Assessment of menstrual cycle and behavioral changes using digital speech processing techniques

Dr. Kavita Thakur[1] , Mohana Roy Chowdhury[2], Dr. Anjali Deshpande[3] Dr. A.S. Zadgaonkar[4]

Abstract-It has been observed that speech can prove to be an important tool for the diagnosis of various physiological parameters. Early use of phonetics in the field of medical study has been reported in 1911 by H. Gutman. With the rapid progress of technology, such techniques are emerging as alternative non-invasive diagnostic tools. Since the onset of menstrual cycle plays a very significant role in the transition of an adolescent female into an adult, it is important to study and monitor the physiological and psychological changes that occur during the cycle. In this work Formant frequency analysis has been carried out, since Formant frequency represent the intricate features of human body. The current techniques used for the diagnosis of hormonal changes are invasive, expensive and require sophisticated laboratory setup, besides being time consuming. In this experiment, we have attempted to study the changes that take place in the quality of speech during the menstrual cycle, with the intention of detecting the hormonal and behavioral changes that occur at the different stages. Further improvement of such techniques should aid in the early diagnosis of fertility based disorders. This method, apart from being non invasive, required no sophisticated laboratory set up, and thus can be used for the diagnosis in rural areas that lack infrastructure.

I. INTRODUCTION

The onset of menstrual cycle marks a very significant phase in the life of a female. It denotes the beginning of a series of physiological and psychological changes that will prepare the body for fertilization and growth and development of the foetus. A regular menstruation is an indicative of the fertility of a woman.

In spite of importance of menstrual cycle in the health of a female, most of the techniques that are currently used to determine the gynecological health of a woman are invasive, expensive, time consuming and require a proper laboratory set up. Monitoring of this cycle is of utmost importance for the detection of diseases like Polycystic Ovarian Syndrome (PCOS), Endometriosis etc. In this study, we have related the changes in speech formants with the different stages of the menstrual cycle. The development of speech processing techniques for the assessment of menstrual cycle can provide a non invasive, cheaper and faster method for the assessment and diagnosis of the physiological condition and also relate to the behavioral changes during the menstrual cycle. Further this method can be developed and implemented in rural areas where provisions of laboratory setups are unavailable.

1.1 IMPORTANCE OF SPEECH:

Speech is a vocalized form of human communication. It is based upon the combination of lexical and names that are drawn from very large vocabularies. Each uttered work is a phonetic combination of a limited set of vowel and consonant sound units. Speech, in its functional setting is a tool for transmitting thoughts, attitudes, emotions and many such informative things that are yet unknown. The air we breathe, the air we talk is much more than simply external air, it consists of inside air as well.

The speech produced by a human depends on many factors including posture. Hence, it can be said that a human speaks with his breathing apparatus, body muscles and his head. The physical efforts accompanied by the vocal efforts lead to the production of speech. Indian mythology has also indicated that speech has different body centers of generation and has the roots of characteristics of their body behavior as phonetic information.

Speech is a very important mode of human communication. Human beings express themselves using visual, audible and tactual signals. However the process of transmission and reception of signals only does not constitute communication. After perceiving the signal, the receiver has the potential to select only particular responses.

The theory of communication is partly concerned with the measurement of information content of signals, as their essential property or potential of the signals, and as a concept is closely related to the idea of selection and discrimination [1].

Variations in speech between individuals lead to difficulties in defining, standardizing and specifying utterances.

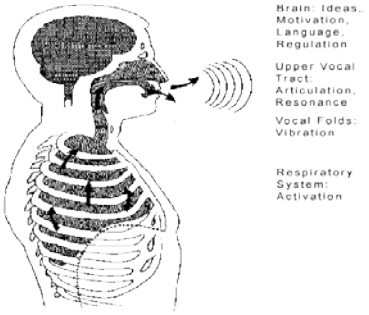

Fig 1.1: organs of speech

1.1 THE MENSTRUAL CYCLE

The monthly cycle of changes in the ovaries and the lining of the uterus (endometrium), starting with the preparation of an egg for fertilization constitute the menstrual cycle. When the follicle of the prepared egg in the ovary breaks, it is released for fertilization and ovulation occurs. Unless pregnancy occurs, the cycle ends with the shedding of part of the endometrium, which is menstruation. There are two prominent cycles:

a)Ovarian cycle: The average ovarian cycle lasts for 28 days, and is interrupted only by pregnancy. Final termination of ovarian cycle is cause on the onset of menopause. It can be further subdivided into two phases,

-Follicular phase- Granulosa cells of some primary follicles proliferate and the oocyte inside each follicle enlarges. Oestrogen secretion increases along with rapid follicular growth. One follicle matures about 14 days after the onset of follicular development. During ovulation, the wall of the Graffian follicle ruptures and the oocyte is permitted to enter the uterine tube. LH surge acts as a trigger.

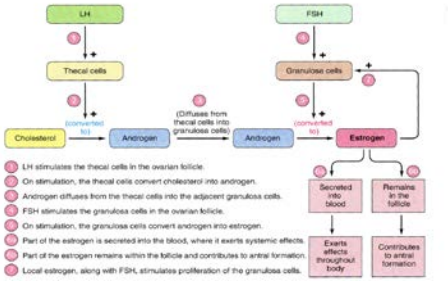

Fig 1.2: follicular phase

-Luteal phase- Last 14 days of the ovarian cycle constitute the luteal phase. Old follicles undergo structural transformation to form corpus luteum which degenerates within about 14 days after formation in absence of fertilization. LH causes development of corpus luteum from empty Graffian follicles.

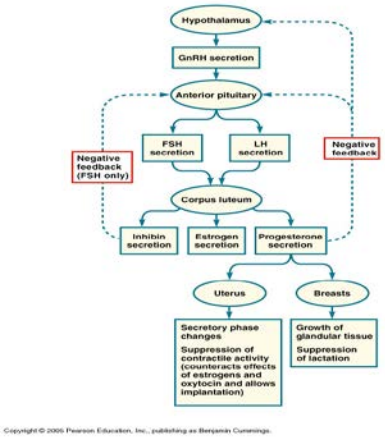

Fig 1.3: luteal phase

a) Uterine cycle: It reflects the hormonal changes during the ovarian cycle. It consists of three phases,

-Menstrual phase: Characterized by discharge of blood and endometrial debris from vagina. First day of menstruation coincides with end of ovarian luteal phase and onset of follicular phase. It is triggered by decreased oestrogen and progesterone.
-Proliferative phase: Begins concurrent with last portion of ovarian follicular phase. The uterus prepares for fertilized ovum and the endometrium starts to repair itself and proliferate under the influence of oestrogen from newly-growing follicles. Peak oestrogen levels trigger LH surge.
-Secretory phase: This phase is promoted by progesterone and the endometrium is prepared for implantation. New corpus luteum is formed which secretes large amounts of progesterone and oestrogen. The endometrial glands actively secrete glycogen and if fertilization and implantation do not occur, corpus luteum degenerates and new follicular phase and menstrual phase begin.

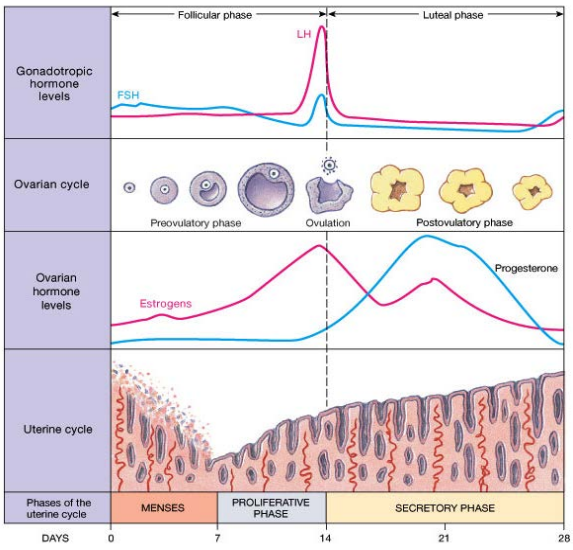

Figure 1.4: the menstrual cycle

II. REVIEW OF LITERATURE

SIGNIFICANCE OF FORMANTS:Speakers possess the anatomical structures for speech movement, but at the same time they must have function motor capability needed to achieve the complex movement as per the speech pattern. A general rule in acoustic-articulatory relationship is that F1 frequency varies inversely with tongue height and F2 frequency or the difference between F2 and F1, varies inversely with tongue advancement [4]. F2 variation generally corresponds to the front/back position of the tongue in articulatory terms.

It has been observed that status of a woman from the level of menstrual cycle to the various stages of pregnancy can be studied using various phonetic parameters [1]. It has been known that the uterus, during the menstrual cycle, undergoes a change in length, width, thickness etc. Hence changes in formant frequency may be observed reflecting the above uterus change during menstrual cycle [2].

It is known from the acoustical theory of speech that formant frequencies F1 and F2 are mostly affected by the opening of this cavity and they also reflect weight gain of this volume. F3 is indicative of the change in length of the resonating cavity. F4, F5 is a measure of changes in width, thickness of changes in cavity [2].

INFLUENCE OF MENSTRUAL CYCLE ON SPEECH**:** Speech movements seem to rely mainly on cortical and neuromuscular processing and control, to place sounds within the pattern, context, and stress of utterances [3]. The left cerebral hemisphere is predominantly responsible for speech functions as far as linguistic, phonemic, and lexical structures are concerned. Similarly, the right hemisphere has been associated with emotional intonation, stability of fundamental frequency, and duration of sentences [3].

The acoustic properties of frequency, amplitude, and length of verbal utterances provide information about the development of organs, speech motor control [5], and the context of expression [6]. The available studies on the effects of hormones on peripheral processes used for vocal emission focus mainly on the larynx, whose morphology, histology, and function are affected by sex hormones[7]. It has been pointed out that fine motor control, fluency, mood, aggressiveness, behavior, concentration, mental alertness, and well-being in women are influenced by the secondary effects of estrogen [8-10]. In females, a slight voice change occurs at the ages of 13 and14, and speaking voice lowers its pitch, as a result of the hormones released by the pituitary gland, suprarenal cortex, and ovaries. After the change to a singing voice, between the ages of 16 and 17, the final maturation of voice patterns extends for 6–12 months [7,9]. During reproductive years, fluctuations in hormone levels can also reduce verbal efficiency and cause temporary lowering of the voice in the premenstrual phase.

EFFECT OF EMOTIONS ON SPEECH: The emotional state of the speaker is reflected in his or her vocal utterances. Listeners are aware of this and they are able to recognize emotional states based on vocal cues alone. Voice quality is primarily associated with the spectral qualities of speech signal [12, 13].

