stress Urinary Incontinence is a common form of women urinary incontinence and has some surgical therapeutic methods. The quality of surgery merely depends on the quality of diagnosis. Before deciding a surgery type, urodynamic testing is applied. Since urodynamic testing is invasive, and difficult to apply, many subjects do not seek therapy. A non-invasive method can encourage more subjects for searching a remedy. At this point, Doppler ultrasound can be a good choice. In this study, we have demonstrated that the blood flow characteristics of healthy subjects and intrinsic sphincter deficiency type stress urinary incontinence subjects have different characteristics and can be classified by using Doppler ultrasound recording.**

***Keywords*** **-** ***intrinsic sphincter deficiency; Doppler ultrasound; singular spectral analysis,emprical mode decomposition***

## I. INTRODUCTION

**U**rinary **I**ncontinence (UI) is a common disorder [1]. It negatively affects the lifestyle of women, although it is not fatal [2].

UI has four basic types; namely **S**tress **U**rinary **I**ncontinence (SUI), Urge Incontinence, mixed incontinence, and overflow incontinence. Each of them has different grounds and needs a different method of handling. SUI is described as the involuntary leakage of urine under stress conditions like coughing, sneezing, laughing. For only SUI, there are some therapeutic surgeries [3].

The **I**nternational **C**onsultation on **I**ncontinence (ICI) set a series of guidelines for the diagnosis of urinary incontinence [4]. The first step is taking the history of the patient followed by physical examination [5]. For SUI suspected cases, the stress test is applied. In this procedure, the patient who is under the stress condition is examined whether there is any leakage or not.

If surgery is needed, urodynamic methods are involved to decide the appropriate surgical method. Pressure profiles, water-filling cystometry, electrophysiological studies, **P**ostvoid **R**esidual (PVR) measurement, urodynamic testing, cystogram are some examples of diagnostic methods. These methods very helpful but they are invasive.

Invasive methods like urodynamic methods are more successful but less comfortable for patients. Therefore, a new method that is non-invasive will encourage subjects who are suffering from SUI is a necessity. In this point ultrasonography can be an alternative method because of its noninvasive nature. Perineal ultrasound is applied in some studies [6] [7] [8]. In these studies, some parameters of blood flow dynamics and some angles, orientations and distances on ultrasound image are used. Unfortunately, these methods have low accuracy.

In urodynamic testing, **A**bdominal **L**eak **P**oint **P**ressure (ALPP) is measured for deciding a surgery type. If it is less than 60 $cmH_2O$, then it is called **I**ntrinsic **S**phincter **D**eficiency (ISD). If ALPP is greater than 90 $cmH_2O$, it is named as **U**rethral **H**yper **M**obility (UHM). The ones who have ALPP value between 60 and 90 $mH_2O$ are called as mid - type. ALPP is also high for continent subjects.

Since the ground of SUI is the physical changes in the anatomy of the pelvic system, it is natural to expect some changes in the blood flow characteristics of SUI subjects. In our previous study, power spectral density of healthy subjects and SUI subjects

 ISBN: 978-1-61208-137-3

are used for classification [9]. In this study, it is aimed to differentiate healthy subjects and ISD type SUI subjects by analyzing Doppler ultrasound records. Nonlinear analysis was successfully applied for Doppler signals in some studies [10].

In this study, **E**mpirical **M**ode **D**ecomposition (EMD) is used to estimate **I**ntrinsic **M**ode **F**unctions (IMF) first, and then **S**ingular **S**pectral **A**nalysis (SSA) of each IMF is calculated. Features extracted from SSA result are used for classification of healthy subjects and ISD subjects.

This article is prepared as follows. In section II, materials used in this study and the methods for classification of healthy subjects and ISD subjects are given. The results of the study are given in section III. In section IV, the discussion and conclusion of the study are given.

## II. MATERIALS AND METHODS

### A. Subjects

Doppler ultrasound signals were recorded from GE Logiq 9 Doppler Ultrasound Unit in the Radiology Department of Haseki Training and Research Hospital, Istanbul, Turkey. Output of Doppler Ultrasound unit was connected to an Olympus LS-10 Digital Voice Recorder, thatstores data in (.wav) format. Recorded signals then transferred to a Laptop where the signal processing and classification processes were performed. The MATLAB® program is used at the signal processing and the classification steps. The study was approved by the ethic committee of Haseki Training and Research Hospital, and informed consent was given by the participating subjects.

A perineal ultrasound probe (7.5 MHz) was used to transmit pulsed Doppler ultrasound signals to the urethral artery. The reflected signals were recorded by the digital sound recorder. These signals give Doppler shift frequencies for healthy and ISD subjects. During recording, the insonation angle and the presetting of the ultrasound were kept constant. This angle was tuned via electronic steering methods to keep at 45° on a longitudinal view and the sampling volume was placed within the center of the artery. The audio output of the Doppler ultrasound was recorded at 44100 Hz, 16 bits, in a stereo channel format. The graphical illustration of data recording scheme is given in Figure 1.