Analysis of emotional state using speech can be aided by the help of the vowel triangle. Vowels show a pattern called vowel triangle where the i, a and u have extreme F1-F2 values and most vowels have formant values lying close to one of the sides on the triangle in the |i|-|a| axis for the front vowels and the |u|-|a| axis for the back vowels. An analysis showed that different emotions indeed differ in the size of their vocalic triangle [11]. In particular, emotions that score high on the dimension potency/control have a larger vocalic triangle than emotions that are low on potency/control [14, 15].

Investigations have showed that emotion has a sizable influence on formant positioning. The mean of F1 of all three vowels /a/, /i/, and /u/ is higher for high aroused emotions and lower for low aroused emotions [11]. In addition, high aroused emotions

have a significantly lower F2 for /a/. These effects confirm the important role of arousal in the vocal expression of emotion. Formant positioning is also significantly affected by the valence dimension. Positive emotions have a higher mean F2 than negative emotions. This holds for all vowels, although the effect is only significant in /a/ and /u/ [11].

III BIOLOGICAL FOUNDATION OF SPEECH

Human speech is produced by vocal organs presented in Fig 3.1. The main energy source is the lungs with the diaphragm. When speaking, the air flow is forced through the glottis between the vocal cords and the larynx to the three main cavities of the vocal tract, the pharynx and the oral and nasal cavities. From the oral and nasal cavities the air flow exits through the nose and mouth, respectively. The V-shaped opening between the vocal cords, called the glottis, is the most important sound source in the vocal system. The vocal cords may act in several different ways during speech. The most important function is to modulate the air flow by rapidly opening and closing, causing buzzing sound from which vowels and voiced consonants are produced. The entire process can be described as follows.

SPEECH PRODUCTION: Speech production is related to a number of very important physiological issues, and for that reason, this activity is studied under the following headings:

Discrete articulatory events:There is a controversy regarding the discreteness of the events that lead to the flow of speech. Current research in this direction has been unable to suggest diving marks between speech sounds in the waveform, and hence it might have been an artifact of perception. Lack of phonetic discreetness would make it difficult for linguists to make phonetic transcriptions of languages of illiterate societies, especially when the linguist is not acquainted with the language himself. However, forms of display such as sound spectrography have indicated clear discontinuities indicating that there are events with definable beginnings and endings. When a muscle contracts, there is a dramatic increase in electrical potentials. When we think of the entire musculature of the speech apparatus in activity, we realize that there is a constant change in states of contraction throughout these muscles.

Rate of articulation: The rate of articulation is an indication of how fast a person speaks. It has been observed that for utterances above a certain length, those who speak English have a constant rate of 210 to 220 syllables per minute including hesitation pauses. [17, 18]. Higher rates indicate shorter utterances.

Ordering of articulatory events: There are many articulatory events or motor events that leave no trace on spectrograms. Before the onset of phonation, muscles in the abdominal and and thoracic wall and in the larynx have to assume certain positions. Also during the silent periods that appear as short blanks in the spectrograms a large number of movements occur, particularly by the tongue. It is very doubtful that the entire bronchial physiology is adjusted to the timing requirements of speaking, but even if it was so, we have to postulate a high degree of neurophysiological specialization due to speech as is necessary for the other postulation.

PRODUCTIVE MECHANISM: Sounds are essentially vibrations whose main characteristics are frequency, intensity, and duration which activate the sensory mechanisms of hearing when received by the ears. The anatomy of the vocal apparatus consists of five cavities (Fig 3.1), the oral, nasal, pharyngeal, pulmonic, and oesophageal cavities. Velic closures terminate the oral and nasal cavities, the glottal and oesophageal cavities are contained within the pharyngeal cavity. There are three major air stream mechanisms- Pulmonic, Pharyngeal, and Oral air stream mechanisms.

a) **Pulmonic air stream mechanism:** The mechanism includes pressing the lung air outward through the pharynx followed by the mouth or nose. The lungs initiate the process.
b) **Pharyngeal air stream mechanism:** The larynx with glottis closed nay be thrust upward compressing the air beyond it.
c) **Oral air stream mechanism:** The posterior portion of the tongue may thrust forward while maintaining contact with the velum, compressing any tongue air caught between it and some structure in front of it, for instance the tongue tip or the lips. If an escape route is provided, an air stream is produced.

PRODUCTION OF VOICE:

a) Motors: These include the lungs, the bronchial tubes, the ribs, and the muscles. These are essentially pumps that compress air.

b) Vibrators: The compressed air is expelled through the trachea into the larynx which consists of the main vibrating unit. The air pushing against and between the vocal folds cause vibrations resulting into sounds. The quality of sound produced depend upon the muscles that control tension and length of the folds.

c) Resonators: Since the sound produced in the larynx is weak, it is resonated by the resonators. These include the upper part of the vestibule, the pharynx, and the mouth. Changes in the shape and size of resonators result in different tone qualities that constitute vowel sounds.

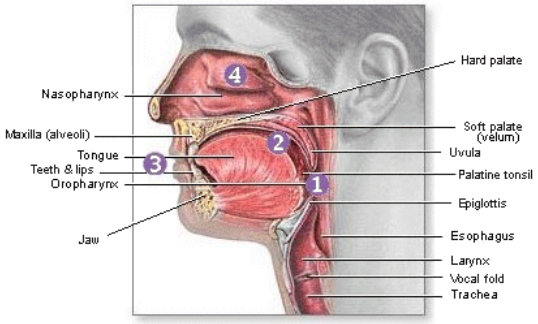

Fig 3.1: organs involved in speech production

3.4 THE ARTICULATORY MECHANISM:

The tongues, lips, teeth, hard and soft palates act as articulators. Their movement alters the shape of the mouth, thus affecting the quality of tone, as well as produce consonants.

3.5 ACOUSTICAL PARAMETERS OF SPEECH SOUND:

- **a) Frequency:** It refers to the number of sound waves per second produced by the vibration of vocal folds.
- **b) Amplitude:** It refers to the extent of displacement of vocal folds.
- **c) Time:** It refers to the duration of speech sound.
- **d) Energy:** The sound produced ultimately depends on the energy with which the exhaled air is propelled from the lungs to the external atmosphere.

3.5.1 FORMANTS:

The human vocal tract exhibits four or more major resonances, collectively known as “formants”. Formants are defined as the spectral peaks of sound spectrum |P(f)| of the voice [16]. In speech science and phonetics, **formant** is also used to mean an acoustic resonance of the human vocal tract [13,14]. It is often measured as an amplitude peak in the frequency spectrum of the sound, using a spectrogram as shown in the figure 3.2.

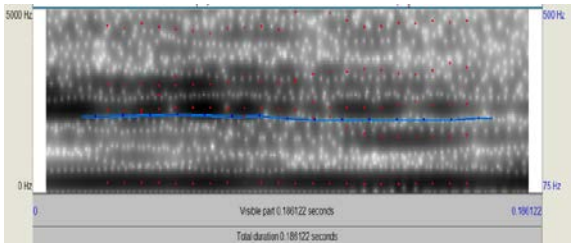

Fig 3.2: spectogram using praat

In the absence of formants, the spectrum envelope of the voice spectrum lacks abrupt peaks. Formants create peaks at specific frequencies.

Formants are essentially frequency information specific and have the characteristics of speech sound. The centre frequency and bandwidth change during dynamic speech. The fundamental frequencies are decided by the shape of the vocal tract and each formant can be associated with a standing wave. The table below shows the first three formant frequencies in hertz for English vowels, in male and female speakers.

Formant	gender	I	I	Ɛ	æ	a	ɔ	ʊ	u	ʌ	ɝ
F1	male	270	350	530	660	730	570	440	300	640	490
	female	310	430	610	860	850	590	470	370	760	550
F2	m	22	1	1	1	1	8	1	8	7	5

	male	90	950	840	720	090	40	020	70	60	00
	female	2790	2480	2330	2050	1220	920	1160	950	1400	1640
F3	male	3010	2550	2480	2410	2440	2440	2240	2240	2390	1690
	female	3310	3070	2990	2850	2810	2710	2680	2670	2780	1960

Table 3.1: first three formants for english vowels, for male and female speakers

As indicated by the table, the most significant factor that is used for distinguishing between male and female speakers is the difference in frequency. The fundamental frequency for females lies in the range of 150 to 300Hz whereas for males it remains around 85 to 180Hz. The energy source for voice generator for males is larger due to physical structure. The intensity of voiced speech generated by a female is about 6dB less than the voiced speech of a male in identical conditions.

IV.MATERIALS AND METHODOLOGY

MATERIALS:

a. **Voice samples:** Voice samples were collected from five patients lying in the age group of 20 to 23 years. Each patient had to utter the 52 alphabets of the Hindi character set for a period of thirty days.

b. **Voice recorder:** Sound recorder version 6.1 available with Microsoft Windows 7 Home Basic was used for recording voice data.

c. **Goldwave digital audio editor:** Goldwave version 5.70 was used for editing and filtering the speech signal and separating the utterances of alphabets.

d. **PRAAT:** PRAAT is used for filtering the samples, analysis of spectrograms and extraction of formants from the samples.

e. **MATLAB:** MATLAB 2012a for 64 bit platform was used for analyzing and plotting the obtained speech data.

V. METHODOLOGY:

The methodology can be described by the following stages:

Stage 1: Speech data was acquired from 5 adult females lying in the age group 20-25 years.

Stage 2: Data was filtered and utterances were separated using Goldwave.

Stage 3: Formants were obtained using PRAAT and plotted against days in MATLAB. Vowel triangles per day were also plotted for each patient

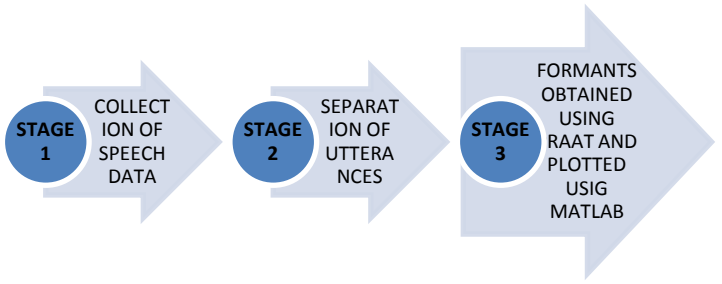

Figure 4.1: flowchart of methodology implemented

V. RESULTS AND CONCLUSION

FORMANT FREQUENCY ASSESSMENT:

ANALYSIS OF MENSTRUAL CYCLE**:**The biological stages of a female life are mostly related to the changes concerned with the ovulation and the formation of corpus luteum in the ovary, i.e., the menstrual cycle. The onset of ovulation is an important factor in reproduction and assessment and treatment of Gynaecological disorders.

Keeping in mind the role of menstrual cycle in the life of a female, it was thought to assess menstrual cycle non-invasively. It has already been verified that

changes in body temperature and level of hormones are reflected during the menstrual cycle. But they need extensive monitoring and clinical laboratory facilities. These techniques are time consuming and expensive.

It is already known that these hormonal changes during menstrual cycle alter the quality of speech. Due to the availability of different audio recording and analyzing software available presently, the effect of menstrual cycle on voice has been studied. Day to day formant frequency measurement of some women have been recorded and it has been observed that formant frequencies share a close relationship with the hormonal changes occurring in a woman, thus representing the menstrual cycle of a woman.

The measured formant frequency measurements of few samples have been displayed in table 5.1(a). and Table5.1(b).

Further Figure 5.26 and 5.27 clearly display the onset of menstrual cycle. The plot and be used to indicate the fertile period as well as hormonal disorders.

Though the observations have been recorded for the entire Hindi character set, the behavior of formant frequency response was same for all the segmental. Also a sudden change in area is observed in the vowel triangle during the onset of the menstrual cycle. This is a clear indicator of the menstrual cycle being reflected acoustically. This by monitoring the formant frequencies, and vowel triangles, menstrual cycle can be assessed non-invasively.

Table 5.1(a): first four formant values for a for speaker1

A	F1	F2	F3	F4		ae	F1	F2	F3	F4
Day 1	891.9671	1406.977	2565.59	4350.59		Day 1	508.7555	2640.435	2891.391	4575.399
Day 2	384.3811	1072.527	2693.901	4249.31		Day 2	419.1618	2219.171	2912.726	4537.494
Day 3	367.2778	1213.192	2532.774	4513.708		Day 3	424.4904	2449.336	3206.53	4324.189
Day 4	476.6084	1843.756	3731.079	4705.467		Day 4	343.1232	1158.349	3040.557	4255.58
Day 5	683.2084	1821.073	3259.389	4510.526		Day 5	409.6585	2315.558	3372.008	4135.57
Day 6	720.2881	1083.73	3125.982	4212.436		Day 6	482.9382	1615.279	2788.891	4341.626
Day 7	399.4686	958.6204	2390.289	3999.294		Day 7	444.8208	1763.439	2948.748	4201.885
Day 8	473.9787	1290.304	2410.58	4268.097		Day 8	383.9969	2614.921	2910.011	4179.618
Day 9	610.7911	1197.252	2606.676	4321.879		Day 9	577.5832	2163.664	2799.178	3835.706
Day 10	555.7792	1011.302	1491.632	4235.012		Day 10	499.4001	2548.039	2853.945	4506.458
Day 11	431.9329	1000.409	2095.624	4337.862		Day 11	366.398	1790.938	2802.134	4220.495
Day 12	343.2173	804.7188	1927.876	3787.339		Day 12	444.7811	2181.824	2874.365	4342.521
Day 13	382.761	936.1482	2140.89	4447.257		Day 13	476.5783	2492.022	3432.25	4694.806
Day 14	584.1356	1275.671	2247.222	4303.483		Day 14	417.2976	2541.835	2800.45	4671.206
Day 15	519.5542	1011.098	2014.437	4101.171		Day 15	362.8816	1548.691	2764.72	3908.528
Day 16	361.7811	797.0961	1320.337	3434.939		Day 16	410.2627	2123.802	3061.374	4705.819

Day17	40	99	19	43	Day17	35	15	27	37
	5.	6.	32	14		0.	45	15	85
	30	76	.5	.1		80	.0	.2	.2
	12	53	57	57		44	74	61	07
Day18	58	14	27	44	Day18	45	24	28	42
	1.	92	92	33		3.	15	56	68
	85	.8	.6	.1		94	.8	.4	.1
	31	21	26	89		35	11	23	59
Day19	37	90	18	38	Day19	30	93	26	35
	3.	8.	10	73		8.	4.	49	62
	85	80	.1	.6		98	94	.2	.4
	05	22	35	28		33	93	12	43
Day20	38	97	19	43	Day20	36	16	29	39
	6.	5.	80	04		8.	03	70	09
	01	33	.5	.2		18	.6	.4	.6
	15	08	77	79		56	12	41	1
Day21	55	12	23	43	Day21	44	21	29	45
	3.	06	47	33		8.	46	55	62
	79	.1	.7	.6		13	.5	.6	.3
	12	96	59	49		97	44	05	23
Day22	42	11	17	45	Day22	60	23	29	46
	3.	86	87	60		1.	82	59	40
	67	.4	.5	.5		16	.7	.0	.0
	71	04	46	94		3	73	21	01
Day23	65	11	23	41	Day23	40	16		37
	0.	81	65	34		1.	93	27	79
	40	.6	.2	.3		55	.1	18	.6
	95	15	21	42		22	17	.2	69
Day24	38	81	15	40	Day24	43	17	27	45
	9.	8.	17	01		5.	81	24	60
	24	17	.6	.8		82	.6	.3	.7
	41	25	11	3		04	52	12	59
Day25	33	78	18	38	Day25	43	20	27	45
	4.	5.	47	23		0.	77	15	37
	17	29	.4	.3		72	.7	.2	.0
	77	9	4	67		49	93	9	21
Day26	36	11	16	40	Day26	46	27	30	46
	8.	02	21	32		2.	68	40	05
	76	.4	.0	.7		11	.1	.5	.5
	34	63	38	79		45	08	04	92
Day27	38	10	31	43	Day27	35	15	31	
	9.	97	96	46		8.	17	92	45
	08	.9	.1	.8		62	.8	.7	25
	94	43	27	98		71	41	42	.4

Day28	53	88	17	42	Day28	46	24	27	46
	6.	3.	73	66		1.	66	38	28
	06	56	.5	.7		97	.6	.4	.2
	76	87	53	91		51	05	42	85
Day29	37	11	19	45	Day29	35		30	39
	8.	58	30	77		3.	18	59	74
	40	.0	.4	.8		07	09	.5	.4
	1	88	58	29		44	.9	32	17

Table 5.1(b): first four formant values for a and ae for speaker1

ga	F1	F2	F3	F4	Cha	F1	F2	F3	F4
Day1	36	14	27	38	Day1	16	39	43	45
	8.	11	47	30		13	69	03	24
	28	.9	.0	.4		.3	.6	.1	.0
	82	85	9	17		44	74	41	71
Day2	25	15	27	41	Day2	98	24	41	46
	1.	38	94	23		3.	00	85	69
	78	.3	.2	.2		53	.0	.4	.9
	02	85	67	38		18	32	65	17
Day3	35	13	29	45	Day3	11	31	41	46
	7.	41	24	28		64	94	91	69
	40	.3	.5	.2		.2	.8	.1	.6
	74	05	58	46		56	62	65	51
Day4	42	10	30	44	Day4	19	27	36	44
	1.	05	56	23		92	10	61	37
	83	.4	.2	.7		.9	.5	.1	.3
	33	68	67	66		93	51	69	23
Day5	42	17	30	45	Day5	12	31	41	45
	2.	44	64	80		76	34	28	75
	36	.0	.9	.1		.6	.0	.8	.0
	99	45	58	66		07	22	33	36
Day6	58	11	29	41	Day6	12	26	42	
	0.	43	87	59		59	01	71	46
	09	.3	.2	.5		.6	.0	.3	85
	29	25	63	81		57	53	15	.2
Day7	39	12	24	39	Day7	12	29	42	47
	9.	52	80	62		13	53	87	80
	63	.2	.9	.6		.8	.8	.5	.8
	14	46	04	66		61	83	94	9
Day8	35	12	21		Day8	18	36	41	46
	1.	04	37	43		03	77	43	88
	58	.3	.7	54		.4	.4	.1	.4
	16	08	95	.4		49	52	67	89
Day9	43	98	21	40	Day9		38	44	47
	9.	9.	10	35		17	49	27	96
	35	34	.0	.2		09	.6	.8	.8
	47	53	28	32		.6	11	42	02
Day	40	76	14	38	Day	18	39	44	50
	8.	6.	77	17		77	47	42	57
	74	85	.7	.9		.1	.3	.5	.6

10	04	14	02	2		10	36	63	15	41
Day11	46.43 06	62.55 68	14.83 .5 96	36.27 .1 49		Day11	17.59 .9 81	34.19 .4 05	44.00 .9 69	47.62 .3 94
Day12	40.09 53	78.69 07	19.73 .8 13	39.00 .5 86		Day12	17.50 .5 96	37.73 .4 73	44.74 .7 75	46.90 .0 59
Day13	44.37 74	64.04 08	18.69 .0 85	39.07 .3 11		Day13	19.28 .9 4	34.79 .2 83	45.25 .9 55	48 53
Day14	38.03 05	13.20 .4 66	24.90 .3 38	42.10 .1 99		Day14	18.70 .6 15	27.46 .0 11	42.63 .0 13	46.30 .3 87
Day15	41.87 98	87.0. 15 76	24.06 .7 78	41.06 .1 42		Day15	84.5. 19 48	20.81 .7 88	43.36 .9 35	45.04 .0 96
Day16	49.35 2	14.46 .0 28	28.37 .5 28	47.98 .5 88		Day16	18.42 .8 56	40.00 .8 73	43.73 .4 24	48.20 .2 68
Day17	48.34 12	12.94 .1 76	32.80 .0 44	47.71 .2 18		Day17	13.67 .6 59	30.42 .6 47	42.08 .3 28	47.36 .6 94
Day18	46.36 6	12.19 .9 21	21.82 .5 5	41.89 .3 33		Day18	18.77 .7 21	22.08 .9 45	40.40 .6 56	45.50 .4 18
Day19	50.3. 84 71	11.69 .5 25	23.13 .5 67	43.55 .1 07		Day19	92.3. 105 99	22.10 .0 67	42.63 .7 86	47.11 .6 91
Day20	44.2. 50 67	87.0. 17 42	23.66 .9 56	40.56 .3 68		Day20	12.28 .1 75	32.94 .3 8	42.70 .4 41	48 18 .1
Day	42.4. 42	83.8. 45	24.68 .4	41.04 .5		Day	13.93 .6	33.50 .2	43.87 .7	48.62 .0