Urethral arterial signals were recorded from 16 ISD patients and 18 healthy volunteers. Patients were clinically tested and proved to be ISD by urodynamic testing. SUI subjects are between 37 and 56 years old (average is 49). Control group was formed from young volunteers whose age is between 38 and 55, with an average of 46.

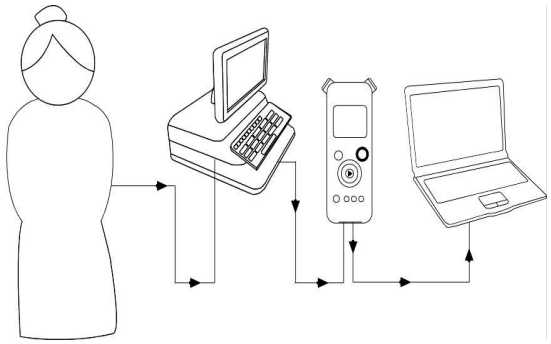

Figure 1. The data recording scheme illustration

### B. Data Analysis

#### B.1. Empirical Mode Decomposition

The empirical mode decomposition (EMD) was proposed by Huang et al., [11]. It is a numerical model to decompose the signal into a finite number of IMF. The IMF function must satisfy two conditions:

(a) The number of the zero crossings and the number of extreme must be either equal or differ by one.

(b) The mean value of the local minima and maxima envelope of the function must be zero.

Once the first IMF is obtained, the restingportion can also include more IMFs. The remaining data can be further decomposed successively to get other IMFs by utilizing EMD.

In the representation of signals in IMF forms, the lower order IMFs hold fast oscillating components. Similarly, higher order IMFs represent slow oscillations.

#### B.2. Singular Spectrum Analysis

Singular Spectrum Analysis (SSA) is a power time series analysis technique. It is a nonparametric spectral estimation method that is based on embedding a time series $X(t):t=1..N$ in a vector space having M dimension. Here, the time series assumed to be stationary.

SSA is suitable for extracting meaningful information from noisy time series. For the assumption of being stationary, the time series must

 ISBN: 978-1-61208-137-3 

have a short duration. It performs an eigen decomposition of the lagged covariance matrix, that is constructed from the time series.

SSA approach is an effective tool for nonlinear analysis and has an important advantage over other time series analysis techniques; it does not need any priory information.

## III. RESULTS

The classification features are extracted from SSA calculation of IMFs. First three IMF of Doppler ultrasound signals recorded from healthy subjects and ISD subjects are extracted, firstly. Then SSA is applied for each IMF and covariance matrix (M=10) is calculated. From the covariance matrix, Eigen values are calculated.

In Figure 2, EMD view of one subject is given. The top three are the first, second, and third IMFs of Doppler ultrasound record of the subject. The last plot is the residue of EMD.

In Table 1, the data used for classifications of healthy subjects and ISD subjects. In this study, 16 ISD subjects and 18 healthy (continent) subjects are used. Healthy subjects are called as CONT.

The classification parameters (features) are given at the second and third columns of Table 1. The explanation of the classification parameters extracted from SSA of IMFs.

$$\text{AreaRatio1} = Area1 / Area2 \quad (1)$$

$$\text{AreaRatio2} = Area2 / Area3 \quad (2)$$

Where

AreaRatio1 and AreaRatio2 are classification features. Here Area1 is the sum of Eigen values for IMF1. Similarly, Area2 and Area3 are the sum of Eigen values for IMF2 and IMF3, respectively.

In the Figure 3, scatter plot of classification parameters is given. The difference between two classes is seen clearly in this illustration. When considering the class centers, these classes are separated definitely. There are some members of ISD and CONT classes very close to each other, so the separation is difficult by pattern recognition techniques.