21	65	7	71	48		21	33	88	84	84
Day21	46.94 45	10.3 67	19.29 .4 8	45.32 .8 84		Day22	16.75 .9 79	32.64 .3 05	44.45 .6 18	47.97 .2 45
Day23	44.98 67	97.94 21	22.75 .0 84	39.81 .7 48		Day23				
Day24	47.1. 05 22	75.6. 43 31	15.91 .7 63	41.81 .0 16		Day24	11.70 .4 22	19.95 .9 09	41.31 .3 64	47.15 .7 9
Day25	37.2. 76 8	78.4. 68 72	23.01 .6 28	43.35 .0 02		Day25	13.87 .5 94	33.77 .6 42	44.89 .8 62	49.73 .1 15
Day26	44.2. 07 5	12.21 .8 72	34.94 .6 06	47.49 .8 09		Day26	15 25 .6	28.99 .1 94	41.61 .1 75	46.26 .9 83
Day27	40.7. 52 99	96.5. 29 92	26.58 .8 09	42.96 .6 79		Day27	16.55 .6 07	36.46 .0 91	44.57 .3 51	49.75 .5 71
Day28	46.4. 03 4	10.45 .1 73	18.89 .1 09	45.04 .0 56		Day28	18.89 .9 21	35.36 .6 77	43.61 .1 33	47.20 .7 64
Day29	45.8. 90 38	11.68 .5 64	27.98 .3 18	47.25 .0 93		Day29	16.25 .1 63	36.72 .5 72	43.56 .4 47	47.03 .9 48

Table 5.2: first four formant values for ga and cha for speaker 1

ja	F1	F2	F3	F4		Jha	F1	F2	F3	F4
Day1	13.72 .6 17	33.26 .3 54	42.49 .9 87	47.34 .1 5		Day1	16.88 .5 68	26.19 .2 89	41.82 .2 37	44.75 .8 36
Day	85.1. 76	18.38 .9	40.32 .1	45.81 .9		Day	12.06 .1	18.42 .1	41.71 .1	45.11 .9

2	27	13	51	34
Day3	882.561	2716.593	4118.555	4636.754
Day4	1590.607	3897.755	4437.197	4881.81
Day5	2065.85	3875.611	4463.924	4816.699
Day6	727.231	1125.045	3010.352	4611.606
Day7	1233.087	3052.502	4318.294	4765.177
Day8	1538.735	3895.298	4030.168	4653.656
Day9	905.945	2960.752	4354.307	4744.528
Day10	968.0766	2666.654	4310.695	4842.373
Day11	810.1954	2723.493	4377.55	4688.877
Day12	1091.725	2413.066	4280.006	4715.311
Day13	629.4134	1910.468	4234.759	4502.912
Day14	1724.404	3920.547	4439.865	4782.905
D	11	27	43	46

2	97	95	97	97
Day3	1351.74	2342.694	4021.927	4390.16
Day4	1835.811	2108.63	3751.465	4291.12
Day5	1880.442	3014.572	3960.897	4433.294
Day6	964.6112	2704.341	4194.235	4718.775
Day7	1351.809	2876.309	4078.428	4483.508
Day8	1773.415	2621.537	3885.165	4392.953
Day9	1904.06	2729.652	4293.179	4817.317
Day10	1848.648	2568.563	4152.836	4542.59
Day11	1343.729	2323.533	4111.398	4487.14
Day12	965.5319	1887.678	3840.682	4473.778
Day13	1685.742	2637.695	4197.997	4580.27
Day14	1993.82	3341.91	4186.53	4824.567
D	18	25	41	44

ay15	48.514	48.027	18.21	67.043
Day16	1328.415	3279.668	4302.958	4808.293
Day17	903.0136	2511.367	4154.965	4668.465
Day18	1115.383	1826.385	3713.193	4322.869
Day19	909.2043	3234.869	4346.612	4926.72
Day20	1095.411	4051.56	4310.766	4812.66
Day21	856.1154	3660.126	4374.657	4628.688
Day22	857.6062	2489.68	4038.697	4656.977
Day23	491.6824	1848.66	4016.804	4667.343
Day24	1108.024	3125.39	4468.836	4974.105
Day25	1009.958	3114.474	4482.192	4937.416
D	87	34	43	47

ay15	52.313	47.795	19.127	81.849
Day16	1516.052	2680.601	4202.142	4630.341
Day17	1614.943	3112.708	4156.704	4544.399
Day18	1097.375	1915.506	3633.201	4245.165
Day19	1744.242	3310.999	4189.74	4710.881
Day20	1601.51	2977.574	4215.963	4582.192
Day21	1974.203	2700.003	4103.536	4360.36
Day22	1334.322	2560.629	3962.747	4379.658
Day23	664.6395	1944.383	3960.065	4443.388
Day24	1849.67	2702.852	4099.588	4711.634
Day25	1503.24	3436.796	4330.321	4960.915
D	15	25	41	45

a y 26	3. 72 61	39 .9 94	23 .8 32	85 .8 86		a y 26	98 .3 42	38 .6 84	02 .5 29	23 .8 13
Day 27	12 53 .0 68	32 24 .9 81	43 97 .7 91	50 68 .2 7		Day 27	16 28 .0 86	33 98 .1 88	41 75 .7 31	47 90 .6 55
Day 28	13 08 .0 45	33 39 .4 24	43 85 .3 2	47 11 .3 34		Day 28	18 14 .2 48	36 25 .2 08	42 51 .0 82	45 39 .0 48
Day 29	50 5. 77 61	29 01 .8 7	42 35 .3 28	47 08 .0 2		Day 29	14 03 .1 97	32 35 .8 86	42 93 .6 48	47 29 .3 81

Table 5.2: first four formant values for ja and jha for speaker 1

ta	F1	F2	F3	F4		da	F1	F2	F3	F4
Day 1	26 9. 73 67	15 92 .3 16	26 74 .7 17	42 95 .3 67		Day 1	50 4. 70 32	17 58 .3 26	31 06 .4 45	42 85 .7 84
Day 2	27 2. 49 36	20 07 .1 48	29 46 .7 06	41 45 .9 65		Day 2	23 5. 47 32	18 71 .6 27	30 52 .1 57	43 80 .9 86
Day 3	27 8. 30 16	15 69 .9 32	29 95 .3 44	42 17 .2 18		Day 3	40 9. 85 5	17 59 .6 42	27 44 .0 92	41 83 .9 21
Day 4	28 5. 01 84	18 26 .1 59	29 49 .7 47	43 30 .9 39		Day 4	42 6. 57 03	19 60 .6 34	28 28 .9 14	38 97 .0 39
Day 5	41 3. 65 36	18 46 .0 93	38 10 .6 51	43 56 .4 88		Day 5	56 5. 70 82	16 11 .4 55	31 13 .3 81	43 72 .5 45
Day 6	54 1. 68 58	13 84 .3 35	28 67 .5 73	41 52 .3 23		Day 6	55 1. 06 38	13 49 .0 78	29 78 .9 8	39 87 .1 53
Day 7	30 1. 88 93	15	31 92 .8 29	39 83 .8 28		Day 7	37 2. 58 33	17 02 .7 87	24 24 .8 2	43 26 .3 41
Day	28 6. 54	14 34 .3	29 49 .3	43 25 .8		Day	26 0. 37	17 24 .7	20 92 .6	36 97 .3

8	25	13	3	26		8	87	9	89	22
Day 9	41 0. 22 38	14 75 .4 11	26 95 .9 24	44 65 .8 76		Day 9	24 3. 42 74	18 20 .0 35	23 77 .8 26	38 94 .3 81
Day 10	43 7. 80 76	15 82 .8 39	27 99 .5 35	42 81 .9 85		Day 10	27 4. 46 99	16 56 .2 7	28 41 .6 56	44 49 .2 99
Day 11	31 4. 24 73	10 79 .3 73	25 42 .4 97	41 62 .1 46		Day 11	28 7. 22 9	16 90 .0 48	29 76 .5 3	44 18 .7 97
Day 12	50 1. 46 23	15 30 .8 86	29 89 .8 28	43 42 .6 15		Day 12	25 3. 08 66	14 15 .3 14	27 46 .5 46	42 54 .2 66
Day 13	41 2. 42 73	12 88 .8 68	22 91 .2 75	39 69 .2 38		Day 13	24 3. 98 81	17 28 .6 2	29 78 .7 49	41 24 .8 02
Day 14	26 3. 37 45	16 56 .8 82	25 49 .8 02	40 .3 29		Day 14	25 2. 62 37	17 45 .3 37	25 13 .1 53	39 62 .7 59
Day 15	40 5. 80 42	12 46 .0 45	23 32 .6 29	37 .6 46		Day 15	24 3. 68 07	15 71 .1 16	25 17 .6 13	38 62 .6 36
Day 16	38 9. 26 16	15 19 .7 33	25 95 .9 81	40 .6 26		Day 16	23 8. 41 99	19 05 .7 54	23 70 .4	41 28 .6 87
Day 17	33 6. 12 71	11 55 .2 52	24 88 .2 79	39 .8 2		Day 17	23 6. 66 64	16 35 .2 99	28 02 .0 73	42 92 .9 86
Day 18	41 0. 24 71	17 38 .5 42	26 54 .7 78	35 .5 13		Day 18	42 9. 69 41	18 45 .3 35	28 75 .3 2	39 33 .7 33
Day 19	38 8. 90 77	10 20 .4 85	27 51 .9 98	40 .8		Day 19	53 2. 11 29	14 50 .0 03	17 65 .9 4	42 69 .1 21