TABLE 1. Features used for Classification

| Subject Name | AreaRatio1 (IMF1/IMF2) | AreaRatio2 (IMF2/IMF3) |
|---|---|---|
| ISD01 | 1.61 | 1.93 |
| ISD02 | 1.06 | 1.74 |
| ISD03 | 1.05 | 1.67 |
| ISD04 | 3.32 | 1.66 |
| ISD05 | 1.44 | 1.57 |
| ISD06 | 1.90 | 1.55 |
| ISD07 | 0.94 | 1.23 |
| ISD08 | 1.21 | 1.18 |
| ISD09 | 0.66 | 1.13 |
| ISD10 | 0.70 | 1.11 |
| ISD11 | 0.44 | 1.09 |
| ISD12 | 0.82 | 1.07 |
| ISD13 | 1.00 | 1.00 |
| ISD14 | 1.18 | 0.97 |
| ISD15 | 0.48 | 0.85 |
| ISD16 | 0.27 | 0.82 |
| CONT01 | 0.63 | 0.97 |
| CONT02 | 0.96 | 0.92 |
| CONT03 | 0.60 | 0.90 |
| CONT04 | 0.66 | 0.79 |
| CONT05 | 0.77 | 0.76 |
| CONT06 | 1.14 | 0.72 |
| CONT07 | 0.50 | 0.71 |
| CONT08 | 0.14 | 0.60 |
| CONT09 | 0.24 | 0.59 |
| CONT10 | 1.91 | 0.52 |
| CONT11 | 0.15 | 0.45 |
| CONT12 | 1.10 | 0.44 |
| CONT13 | 0.00 | 0.39 |
| CONT14 | 1.30 | 0.35 |
| CONT15 | 1.86 | 0.28 |
| CONT16 | 0.86 | 0.19 |
| CONT17 | 0.61 | 0.19 |
| CONT18 | 2.39 | 0.01 |

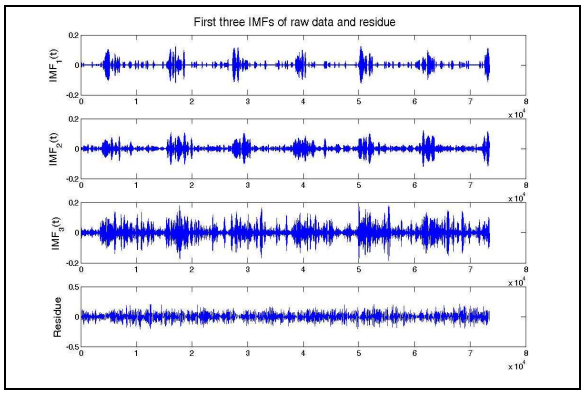


Figure 2. Empirical mode Decomposition (EMD) of one subjects

 ISBN: 978-1-61208-137-3

## IV. DISCUSSION AND CONGLUSION

In this study, healthy (continent) and ISD type SUI subjects are classified by using Doppler ultrasound records.

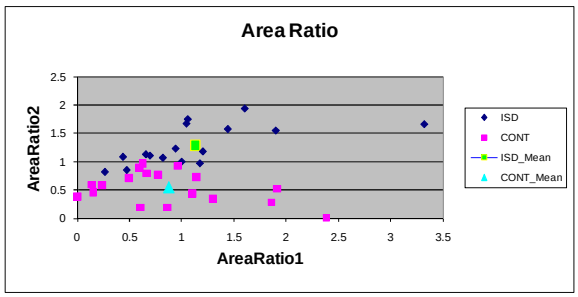


Figure 3. Scatter of features of ISD and healthy (continent) subjects

*ISD: Subjects having ISD disorder*

*CONT: Healthy (continent) subjects*

*ISD_Mean: Average of ISD subjects*

*CONT_Mean: Average of healthy subjects*

In the first step, signal is divided into IMFs by using empirical mode decomposition. Then Singular Spectrum Analysis (SSA) is applied to each IMF. Then the area ratios of SSA of IMFs are calculated as the feature for classification.

When the scatter plot of classification parameters given in Figure 3 is analyzed, AreaRatio2 values of ISD subjects are generally higher than that of healthy subjects. It means that the ratio between IMF2 and IMF3 of ISD subjects shows the greater difference when compared with healthy subjects. This is actually theoretically expected. In ISD subjects, since the sphincter muscles loose their contractility, the blood flow of the urethral artery should be more laminar than healthy subjects. In this type flow, the Eigen values should be concentrated in a few IMFs. In other words, the area ratios of more laminar flows are higher than more complex flows. This is proven in this study.

SUI is the result of physical deformation on the continence supporting system. It is natural to expect some changes in the blood flow dynamics of urethral artery that feeds the pelvic region. In this study, we have demonstrated that healthy subjects and ISD type SUI subjects can be classified by using Doppler ultrasound records of subjects.

The noninvasive nature of Doppler ultrasound makes it a suitable candidate for diagnosis of SUI. The gold standard method used in diagnosis of the disorder is invasive urodynamic testing that prevents many subjects from seeking a remedy. Method proposed in this study can be a good alternative for urodynamic testing.

In future studies, the discrimination of subtypes of SUI subjects (UHM or ISD types) will be tried by using Doppler ultrasound records of urethral artery.

## ACKNOWLEDGEMENT

This work is supported by the Scientific Research Fund of Fatih University under the project number P50060901-2.

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 ISBN: 978-1-61208-137-3 