Day 2000	41 7.00 56	18 48 .4 79	33 50 .4 04	46 88 .5 3	Day 2000	50 4.61 02	86 5.13 93	19 55 .2 02	37 70 .1 5
Day 2001	39 9.86 16	15 60 .0 79	33 87 .6 4	45 07 .4 73	Day 2001	33 8.67 3	70 7.05 04	19 98 .9 98	42 73 .7 53
Day 2002	34 1.91 24	11 96 .2 6	20 69 .3 83	41 87 .3 62	Day 2002	53 6.25 64	11 07 .9 96	18 51 .9 04	37 36 .4 79
Day 2003	42 5.50 01	14 68 .1 11	25 47 .9 3	43 52 .4 77	Day 2003	48 2.31 72	10 28 .9 73	19 51 .2 28	37 16 .1 34
Day 2004	34 5.55 52	10 68 .4 05	22 33 .6 34	40 36 .1 79	Day 2004	54 3.32 02	11 66 .1 99	19 29 .8 31	39 63 .7 76
Day 2005	41 2.81 55	15 72 .3 4	31 01 .9 87	43 60 .6 64	Day 2005	52 9.53 72	15 01 .2 57	20 88 .9 08	41 34 .9 32
Day 2006	41 3.29 1	18 11 .9 86	37 40 .0 58	45 48 .1 43	Day 2006	46 5.53 77	13 48 .7 76	16 73 .7 62	40 39 .6 96
Day 2007	35 3.59 27	15 79 .9 46	27 23 .7 29	40 89 .0 52	Day 2007	43 9.08 97	16 63 .0 57	19 34 .0 36	44 40 .0 4
Day 2008	40 5.41 57	16 26 .1 43	37 92 .9 84	45 41 .0 5	Day 2008	52 9.19 52	11 18 .5 62	21 96 .0 7	39 95 .1 3
Day 2009	36 9.79	18 45 .5 91	30 86 .9 23	44 98 .2 36	Day 2009	47 8.59 87	10 97 .5 42	18 71 .4 66	35 92 .9 35

a) 30 day plots for utterances

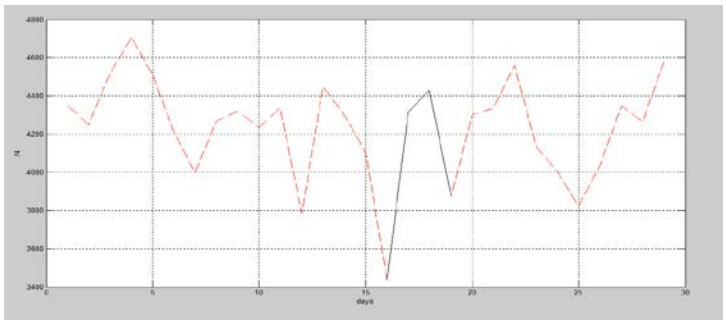

Fig 5.1: fourth formant for a

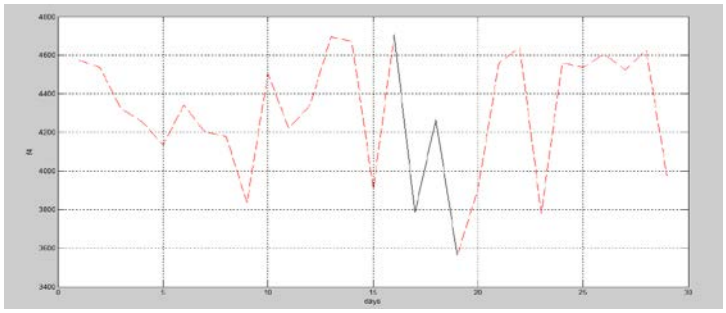

Fig 5.2: fourth formant for ae

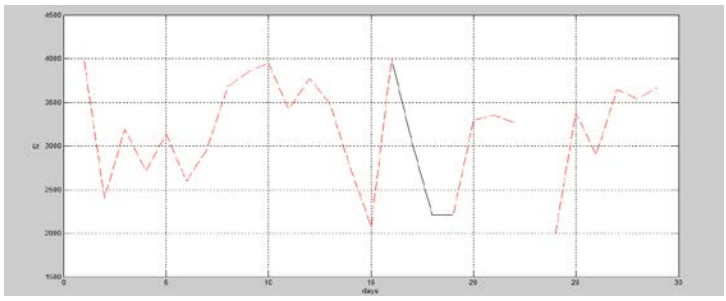

Fig 5.3: second formant for cha

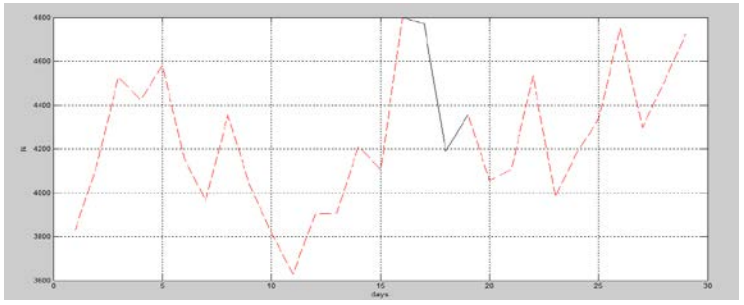

Fig 5.4: fourth formant for ga

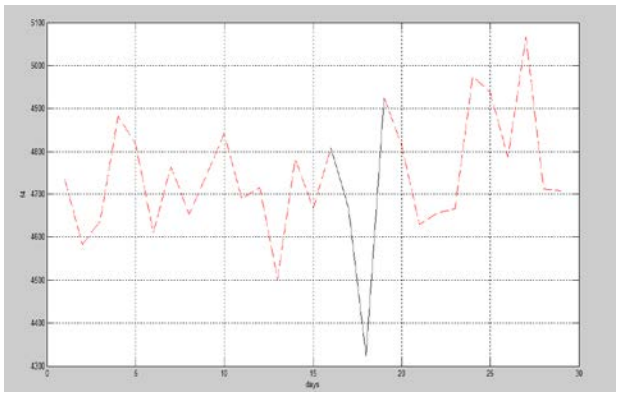

Fig 5.5: fourth formant for ja

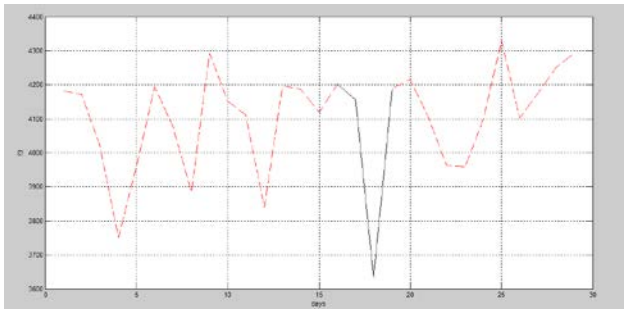

Fig 5.6: third formant for jha

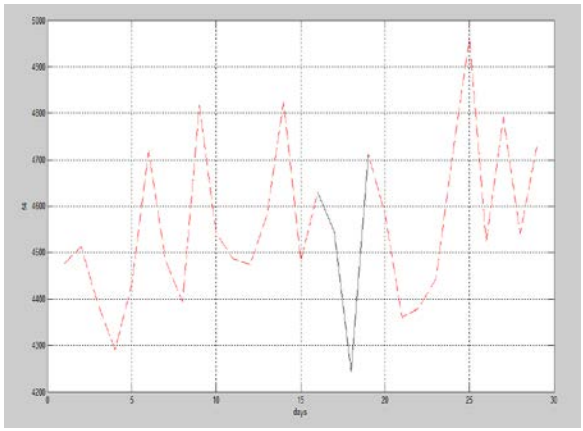

Fig 5.7: fourth formant for jha

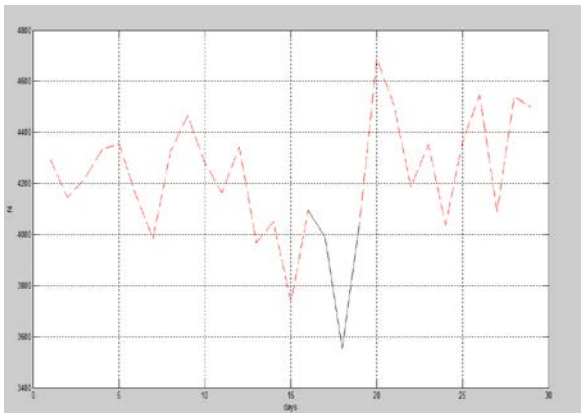

Fig 5.8: fourth formant for tha

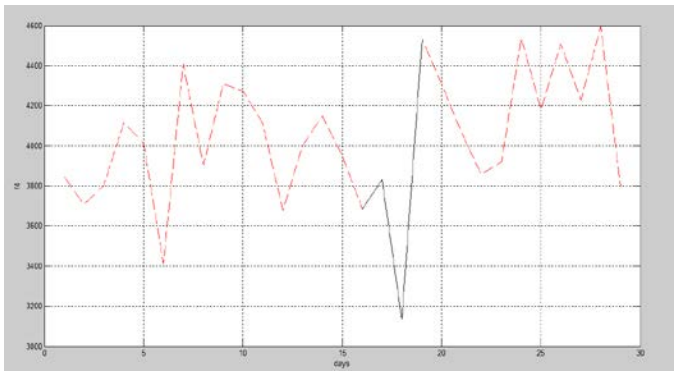

Fig 5.9: fourth formant for da

30 day vowel triangles for a, I and u in the plot :

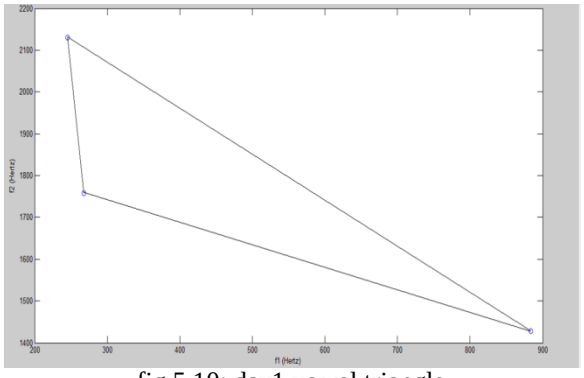

fig 5.10: day1 vowel triangle

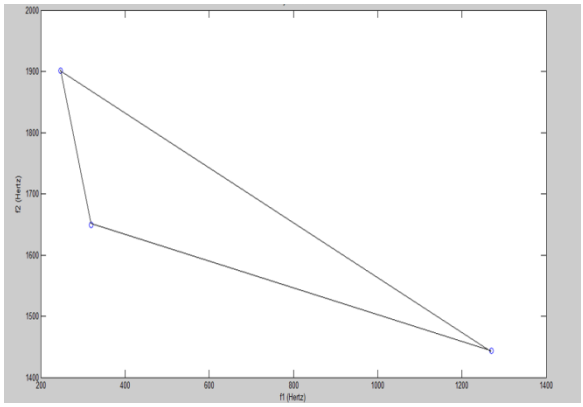

Fig 5.11: day 2 vowel triangle

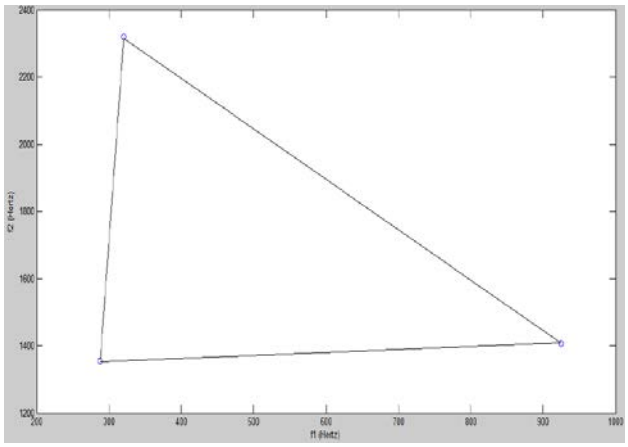

Fig 5.12: day 3 vowel traingle

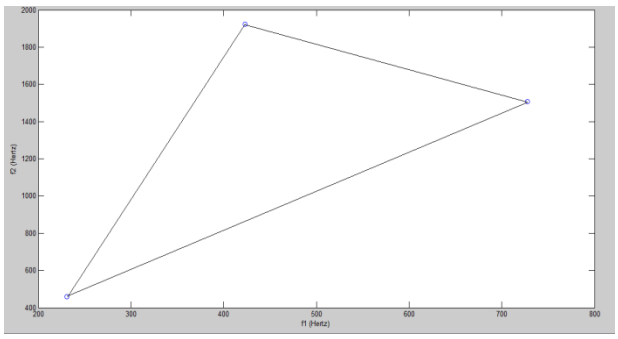

Fig 5.13: day 4 vowel triangle

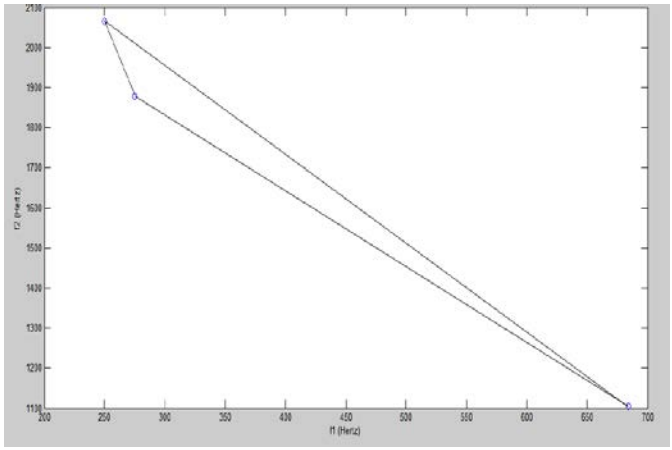

Fig 5.14: day 5 vowel triangle

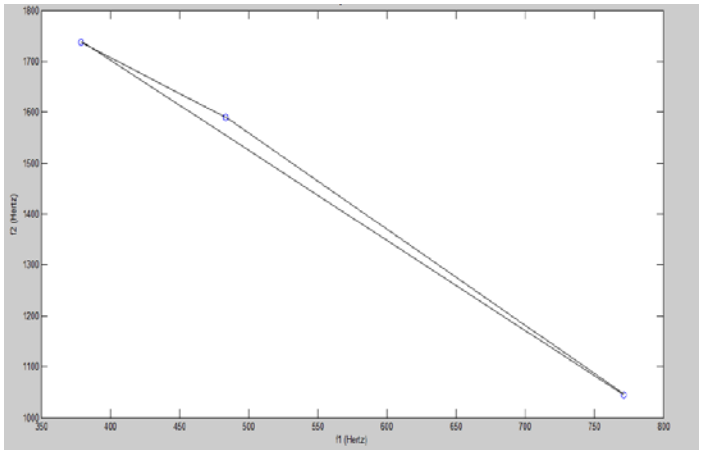

Fig 5.15: day 6 vow el triangle

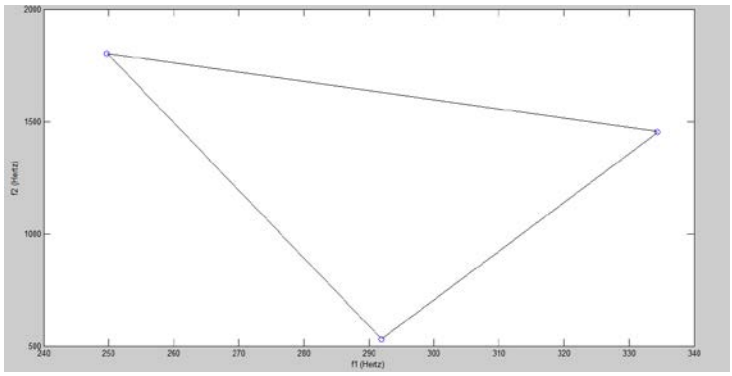

Fig 5.16: day 7 vowel triangle

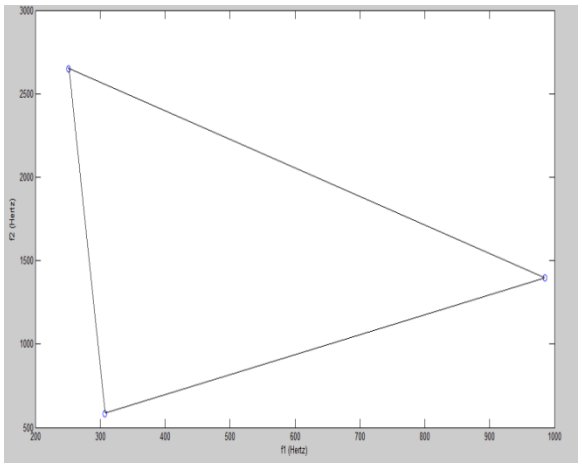

Fig 5.17: day 8 vowel triangle

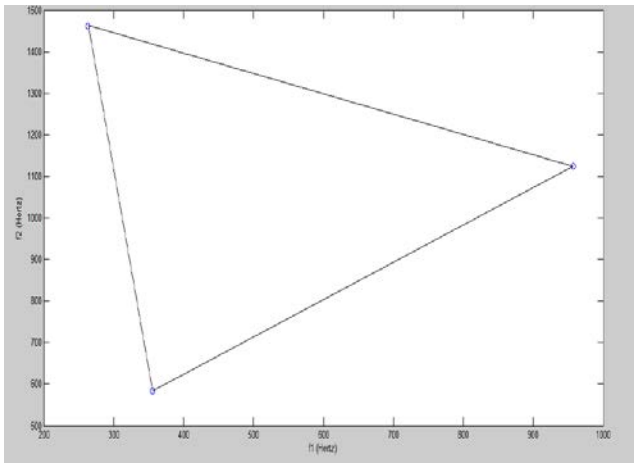

Fig5.20: day 11 vowel triangle

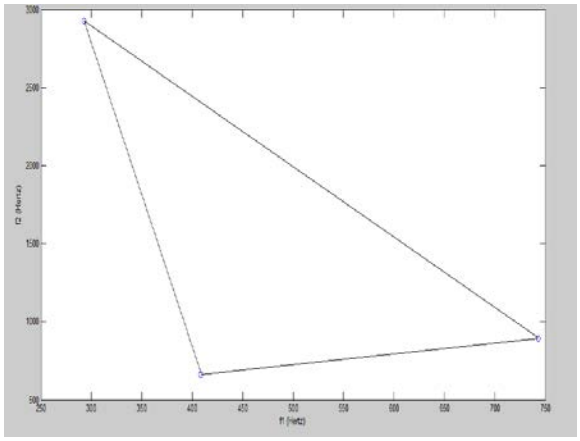

Fig 5.18: day 9 vowel triangle

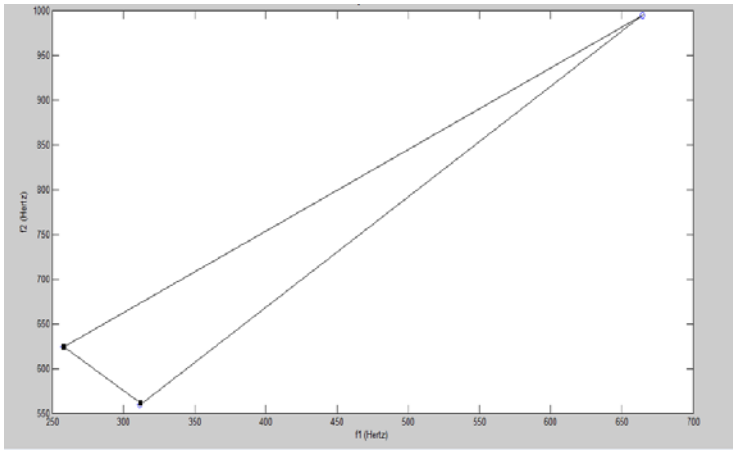

Fig 5.23: day 12 vowel triangle

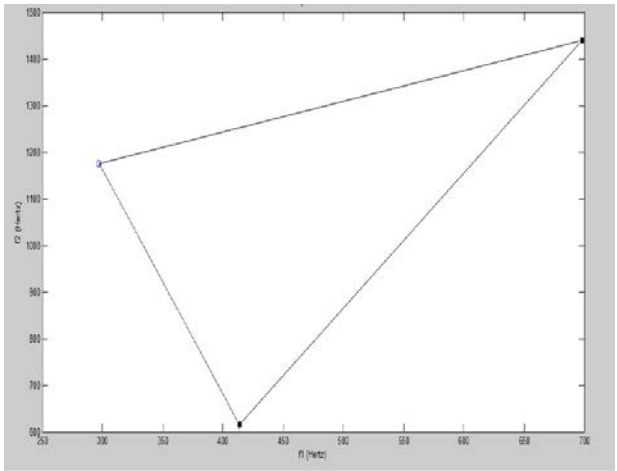

Fig 5.19: day 10 vowel triangle

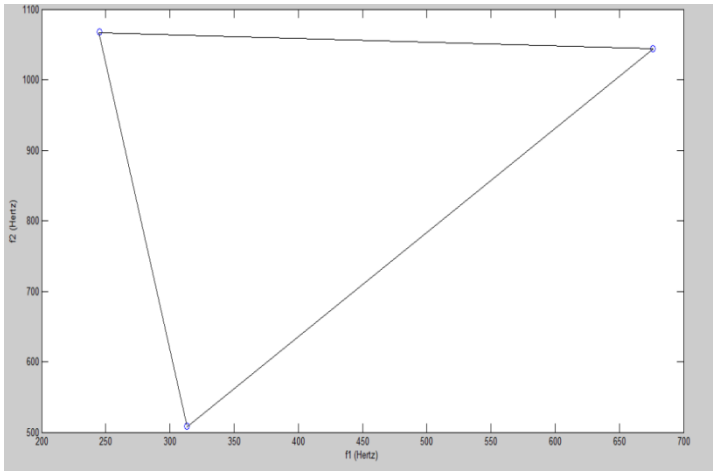

Fig 5.24: day 13 vowel triangle

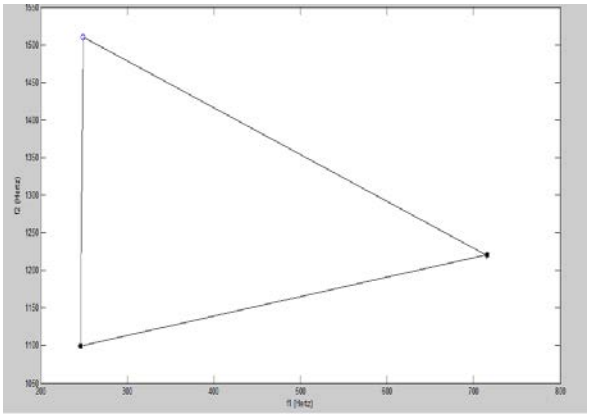

Fig 5.25: day 14 vowel triangle

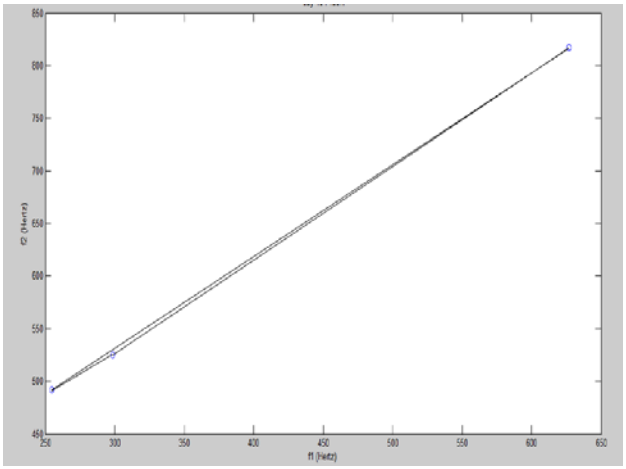

Fig 5.26: day 15 vowel triangle

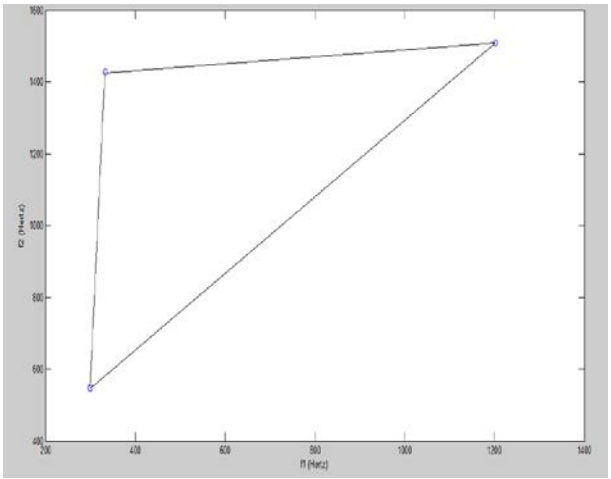

Fig 5.27: day 16 vowel triangle

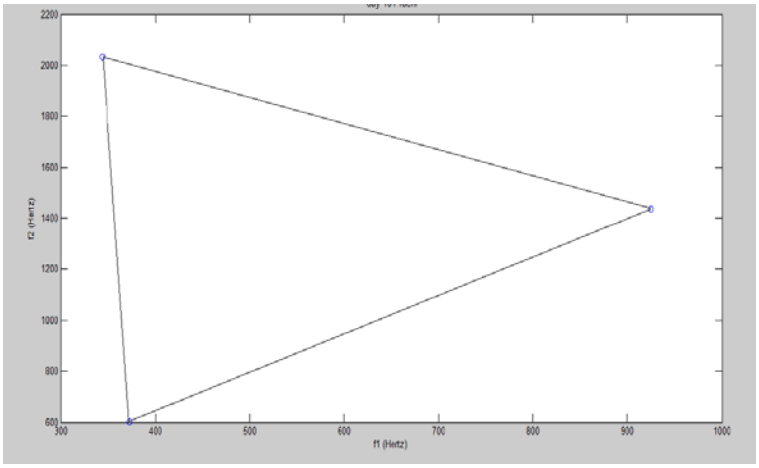

Fig 5.28: day 17 vowel triangle

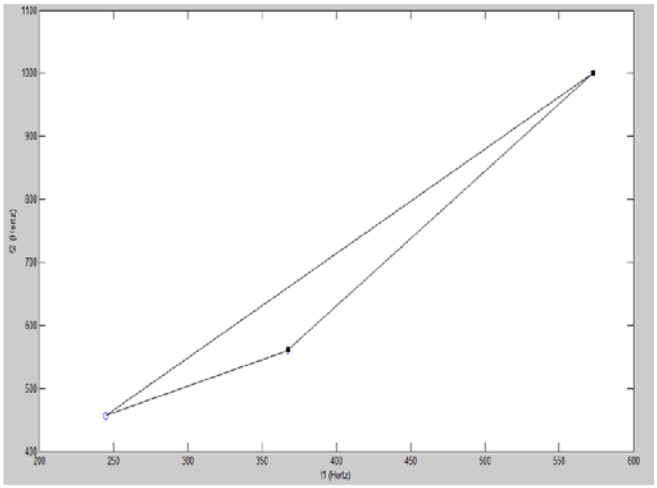

Fig 5.29: day 18 vowel triangle

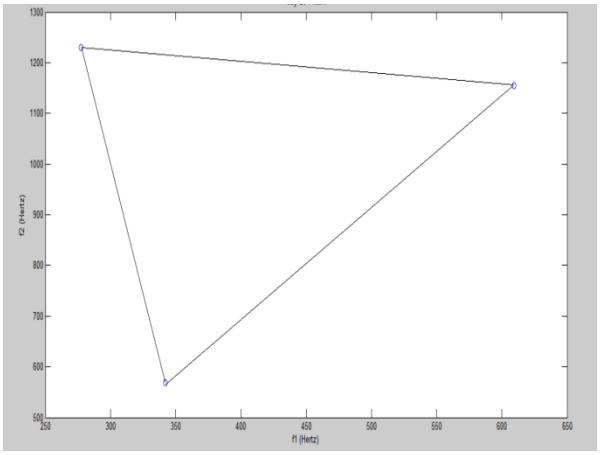

Fig 5.30: day 19 vowel triangle

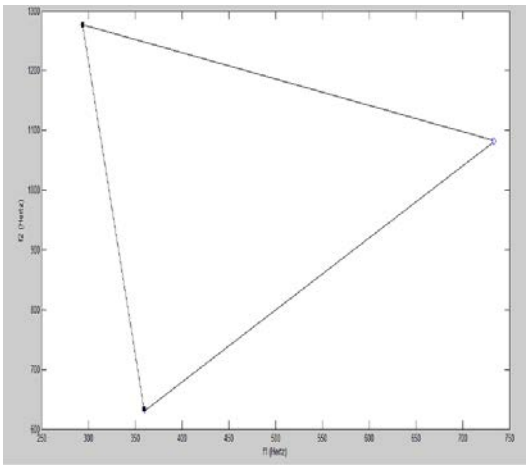

Figure 5.31: day 20 vowel triangle

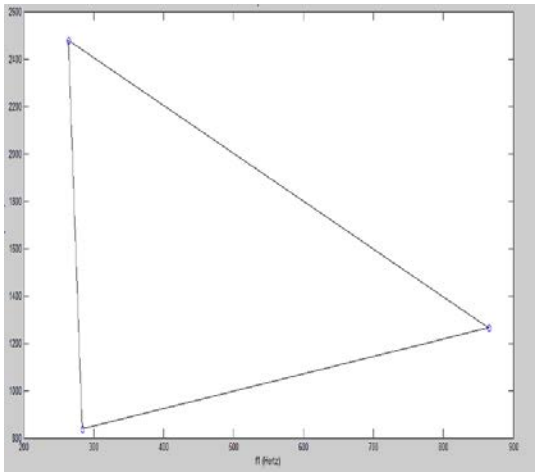

Fig 5.32: day 21 vowel triangle

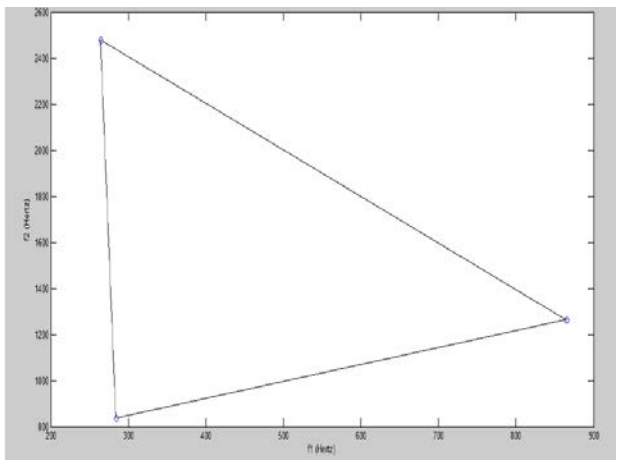

Fig 5.33: day 22 vowel triangle

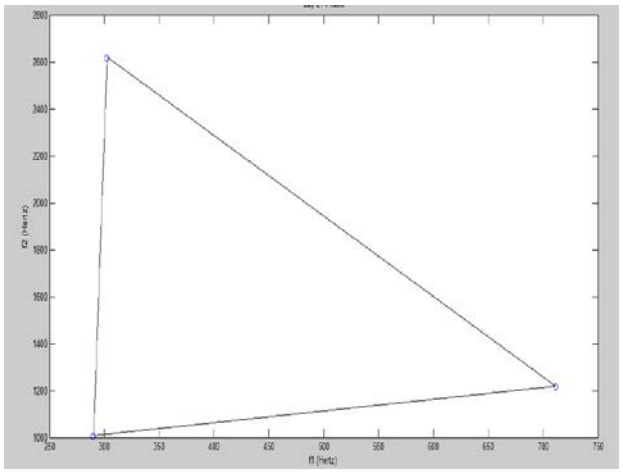

Fig 5.34: day 23 vowel triangle

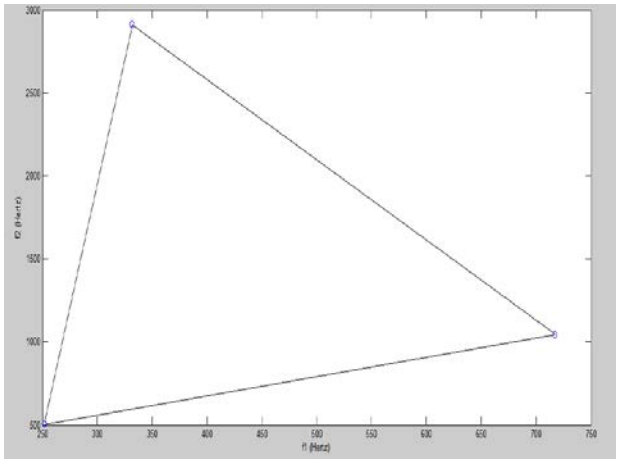

Fig 5.35: day 24 vowel triangle

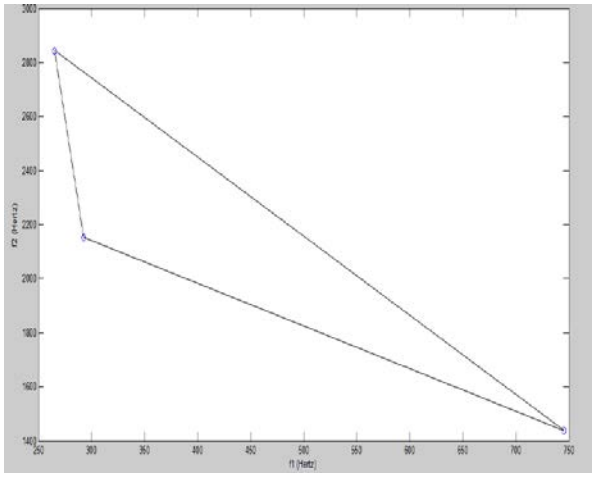

Fig 5.36: day 25 vowel triangle

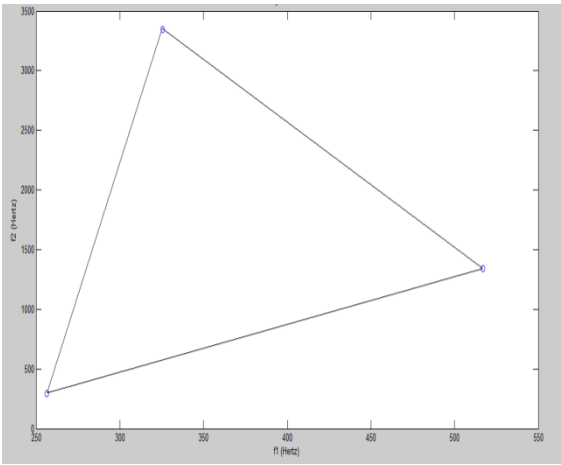

Fig 5.37: day 27 vowel triangle

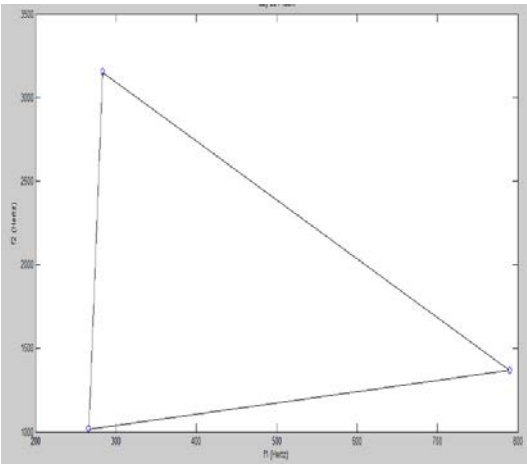

Fig 5.38: day 28 vowel triangle

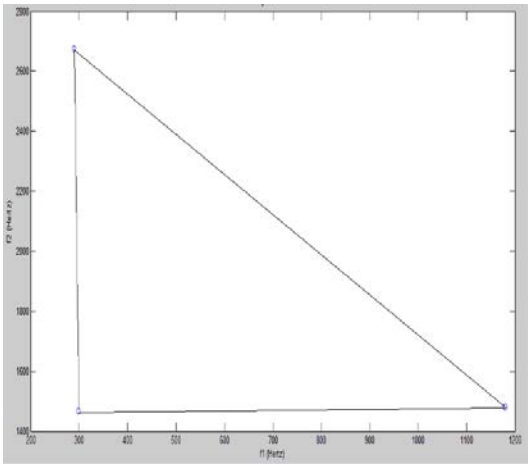

Fig 5.39: day 29 vowel triangle

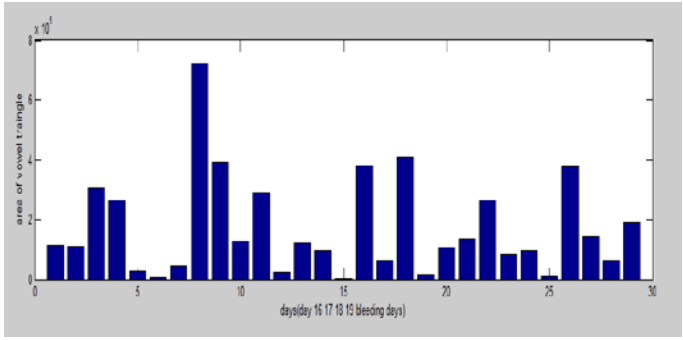

Fig 5.40: variation in area of vowel traingle with days

(day 16, 17, 18, 19-menstrual phase, day 8- angry, day 9-tensed, day 26-tensed)

V DISCUSSION AND FUTURE SCOPE

From the point of view of our studies, it has been observed that the uterus undergoes a change in length, width, thickness, weight etc. during the menstrual cycle. It has been discussed earlier that the formant frequency F3 is an indicative of change in length of the resonating cavity, and F4 is a measure of width, thickness of the changes in the cavity. The changes in formant frequencies were clearly observed during the menstrual cycle in all four formants, however it was dominant in the fourth formant frequency, F4. A significant change in F4 value mostly was observed during the menstrual phase from day 16 to 19, as shown in Figures 5.1 to 5.9. This further confirms that the physiological changes during the menstrual cycle are reflected in speech. Other notable changes in formant frequency values were observed on day 9, 10 and 26, which the patient had mentioned as emotional distress due to external factors. Hence emotional disturbances are also detectable through digital speech processing.

To support the observations of the formant frequency analysis, vowel triangles were plotted for each patient for the 30 days (Figure 5.10 to Figure 5.38). The observations were similar to that obtained using formant frequencies. Days 9, 10, and 26 had notably higher values due to emotional distress. A sudden increase in the area of triangle was observed starting from day 16 to day 19 (Figure 5.39), during the menstrual phase. However, this was followed by a sudden drop in the area, on day 20 which marked the end of the Menstrual phase and the beginning of the Proliferative phase. The sudden increase of the area is synchronous with the sudden decrease in oestrogen

and progesterone with the onset of the menstrual phase, the fall in the area of triangle is in synchrony with the rise in oestrogen level at the end of the menstrual phase. This observation can also be used to account for the fact that decrease of oestrogen results in the depressive mood swings which are common to many women during the onset of menstrual phase, and higher levels of oestrogen stimulate a more relaxed behavior post menstrual phase. Thus these results indicate that speech can be used to diagnose and monitor the menstrual cycle and can be used to develop faster, cheaper, non-invasive alternatives for hormonal analysis that can be used even in rural areas that lack from laboratory set ups.

7. REFERENCES

[1] Dr A.S. Zadgaonkar, Anupam Shukla, Atul Tiwari, "Speech Pathological Study of Epinosic Patient Using Artificial Neural Network", Proc. of IEEE-EMBS & 14th BMESI-1995.

[2] Dr A.S. Zadgaonkar, Dr. (Mrs.) Kavita Thakur, "Formant Frequency as an effective treatment for Non-Invasive assessment of menstrual cycle", Proc. of IEEE-BMES/EMBS conference-1999.

[3] Elisea M. Meurer, Vera Garcez, Helena von Eye Corleta, Edison Capp, "Menstrual Cycle Influences on Voice and Speech in Adolescent Females", Journal of Voice, Volume 23, No. 1, 2009.

[4] Vaishna Narang, Deepshikha Misra, Ritu Yadav, "F1 and F2 correlation with F0: A study of vowels of Hindi, Punjabi, Korean and Thai", International Journal of Asian Language Processing, 22(2): 63-73.

[5] Lee S, Potamianos A, Narayanan S., "Acoustics of children's speech: developmental changes of temporal and spectral parameters"J Acoust Soc Am.1999; 105:1455-1468.

[6] Zraick RI, Birdwell KY, Smith-Olinde L, "The effect of speaking sample duration on determination of habitual pitch", Journal of Voice. 2005;19: 197-201.

[7] Amir O, Biron-Shental T., "The impact of hormonal fluctuations on female vocal folds", Curr Opin Otolaryngol Head Neck Surg. 2004;12: 180-184.

[8] Manolagas SC, Kousteni S., "Perspective: non reproductive sites of action of reproductive hormones", Endocrinology. 2001;142: 2200-2204.

[9] Sherwin BB., "Estrogen and cognitive functioning in women", Endocr Rev. 2003;24: 133-151

[10] Whiteside SP, Hanson A, Cowell PE., "Hormones and temporal components of speech: sex differences and effects of menstrual cyclicity on speech" ,Neurosci Lett. 2004;367: 44-47.

[11] Martijn Goudbeek, Jean Philippe Goldman, Klaus R. Scherer, "Emotion dimensions and formant position", Swiss Center for Affective Sciences, Switzerland.

[12] Banse R., Scherer K.R., "Acoustic profiles in vocal emotion expression." J Pers Soc Psychol., 1996, 3, 614-636.

[13] Gobl, C., Ni Chasaide A. N., "The role of the voice quality in communicating emotions, mood and attitude" Speech Comm., 2003, 40, 189-212.

[14] Fontaine J. R., Scherer K. R., Roesch E. B., and Ellsworth P., "The world of emotion is not two-dimensional." Psych Science, 2007, 13, 1050-1057.

[15] Scherer K.R. "Vocal communication of emotion: A review of research paradigms." Speech Comm., 2003, 40, 227-256.

[16] Nivedita Deshpande, Kavita Thakur, A.S. Zadgaonkar, "Assessment of heart rate variability from speech analysis", 167th Meeting of the Acoustical Society of America, Providence, Rhode

Island, 5 - 9 May 2014Session 5aSP: Signal Processing in Acoustics.

[17] Jacob A.V., “Foundation of Voice Recognition and synthesis”, Part-I, Electronics for You, p-44, July-1997.

[18] Jeffcoate T., “Principles of Gynaecology”, 5th Edition, Butter Worth, Heinnemann, 1996.